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Coral Reefs, Volcanic Islands, South American Geology

by Charles Darwin

EDITORIAL NOTE

Although in some respects more technical in their subjects and style than Darwin's "Journal," the books here reprinted will never lose their value and interest for the originality of the observations they contain. Many parts of them are admirably adapted for giving an insight into problems regarding the structure and changes of the earth's surface, and in fact they form a charming introduction to physical geology and physiography in their application to special domains. The books themselves cannot be obtained for many times the price of the present volume, and both the general reader, who desires to know more of Darwin's work, and the student of geology, who naturally wishes to know how a master mind reasoned on most important geological subjects, will be glad of the opportunity of possessing them in a convenient and cheap form.

The three introductions, which my friend Professor Judd has kindly furnished, give critical and historical information which makes this edition of special value.

G.T.B.

CONTENTS

GEOLOGICAL OBSERVATIONS ON VOLCANIC ISLANDS.

GEOLOGICAL OBSERVATIONS ON SOUTH AMERICA.

THE STRUCTURE AND DISTRIBUTION OF CORAL REEFS.

CRITICAL INTRODUCTION

A scientific discovery is the outcome of an interesting process of evolution in the mind of its author. When we are able to detect the germs of thought in which such a discovery has originated, and to trace the successive stages of the reasoning by which the crude idea has developed into an epoch-making book, we have the materials for reconstructing an important chapter of scientific history. Such a contribution to the story of the "making of science" may be furnished in respect to Darwin's famous theory of coral-reefs, and the clearly reasoned treatise in which it was first fully set forth.

The subject of corals and coral-reefs is one concerning which much popular misconception has always prevailed. The misleading comparison of coral-rock with the combs of bees and the nests of wasps is perhaps responsible for much of this misunderstanding; one writer has indeed described a coral-reef as being "built by fishes by means of their teeth." Scarcely less misleading, however, are the references we so frequently meet with, both in prose and verse, to the "skill," "industry," and "perseverance" of the "coral-insect" in "building" his "home." As well might we praise men for their cleverness in making their own skeletons, and laud their assiduity in filling churchyards with the same. The polyps and other organisms, whose remains accumulate to form a coral-reef, simply live and perform their natural functions, and then die, leaving behind them, in the natural course of events, the hard calcareous portions of their structures to add to the growing reef.

While the forms of coral-reefs and coral-islands are sometimes very remarkable and worthy of attentive study, there is no ground, it need scarcely be added, for the suggestion that they afford proofs of design on the part of the living builders, or that, in the words of Flinders, they constitute breastworks, defending the workshops from whence "infant colonies might be safely sent forth."

It was not till the beginning of the present century that travellers like Beechey, Chamisso, Quoy and Gaimard, Moresby, Nelson, and others, began to collect accurate details concerning the forms and structure of coral-masses, and to make such observations on the habits of reef-forming polyps, as might serve as a basis for safe reasoning concerning the origin of coral-reefs and islands. In the second volume of Lyell's "Principles of Geology," published in 1832, the final chapter gives an admirable summary of all that was then known on the subject. At that time, the ring-form of the atolls was almost universally regarded as a proof that they had grown up on submerged volcanic craters; and Lyell gave his powerful support to that theory.

Charles Darwin was never tired of acknowledging his indebtedness to Lyell. In dedicating to his friend the second edition of his "Naturalist's Voyage Round the World," Darwin writes that he does so "with grateful pleasure, as an acknowledgment that the chief part of whatever scientific merit this journal and the other works of the author may possess, has been derived from studying the well-known and admirable 'Principles of Geology.'"

The second volume of Lyell's "Principles" appeared after Darwin had left England; but it was doubtless sent on to him without delay by his faithful friend and correspondent, Professor Henslow. It appears to have reached Darwin at a most opportune moment, while, in fact, he was studying the striking evidences of slow and long-continued, but often interrupted movement on the west coast of South America. Darwin's acute mind could not fail to detect the weakness of the then prevalent theory concerning the origin of the ring-shaped atolls—and the difficulty which he found in accepting the volcanic theory, as an explanation of the phenomena of coral-reefs, is well set forth in his book.

In an interesting fragment of autobiography, Darwin has given us a very clear account of the way in which the leading idea of the theory of coral-reefs originated in his mind; he writes, "No other work of mine was begun in so deductive a spirit as this, for the whole theory was thought out on the west coast of South America, before I had seen a true coral-reef. I had therefore only to verify and extend my views by a careful examination of living reefs. But it should be observed that I had during the two previous years been incessantly attending to the effects on the shores of South America of the intermittent elevation of the land, together with the denudation and deposition of sediment. This necessarily led me to reflect much on the effects of subsidence, and it was easy to replace in imagination the continued deposition of sediment by the upward growth of corals. To do this was to form my theory of the formation of barrier-reefs and atolls."

On her homeward voyage, the *Beagle* visited Tahiti, Australia, and some of the coral-islands in the Indian Ocean, and Darwin had an opportunity of testing and verifying the conclusion at which he had arrived by studying the statements of other observers.

I well recollect a remarkable conversation I had with Darwin, shortly after the death of Lyell. With characteristic modesty, he told me that he never fully realised the importance of his theory of coral-reefs till he had an opportunity of discussing it with Lyell, shortly after the return of the *Beagle*. Lyell, on receiving from the lips of its author a sketch of the new theory, was so overcome with delight that he danced about and threw himself into the wildest contortions, as was his manner when excessively pleased. He wrote shortly afterwards to Darwin as follows:—"I could think of nothing for days after your lesson on coral-reefs, but of the tops of submerged continents. It is all true, but do not flatter yourself that you will be believed till you are growing bald like me, with hard work and vexation at the incredulity of the world." On May 24th, 1837, Lyell wrote to Sir John Herschel as follows:—"I am very full of Darwin's new theory of coral-islands, and have urged Whewell to make him read it at our next meeting. I must give up my volcanic crater forever, though it cost me a pang at first, for it accounted for so much." Dr. Whewell was president of the Geological Society at the time, and on May 31st, 1837, Darwin read a paper entitled "On Certain Areas of Elevation and Subsidence in the Pacific and Indian oceans, as deduced from the Study of Coral Formations," an abstract of which appeared in the second volume of the Society's proceedings.

It was about this time that Darwin, having settled himself in lodgings at Great Marlborough Street, commenced the writing of his book on "Coral-Reefs." Many delays from ill-health and the interruption of other work, caused the progress to be slow, and his journal speaks of "recommencing" the subject in February 1839, shortly after his marriage, and again in October of the same year. In July 1841, he states that he began once more "after more than thirteen month's interval," and the last proof-sheet of the book was not corrected till May 6th, 1842. Darwin writes in his autobiography, "This book, though a small one, cost me twenty months of hard work, as I had to read every work on the islands of the Pacific, and to consult many charts." The task of elaborating and writing out his books was, with Darwin, always a very slow and laborious one; but it is clear that in accomplishing the work now under consideration, there was a long and constant struggle with the lethargy and weakness resulting from the sad condition of his health at that time.

Lyell's anticipation that the theory of coral-reefs would be slow in meeting with general acceptance was certainly not justified by the actual facts. On the contrary the new book was at once received with general assent among both geologists and zoologists, and even attracted a considerable amount of attention from the general public.

It was not long before the coral-reef theory of Darwin found an able exponent and sturdy champion in the person of the great American naturalist, Professor James D. Dana. Two years after the return of the *Beagle* to England, the ships of the United States Exploring Expedition set sail upon their four years' cruise, under the command of Captain Wilkes, and Dana was a member of the scientific staff. When, in 1839, the expedition arrived at Sydney, a newspaper paragraph was found which gave the American naturalist the first intimation of Darwin's new theory of the origin of atolls and barrier-reefs. Writing in 1872, Dana describes the effect produced on his mind by reading this passage:—"The paragraph threw a flood of light over the subject, and called forth feelings of peculiar satisfaction, and of gratefulness to Mr. Darwin, which still come up afresh whenever the subject of coral islands is mentioned. The Gambier Islands in the Paumotus, which gave him the key to the theory, I had not seen; but on reaching the Feejees, six months later, in 1840, I found there similar facts on a still grander scale and of a more diversified character, so that I was afterward enabled to speak of his theory as established with more positiveness than he himself, in his philosophic caution, had been ready to adopt. His work on coral-reefs appeared in 1842, when my report on the subject was already in manuscript. It showed that the conclusions on other points, which we had independently reached, were for the most part the same. The principal points of difference relate to the reason for the absence of corals from some coasts, and the evidence therefrom as to changes of level, and the distribution of the oceanic regions of elevation and subsidence—topics which a wide range of travel over the Pacific brought directly and constantly to my attention."

Among the Reports of the United States Exploring Expedition, two important works from the pen of Professor Dana made their appearance;—one on “Zoophytes,” which treats at length on “Corals and Coral-Animals,” and the other on “Coral-Reefs and Islands.” In 1872, Dana prepared a work of a more popular character in which some of the chief results of his studies are described; it bore the title of “Corals and Coral-Islands.” Of this work, new and enlarged editions appeared in 1874 and 1890 in America, while two editions were published in this country in 1872 and 1875. In all these works their author, while maintaining an independent judgment on certain matters of detail, warmly defends the views of Darwin on all points essential to the theory.

Another able exponent and illustrator of the theory of coral-reefs was found in Professor J. B. Jukes, who accompanied H.M.S. *Fly*, as naturalist, during the survey of the Great Barrier-Reef—in the years 1842 to 1846. Jukes, who was a man of great acuteness as well as independence of mind, concludes his account of the great Australian reefs with the following words:—“After seeing much of the Great Barrier-Reefs, and reflecting much upon them, and trying if it were possible by any means to evade the conclusions to which Mr. Darwin has come, I cannot help adding that his hypothesis is perfectly satisfactory to my mind, and rises beyond a mere hypothesis into the true theory of coral-reefs.”

As the result of the clear exposition of the subject by Darwin, Lyell, Dana, and Jukes, the theory of coral-reefs had, by the middle of the present century, commanded the almost universal assent of both biologists and geologists. In 1859 Baron von Richthofen brought forward new facts in its support, by showing that the existence of the thick masses of dolomitic limestone in the Tyrol could be best accounted for if they were regarded as of coralline origin and as being formed during a period of long continued subsidence. The same views were maintained by Professor Mojsisovics in his “Dolomit-riffe von Südtirol und Venetien,” which appeared in 1879.

The first serious note of dissent to the generally accepted theory was heard in 1863, when a distinguished German naturalist, Dr. Karl Semper, declared that his study of the Pelew Islands showed that uninterrupted subsidence could not have been going on in that region. Dr. Semper’s objections were very carefully considered by Mr. Darwin, and a reply to them appeared in the second and revised edition of his “Coral-Reefs,” which was published in 1874. With characteristic frankness and freedom from prejudice, Darwin admitted that the facts brought forward by Dr. Semper proved that in certain specified cases, subsidence could not have played the chief part in originating the peculiar forms of the coral-islands. But while making this admission, he firmly maintained that exceptional cases, like those described in the Pelew Islands, were not sufficient to invalidate the theory of subsidence as applied to the widely spread atolls, encircling reefs, and barrier-reefs of the Pacific and Indian Oceans. It is worthy of note that to the end of his life Darwin maintained a friendly correspondence with Semper concerning the points on which they were at issue.

After the appearance of Semper’s work, Dr. J. J. Rein published an account of the Bermudas, in which he opposed the interpretation of the structure of the islands given by Nelson and other authors, and maintained that the facts observed in them are opposed to the views of Darwin. Although, so far as I am aware, Darwin had no opportunity of studying and considering these particular objections, it may be mentioned that two American geologists have since carefully re-examined the district—Professor W. N. Rice in 1884 and Professor A. Heilprin in 1889—and they have independently arrived at the conclusion that Dr. Rein’s objections cannot be maintained.

The most serious opposition to Darwin’s coral-reef theory, however, was that which developed itself after the return of H.M.S. *Challenger* from her famous voyage. Mr. John Murray, one of the staff of naturalists on board that vessel, propounded a new theory of coral-reefs, and maintained that the view that they were formed by subsidence was one that was no longer tenable; these objections have been supported by Professor Alexander Agassiz in the United States, and by Dr. A. Geikie, and Dr. H. B. Guppy in this country.

Although Mr. Darwin did not live to bring out a third edition of his “Coral-Reefs,” I know from several conversations with him that he had given the most patient and thoughtful consideration to Mr. Murray’s paper on the subject. He admitted to me that had he known, when he wrote his work, of the abundant deposition of the remains of calcareous organisms on the sea floor, he might have regarded this cause as sufficient in a few cases to raise the summits of submerged volcanoes or other mountains to a level at which reef-forming corals can commence to flourish. But he did not think that the admission that under certain favourable conditions, atolls might be thus formed without subsidence, necessitated an abandonment of his theory in the case of the innumerable examples of the kind which stud the Indian and Pacific Oceans.

A letter written by Darwin to Professor Alexander Agassiz in May 1881 shows exactly the attitude which careful consideration of the subject led him to maintain towards the theory propounded by Mr. Murray:—“You will have seen,” he writes, “Mr. Murray’s views on the formation of atolls and barrier-reefs. Before publishing my book, I thought long over the same view, but only as far as ordinary marine organisms are concerned, for at that time little was known of the multitude of minute oceanic organisms. I rejected this view, as from the few dredgings made in the *Beagle*, in the south temperate regions, I concluded that shells, the smaller corals, etc., decayed and were dissolved when not protected by the deposition of sediment, and sediment could not accumulate in the open ocean. Certainly, shells, etc., were in several cases completely rotten, and crumbled into mud between my fingers; but you will know whether this is in any degree common. I have expressly said that a bank at the proper depth would give rise to an atoll, which could not be distinguished from one formed during subsidence. I can, however, hardly believe in the existence of as many banks (there having been no subsidence) as there are atolls in the great oceans, within a reasonable depth, on which minute oceanic organisms could have accumulated to the depth of many hundred feet.”

Darwin’s concluding words in the same letter written within a year of his death, are a striking proof of the candour and openness of mind which he preserved so well to the end, in this as in other controversies.

“If I am wrong, the sooner I am knocked on the head and annihilated so much the better. It still seems to me a marvellous thing that there should not have been much, and long-continued, subsidence in the beds of the great oceans. I wish some doubly rich millionaire would take it into his head to have borings made in some of the Pacific and Indian atolls, and bring home cores for slicing from a depth of 500 or 600 feet.”

It is noteworthy that the objections to Darwin’s theory have for the most part proceeded from zoologists, while those who have fully appreciated the geological aspect of the question, have been the staunchest supporters of the theory of subsidence. The desirability of such boring operations in atolls has been insisted upon by several geologists, and it may be hoped that before many years have passed away, Darwin’s hopes may be realised, either with or without the intervention of the “doubly rich millionaire.”

Three years after the death of Darwin, the veteran Professor Dana re-entered the lists and contributed a powerful defence of the theory of subsidence in the form of a reply to an essay written by the ablest exponent of the anti-Darwinian views on this subject, Dr. A. Geikie. While pointing out that the Darwinian position had been to a great extent misunderstood by its opponents, he showed that the rival theory presented even greater difficulties than those which it professed to remove.

During the last five years, the whole question of the origin of coral-reefs and islands has been re-opened, and a controversy has arisen, into which, unfortunately, acrimonious elements have been very unnecessarily introduced. Those who desire it, will find clear and impartial statements of the varied and often mutually destructive views put forward by different authors, in three works which have made their appearance within the last year,—“The Bermuda Islands,” by Professor Angelo Heilprin; “Corals and Coral-Islands,” new edition by Professor J. D. Dana; and the third edition of Darwin’s “Coral-Reefs,” with Notes and Appendix by Professor T. G. Bonney.

Most readers will, I think, rise from the perusal of these works with the conviction that, while on certain points of detail it is clear that, through the want of knowledge concerning the action of marine organisms in the open ocean, Darwin was betrayed into some grave errors, yet the main foundations of his argument have not been seriously impaired by the new facts observed in the deep-sea researches, or by the severe criticism to which his theory has been subjected during the last ten years. On the other hand, I think it will appear that much misapprehension has been exhibited by some of Darwin’s critics, as to what his views and arguments really were; so that the reprint and wide circulation of the book in its original form is greatly to be desired, and cannot but be attended with advantage to all those who will have the fairness to acquaint themselves with Darwin's views at first hand, before attempting to reply to them.

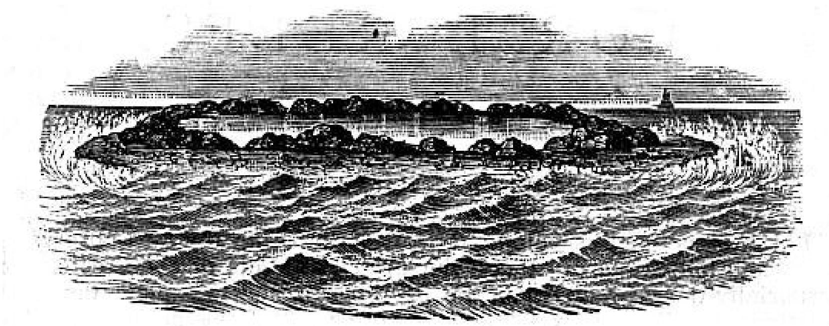
JOHN W. JUDD.

CORAL-REEFS

INTRODUCTION

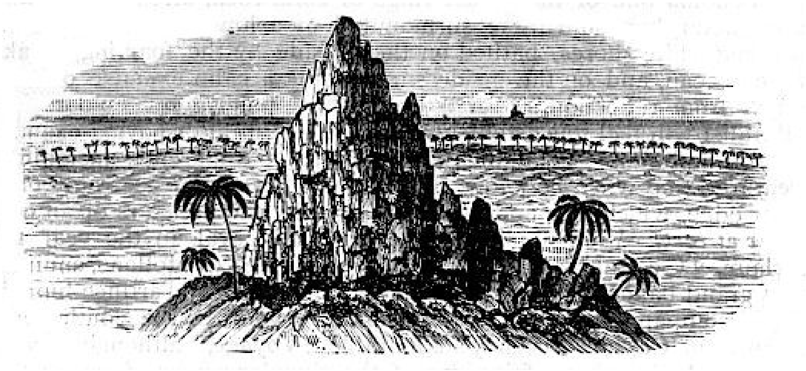
The object of this volume is to describe from my own observation and the works of others, the principal kinds of coral-reefs, more especially those occurring in the open ocean, and to explain the origin of their peculiar forms. I do not here treat of the polypifers, which construct these vast works, except so far as relates to their distribution, and to the conditions favourable to their vigorous growth. Without any distinct intention to classify coral-reefs, most voyagers have spoken of them under the following heads: "lagoon-islands," or "atolls," "barrier" or "encircling reefs," and "fringing" or "shore-reefs." The lagoon-islands have received much the most attention; and it is not surprising, for every one must be struck with astonishment, when he first beholds one of these vast rings of coral-rock, often many leagues in diameter, here and there surmounted by a low verdant island with dazzling white shores, bathed on the outside by the foaming breakers of the ocean, and on the inside surrounding a calm expanse of water, which from reflection, is of a bright but pale green colour. The naturalist will feel this astonishment more deeply after having examined the soft and almost gelatinous bodies of these apparently insignificant creatures, and when he knows that the solid reef increases only on the outer edge, which day and night is lashed by the breakers of an ocean never at rest. Well did François Pyrard de Laval, in the year 1605, exclaim, "C'est une méruelle de voir chacun de ces atollons, enuironné d'un grand banc de pierre tout autour, n'y ayant point d'artifice humain." The accompanying sketch of Whitsunday island, in the South Pacific, taken from Captain Beechey's admirable "Voyage," although excellent of its kind, gives but a faint idea of the singular aspect of one of these lagoon-islands.

Whitsunday Island is of small size, and the whole circle has been converted into land, which is a comparatively rare circumstance. As the reef of a lagoon-island generally supports many separate small islands, the word "island," applied to the whole, is often the cause of confusion; hence I have invariably used in this volume the term "atoll," which is the name given to these circular groups of coral-islets by their inhabitants in the Indian Ocean, and is synonymous with "lagoon- island."



Barrier-reefs, when encircling small islands, have been comparatively little noticed by voyagers; but they well deserve attention. In their structure they are little less marvellous than atolls, and they give a singular and most picturesque character to the scenery of the islands they surround. In the accompanying sketch, taken from the "Voyage of the *Coquille*," the reef is seen from within, from one of the high peaks of the island of Bolabola.[1] Here, as in Whitsunday Island, the whole of that part of the reef which is visible is converted into land. This is a circumstance of rare occurrence; more usually a snow-white line of great breakers, with here and there an islet crowned by cocoa-nut trees, separates the smooth waters of the lagoon-like channel from the waves of the open sea. The barrier-reefs of Australia and of New Caledonia, owing to their enormous dimensions, have excited much attention: in structure and form they resemble those encircling many of the smaller islands in the Pacific Ocean.

[1] I have taken the liberty of simplifying the foreground, and leaving out a mountainous island in the far distance.



With respect to fringing, or shore-reefs, there is little in their structure which needs explanation; and their name expresses their comparatively small extension. They differ from barrier-reefs in not lying so far from the shore, and in not having within a broad channel of deep water. Reefs also occur around submerged banks of sediment and of worn-down rock; and others are scattered quite irregularly where the sea is very shallow; these in most respects are allied to those of the fringing class, but they are of comparatively little interest.

I have given a separate chapter to each of the above classes, and have described some one reef or island, on which I possessed most information, as typical; and have afterwards compared it with others of a like kind. Although this classification is useful from being obvious, and from including most of the coral-reefs existing in the open sea, it admits of a more fundamental division into barrier and atoll-formed reefs on the one hand, where there is a great apparent difficulty with respect to the foundation on which they must first have grown; and into fringing-reefs on the other, where, owing to the nature of the slope of the adjoining land, there is no such difficulty. The two blue tints and the red colour[2] on the map (Plate III), represent this main division, as explained in the beginning of the last chapter. In the Appendix, every existing coral-reef, except some on the coast of Brazil not included in the map, is briefly described in geographical order, as far as I possessed information; and any particular spot may be found by consulting the Index.

Several theories have been advanced to explain the origin of atolls or lagoon-islands, but scarcely one to account for barrier-reefs. From the limited depths at which reef-building polypifers can flourish, taken into consideration with certain other circumstances, we are compelled to conclude, as it will be seen, that both in atolls and barrier-reefs, the foundation on which the coral was primarily attached, has subsided; and that during this downward movement, the reefs have grown upwards. This conclusion, it will be further seen, explains most satisfactorily the outline and general form of atolls and barrier-reefs, and likewise certain peculiarities in their structure. The distribution, also, of the different kinds of coral-reefs, and their position with relation to the areas of recent elevation, and to the points subject to volcanic eruptions, fully accord with this theory of their origin.[3]

[2] Replaced by numbers in this edition.

[3] A brief account of my views on coral formations, now published in my Journal of Researches, was read May 31st, 1837, before the Geological Society, and an abstract has appeared in the Proceedings.

In the several original surveys, from which the small plans on this plate have been reduced, the coral-reefs are engraved in very different styles. For the sake of uniformity, I have adopted the style used in the charts of the Chagos Archipelago, published by the East Indian Company, from the survey by Captain Moresby and Lieutenant Powell. The surface of the reef, which dries at low water, is represented by a surface with small crosses: the coral-islets on the reef are marked by small linear spaces, on which a few cocoa-nut trees, out of all proportion too large, have been introduced for the sake of clearness. The entire *annular reef*, which when surrounding an open expanse of water, forms an "atoll," and when surrounding one or more high islands, forms an encircling "barrier-reef," has a nearly uniform structure. The reefs in some of the original surveys are represented merely by a single line with crosses, so that their breadth is not given; I have had such reefs engraved of the width usually attained by coral-reefs. I have not thought it worth while to introduce all those small and very numerous reefs, which occur within the lagoons of most atolls and within the lagoon-channels of most barrier-reefs, and which stand either isolated, or are attached to the shores of the reef or land. At Peros Banhos none of the lagoon-reefs rise to the surface of the water; a few of them have been introduced, and are marked by plain dotted circles. A few of the deepest soundings are laid down within each reef; they are in fathoms, of six English feet.

Plate I—Map showing the resemblance in form between barrier coral-reefs surrounding mountainous islands, and atolls or lagoon islands.

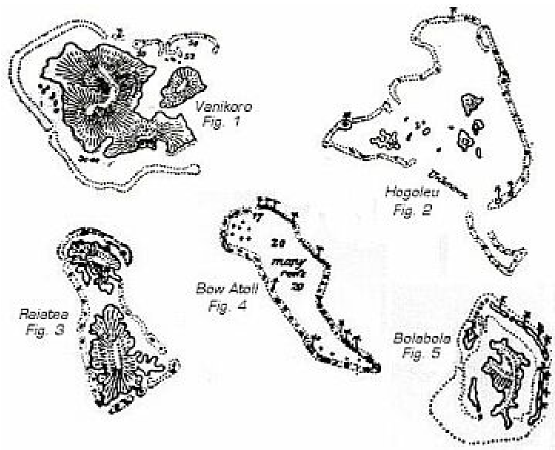


Fig. 1—VANIKORO, situated in the western part of the South Pacific; taken from the survey by Captain D'Urville in the *Astrolabe*; the soundings on the southern side of the island, namely, from thirty to forty fathoms, are given from the voyage of the Chev. Dillon; the other soundings are laid down from the survey by D'Urville; height of the summit of the island is 3,032 feet. The principal small detached reefs within the lagoon-channel have in this instance been represented. The southern shore of the island is narrowly fringed by a reef: if the engraver had carried this reef entirely round both islands, this figure would have served (by leaving out in imagination the barrier-reef) as a good specimen of an abruptly-sided island, surrounded by a reef of the fringing class.

Fig. 2—HOGOLEU, or ROUG, in the Caroline Archipelago; taken from the "Atlas of the Voyage of the *Astrolabe*," compiled from the surveys of Captains Duperrey and D'Urville; the depth of the immense lagoon-like space within the reef is not known.

Fig. 3—RAIATEA, in the Society Archipelago; from the map given in the quarto edition of "Cook's First Voyage;" it is probably not accurate.

Fig. 4—BOW, or HEYOU ATOLL (or lagoon-island), in the Low Archipelago, from the survey by Captain Beechey, R.N.; the lagoon is choked up with reefs, but the average greatest depth of about twenty fathoms, is given from the published account of the voyage.

Fig. 5—BOLABOLA, in the Society Archipelago, from the survey of Captain Duperrey in the *Coquille*: the soundings in this and the following figures have been altered from French feet to English fathoms; height of highest point of the island 4,026 feet.

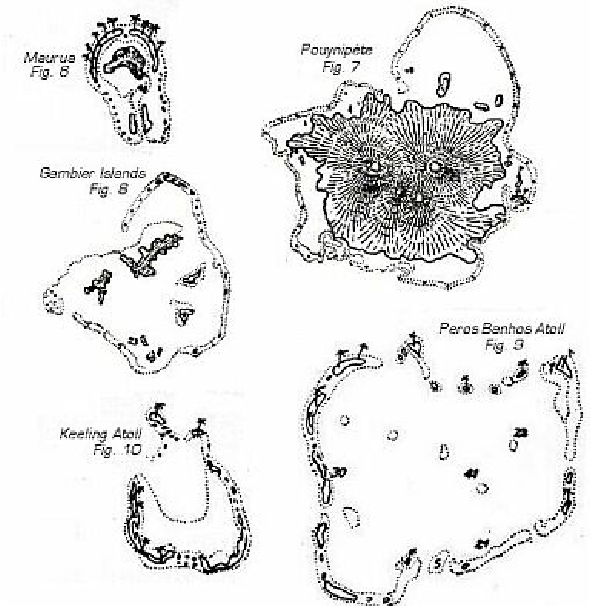


Fig. 6.—MAURUA, in the Society Archipelago; from the survey by Captain Duperrey in the *Coquille*: height of land about eight hundred feet.

Fig. 7—POUYNIPÈTE, or SENIAVINE, in the Caroline Archipelago; from the survey by Admiral Lutké.

Fig. 8—GAMBIER ISLANDS, in the southern part of the Low Archipelago; from the survey by Captain Beechey; height of highest island, 1,246 feet; the islands are surrounded by extensive and irregular reefs; the reef on the southern side is submerged.

Fig. 9—PEROS BANHOS ATOLL (or lagoon-island), in the Chagos group in the Indian Ocean; from the survey by Captain Moresby and Lieutenant Powell; not nearly all the small submerged reefs in the lagoon are represented; the annular reef on the southern side is submerged.

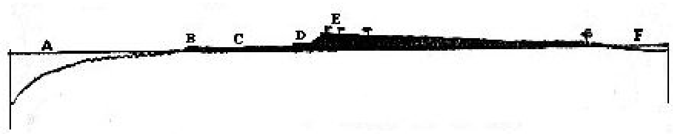
Fig. 10—KEELING, or COCOS ATOLL (or lagoon-island), in the Indian Ocean; from the survey by Captain Fitzroy; the lagoon south of the dotted line is very shallow, and is left almost bare at low water; the part north of the line is choked up with irregular reefs. The annular reef on the north-west side is broken, and blends into a shoal sandbank, on which the sea breaks.

Chapter I
ATOLLS OR LAGOON-ISLANDS

Section I—KEELING ATOLL

Corals on the outer margin.—Zone of Nulliporæ.—Exterior reef.—Islets.—Coral-conglomerate.—Lagoon.—Calcareous sediment.—Scari and Holuthuriæ subsisting on corals.—Changes in the condition of the reefs and islets.—Probable subsidence of the atoll.—Future state of the lagoon.

KEELING or COCOS atoll is situated in the Indian Ocean, in 12° 5′ S., and longitude 90° 55′ E.: a reduced chart of it was made from the survey of Captain Fitzroy and the Officers of H.M.S. *Beagle*, is given in Plate I, Fig. 10. The greatest width of this atoll is nine miles and a half. Its structure is in most respects characteristic of the class to which it belongs, with the exception of the shallowness of the lagoon. The accompanying woodcut represents a vertical section, supposed to be drawn at low water from the outer coast across one of the low islets (one being taken of average dimensions) to within the lagoon.



A.—Level of the sea at low water: where the letter A is placed, the depth is twenty-five fathoms, and the distance rather more than one hundred and fifty yards from the edge of the reef.
B.—Outer edge of that flat part of the reef, which dries at low water: the edge either consists of a convex mound, as represented, or of rugged points, like those a little farther seaward, beneath the water.
C.—A flat of coral-rock, covered at high water.
D.—A low projecting ledge of brecciated coral-rock washed by the waves at high water.
E.—A slope of loose fragments, reached by the sea only during gales: the upper part, which is from six to twelve feet high, is clothed with vegetation. The surface of the islet gently slopes to the lagoon.
F.—Level of the lagoon at low water.

The section is true to the scale in a horizontal line, but it could not be made so in a vertical one, as the average greatest height of the land is only between six and twelve feet above high-water mark. I will describe the section, commencing with the outer margin. I must first observe that the reef-building polypifers, not being tidal animals, require to be constantly submerged or washed by the breakers. I was assured by Mr. Liesk, a very intelligent resident on these islands, as well as by some chiefs at Tahiti (Otaheite), that an exposure to the rays of the sun for a very short time invariably causes their destruction. Hence it is possible only under the most favourable circumstances, afforded by an unusually low tide and smooth water, to reach the outer margin, where the coral is alive. I succeeded only twice in gaining this part, and found it almost entirely composed of a living Porites, which forms great irregularly rounded masses (like those of an Astræa, but larger) from four to eight feet broad, and little less in thickness. These mounds are separated from each other by narrow crooked channels, about six feet deep, most of which intersect the line of reef at right angles. On the furthest mound, which I was able to reach by the aid of a leaping-pole, and over which the sea broke with some violence, although the day was quite calm and the tide low, the polypifers in the uppermost cells were all dead, but between three and four inches lower down on its side they were living, and formed a projecting border round the upper and dead surface. The coral being thus checked in its upward growth, extends laterally, and hence most of the masses, especially those a little further inwards, had broad flat dead summits. On the other hand I could see, during the recoil of the breakers, that a few yards further seaward, the whole convex surface of the Porites was alive; so that the point where we were standing was almost on the exact upward and shoreward limit of existence of those corals which form the outer margin of the reef. We shall presently see that there are other organic productions, fitted to bear a somewhat longer exposure to the air and sun.

Next, but much inferior in importance to the Porites, is the *Millepora complanata*.[1]

> [1] This Millepora (Palmipora of Blainville), as well as the *M. alcicornis*, possesses the singular property of stinging the skin where it is delicate, as on the face and arm.

It grows in thick vertical plates, intersecting each other at various angles, and forms an exceedingly strong honeycombed mass, which generally affects a circular form, the marginal plates alone being alive. Between these plates and in the protected crevices on the reef, a multitude of branching zoophytes and other productions flourish, but the Porites and Millepora alone seem able to resist the fury of the breakers on its upper and outer edge: at the depth of a few fathoms other kinds of stony corals live. Mr. Liesk, who was intimately acquainted with every part of this reef, and likewise with that of North Keeling atoll, assured me that these corals invariably compose the outer margin. The lagoon is inhabited by quite a distinct set of corals, generally brittle and thinly branched; but a Porites, apparently of the same species with that on the outside, is found there, although it does not seem to thrive, and certainly does not attain the thousandth part in bulk of the masses opposed to the breakers.

The woodcut shows the form of the bottom off the reef: the water deepens for a space between one and two hundred yards wide, very gradually to twenty-five fathoms (A in section), beyond which the sides plunge into the unfathomable ocean at an angle of 45°.[2] To the depth of ten or twelve fathoms the bottom is exceedingly rugged, and seems formed of great masses of living coral, similar to those on the margin. The arming of the lead here invariably came up quite clean, but deeply indented, and chains and anchors which were lowered, in the hopes of tearing up the coral, were broken. Many small fragments, however, of *Millepora alcicornis* were brought up; and on the arming from an eight-fathom cast, there was a perfect impression of an Astræa, apparently alive. I examined the rolled fragments cast on the beach during gales, in order further to ascertain what corals grew outside the reef. The fragments consisted of many kinds, of which the Porites already mentioned and a Madrepora, apparently the *M. corymbosa*, were the most abundant. As I searched in vain in the hollows on the reef and in the lagoon, for a living specimen of this Madrepore, I conclude that it is confined to a zone outside, and beneath the surface, where it must be very abundant. Fragments of the *Millepora alcicornis* and of an Astræa were also numerous; the former is found, but not in proportionate numbers, in the hollows on the reef; but the Astræa I did not see living. Hence we may infer, that these are the kinds of coral which form the rugged sloping surface (represented in the woodcut by an uneven line), round and beneath the external margin. Between twelve and twenty fathoms the arming came up an equal number of times smoothed with sand, and indented with coral: an anchor and lead were lost at the respective depths of thirteen and sixteen fathoms. Out of twenty-five soundings taken at a greater depth than twenty fathoms, every one showed that the bottom was covered with sand; whereas, at a less depth than twelve fathoms, every sounding showed that it was exceedingly rugged, and free from all extraneous particles. Two soundings were obtained at the depth of 360 fathoms, and several between two hundred and three hundred fathoms. The sand brought up from these depths consisted of finely triturated fragments of stony zoophytes, but not, as far as I could distinguish, of a particle of any lamelliform genus: fragments of shells were rare.

> [2] The soundings from which this section is laid down were taken with great care by Captain Fitzroy himself. He used a bell-shaped lead, having a diameter of four inches, and the armings each time were cut off and brought on board for me to examine. The arming is a preparation of tallow, placed in the concavity at the bottom of the lead. Sand, and even small fragments of rock, will adhere to it; and if the bottom be of rock it brings up an exact impression of its surface.

At a distance of 2,200 yards from the breakers, Captain Fitzroy found no bottom with a line of 7,200 feet in length; hence the submarine slope of this coral formation is steeper than that of any volcanic cone. Off the mouth of the lagoon, and likewise off the northern point of the atoll, where the currents act violently, the inclination, owing to the accumulation of sediment, is less. As the arming of the lead from all the greater depths showed a smooth sandy bottom, I at first concluded that the whole consisted of a vast conical pile of calcareous sand, but the sudden increase of depth at some points, and the circumstance of the line having been cut, as if rubbed, when between five hundred and six hundred fathoms were out, indicate the probable existence of submarine cliffs.

On the margin of the reef, close within the line where the upper surface of the Porites and of the Millepora is dead, three species of Nullipora flourish. One grows in thin sheets, like a lichen on old trees; the second in stony knobs, as thick as a man’s finger, radiating from a common centre; and the third, which is less common, in a moss-like reticulation of thin, but perfectly rigid branches.[3] The three species occur either separately or mingled together; and they form by their successive growth a layer two or three feet in thickness, which in some cases is hard, but where formed of the lichen-like kind, readily yields an impression to the hammer: the surface is of a reddish colour. These Nulliporæ, although able to exist above the limit of true corals, seem to require to be bathed during the greater part of each tide by breaking water, for they are not found in any abundance in the protected hollows on the back part of the reef, where they might be immersed either during the whole or an equal proportional time of each tide. It is remarkable that organic productions of such extreme simplicity, for the Nulliporæ undoubtedly belong to one of the lowest classes of the vegetable kingdom, should be limited to a zone so peculiarly circumstanced. Hence the layer composed by their growth merely fringes the reef for a space of about twenty yards in width, either under the form of separate mammillated projections, where the outer masses of coral are separate, or, more commonly, where the corals are united into a solid margin, as a continuous smooth convex mound (B in woodcut), like an artificial breakwater. Both the mound and mammillated projections stand about three feet higher than any other part of the reef, by which term I do not include the islets, formed by the accumulation of rolled fragments. We shall hereafter see that other coral reefs are protected by a similar thick growth of Nulliporæ on the outer margin, the part most exposed to the breakers, and this must effectually aid in preserving it from being worn down.

[3] This last species is of a beautiful bright peach-blossom colour. Its branches are about as thick as crow-quills; they are slightly flattened and knobbed at the extremities. The extremities only are alive and brightly coloured. The two other species are of a dirty purplish-white. The second species is extremely hard; its short knob-like branches are cylindrical, and do not grow thicker at their extremities.

The woodcut represents a section across one of the islets on the reef, but if all that part which is above the level of C were removed, the section would be that of a simple reef, as it occurs where no islet has been formed. It is this reef which essentially forms the atoll. It is a ring, enclosing the lagoon on all sides except at the northern end, where there are two open spaces, through one of which ships can enter. The reef varies in width from two hundred and fifty to five hundred yards, its surface is level, or very slightly inclined towards the lagoon, and at high tide the sea breaks entirely over it: the water at low tide thrown by the breakers on the reef, is carried by the many narrow and shoal gullies or channels on its surface, into the lagoon: a return stream sets out of the lagoon through the main entrance. The most frequent coral in the hollows on the reef is *Pocillopora verrucosa*, which grows in short sinuous plates, or branches, and when alive is of a beautiful pale lake-red: a Madrepora, closely allied or identical with *M. pocillifera*, is also common. As soon as an islet is formed, and the waves are prevented breaking entirely over the reef, the channels and hollows in it become filled up with cemented fragments, and its surface is converted into a hard smooth floor (C of woodcut), like an artificial one of freestone. This flat surface varies in width from one hundred to two hundred, or even three hundred yards, and is strewed with a few large fragments of coral torn up during gales: it is uncovered only at low water. I could with difficulty, and only by the aid of a chisel, procure chips of rock from its surface, and therefore could not ascertain how much of it is formed by the aggregation of detritus, and how much by the outward growth of mounds of corals, similar to those now living on the margin. Nothing can be more singular than the appearance at low tide of this “flat” of naked stone, especially where it is externally bounded by the smooth convex mound of Nulliporæ, appearing like a breakwater built to resist the waves, which are constantly throwing over it sheets of foaming water. The characteristic appearance of this “flat” is shown in the foregoing woodcut of Whitsunday atoll.

The islets on the reef are first formed between two hundred and three hundred yards from its outer edge, through the accumulation of a pile of fragments, thrown together by some unusually strong gale. Their ordinary width is under a quarter of a mile, and their length varies from a few yards to several miles. Those on the south-east and windward side of the atoll, increase solely by the addition of fragments on their outer side; hence the loose blocks of coral, of which their surface is composed, as well as the shells mingled with them, almost exclusively consist of those kinds which live on the outer coast. The highest part of the islets (excepting hillocks of blown sand, some of which are thirty feet high), is close to the outer beach (E of the woodcut), and averages from six to ten feet above ordinary high-water mark. From the outer beach the surface slopes gently to the shores of the lagoon, which no doubt has been caused by the breakers the further they have rolled over the reef, having had less power to throw up fragments. The little waves of the lagoon heap up sand and fragments of thinly-branched corals on the inner side of the islets on the leeward side of the atoll; and these islets are broader than those to windward, some being even eight hundred yards in width; but the land thus added is very low. The fragments beneath the surface are cemented into a solid mass, which is exposed as a ledge (D of the woodcut), projecting some yards in front of the outer shore and from two to four feet high. This ledge is just reached by the waves at ordinary high-water: it extends in front of all the islets, and everywhere has a water-worn and scooped appearance. The fragments of coral which are occasionally cast on the “flat” are during gales of unusual violence swept together on the beach, where the waves each day at high-water tend to remove and gradually wear them down; but the lower fragments having become firmly cemented together by the percolation of calcareous matter, resist the daily tides longer, and hence project as a ledge. The cemented mass is generally of a white colour, but in some few parts reddish from ferruginous matter; it is very hard, and is sonorous under the hammer; it is obscurely divided by seams, dipping at a small angle seaward; it consists of fragments of the corals which grow on the outer margin, some quite and others partially rounded, some small and others between two and three feet across; and of masses of previously formed conglomerate, torn up, rounded, and re-cemented; or it consists of a calcareous sandstone, entirely composed of rounded particles, generally almost blended together, of shells, corals, the spines of echini, and other such organic bodies; rocks, of this latter kind, occur on many shores, where there are no coral reefs. The structure of the coral in the conglomerate has generally been much obscured by the infiltration of spathose calcareous matter; and I collected a very interesting series, beginning with fragments of unaltered coral, and ending with others, where it was impossible to discover with the naked eye any trace of organic structure. In some specimens I was unable, even with the aid of a lens, and by wetting them, to distinguish the boundaries of the altered coral and spathose limestone. Many even of the blocks of coral lying loose on the beach, had their central parts altered and infiltrated.

The lagoon alone remains to be described; it is much shallower than that of most atolls of considerable size. The southern part is almost filled up with banks of mud and fields of coral, both dead and alive, but there are considerable spaces, between three and four fathoms, and smaller basins, from eight to ten fathoms deep. Probably about half its area consists of sediment, and half of coral-reefs. The corals composing these reefs have a very different aspect from those on the outside; they are very numerous in kind, and most of them are thinly branched. Meandrina, however, lives in the lagoon, and great rounded masses of this coral are numerous, lying quite or almost loose on the bottom. The other commonest kinds consist of three closely allied species of true Madrepora in thin branches; of *Seriatapora subulata*; two species of Porites[4] with cylindrical branches, one of which forms circular clumps, with the exterior branches only alive; and lastly, a coral something like an Explanaria, but with stars on both surfaces, growing in thin, brittle, stony, foliaceous expansions, especially in the deeper basins of the lagoon. The reefs on which these corals grow are very irregular in form, are full of cavities, and have not a solid flat surface of dead rock, like that surrounding the lagoon; nor can they be nearly so hard, for the inhabitants made with crowbars a channel of considerable length through these reefs, in which a schooner, built on the S.E. islet, was floated out. It is a very interesting circumstance, pointed out to us by Mr. Liesk, that this channel, although made less than ten years before our visit, was then, as we saw, almost choked up with living coral, so that fresh excavations would be absolutely necessary to allow another vessel to pass through it.

> [4] This Porites has somewhat the habit of *P. clavaria*, but the branches are not knobbed at their ends. When alive it is of a yellow colour, but after having been washed in fresh water and placed to dry, a jet-black slimy substance exuded from the entire surface, so that the specimen now appears as if it had been dipped in ink.

The sediment from the deepest parts in the lagoon, when wet, appeared chalky, but when dry, like very fine sand. Large soft banks of similar, but even finer grained mud, occur on the S.E. shore of the lagoon, affording a thick growth of a Fucus, on which turtle feed: this mud, although discoloured by vegetable matter, appears from its entire solution in acids to be purely calcareous. I have seen in the Museum of the Geological Society, a similar but more remarkable substance, brought by Lieutenant Nelson from the reefs of Bermuda, which, when shown to several experienced geologists, was mistaken by them for true chalk. On the outside of the reef much sediment must be formed by the action of the surf on the rolled fragments of coral; but in the calm waters of the lagoon, this can take place only in a small degree. There are, however, other and unexpected agents at work here: large shoals of two species of Scarus, one inhabiting the surf outside the reef and the other the lagoon, subsist entirely, as I was assured by Mr. Liesk, the intelligent resident before referred to, by browsing on the living polypifers. I opened several of these fish, which are very numerous and of considerable size, and I found their intestines distended by small pieces of coral, and finely ground calcareous matter. This must daily pass from them as the finest sediment; much also must be produced by the infinitely numerous vermiform and molluscous animals, which make cavities in almost every block of coral. Dr. J. Allan, of Forres, who has enjoyed the best means of observation, informs me in a letter that the Holothuriæ (a family of Radiata) subsist on living coral; and the singular structure of bone within the anterior extremity of their bodies, certainly appears well adapted for this purpose. The number of the species of Holothuria, and of the individuals which swarm on every part of these coral-reefs, is extraordinarily great; and many shiploads are annually freighted, as is well-known, for China with the trepang, which is a species of this genus. The amount of coral yearly consumed, and ground down into the finest mud, by these several creatures, and probably by many other kinds, must be immense. These facts are, however, of more importance in another point of view, as showing us that there are living checks to the growth of coral-reefs, and that the almost universal law of “consumed and be consumed,” holds good even with the polypifers forming those massive bulwarks, which are able to withstand the force of the open ocean.

Considering that Keeling atoll, like other coral formations, has been entirely formed by the growth of organic beings, and the accumulation of their detritus, one is naturally led to inquire how long it has continued, and how long it is likely to continue, in its present state. Mr. Liesk informed me that he had seen an old chart in which the present long island on the S.E. side was divided by several channels into as many islets; and he assures me that the channels can still be distinguished by the smaller size of the trees on them. On several islets, also, I observed that only young cocoa-nut trees were growing on the extremities; and that older and taller trees rose in regular succession behind them; which shows that these islets have very lately increased in length. In the upper and south-eastern part of the lagoon, I was much surprised by finding an irregular field of at least a mile square of branching corals, still upright, but entirely dead. They consisted of the species already mentioned; they were of a brown colour, and so rotten, that in trying to stand on them I sank halfway up the leg, as if through decayed brushwood. The tops of the branches were barely covered by water at the time of lowest tide. Several facts having led me to disbelieve in any elevation of the whole atoll, I was at first unable to imagine what cause could have killed so large a field of coral. Upon reflection, however, it appeared to me that the closing up of the above-mentioned channels would be a sufficient cause; for before this, a strong breeze by forcing water through them into the head of the lagoon, would tend to raise its level. But now this cannot happen, and the inhabitants observe that the tide rises to a less height, during a high S.E. wind, at the head than at the mouth of the lagoon. The corals, which, under the former condition of things, had attained the utmost possible limit of upward growth, would thus occasionally be exposed for a short time to the sun, and be killed.

Besides the increase of dry land, indicated by the foregoing facts, the exterior solid reef appears to have grown outwards. On the western side of the atoll, the “flat” lying between the margin of the reef and the beach, is very wide; and in front of the regular beach with its conglomerate basis, there is, in most parts, a bed of sand and loose fragments with trees growing out of it, which apparently is not reached even by the spray at high water. It is evident some change has taken place since the waves formed the inner beach; that they formerly beat against it with violence was evident, from a remarkably thick and water-worn point of conglomerate at one spot, now protected by vegetation and a bank of sand; that they beat against it in the same peculiar manner in which the swell from windward now obliquely curls round the margin of the reef, was evident from the conglomerate having been worn into a point projecting from the beach in a similarly oblique manner. This retreat in the line of action of the breakers might result, either from the surface of the reef in front of the islets having been submerged at one time, and afterward having grown upwards, or from the mounds of coral on the margin having continued to grow outwards. That an outward growth of this part is in process, can hardly be doubted from the fact already mentioned of the mounds of Porites with their summits apparently lately killed, and their sides only three or four inches lower down thickened by a fresh layer of living coral. But there is a difficulty on this supposition which I must not pass over. If the whole, or a large part of the “flat,” had been formed by the outward growth of the margin, each successive margin would naturally have been coated by the Nulliporæ, and so much of the surface would have been of equal height with the existing zone of living Nulliporæ: this is not the case, as may be seen in the woodcut. It is, however, evident from the abraded state of the “flat,” with its original inequalities filled up, that its surface has been much modified; and it is possible that the hinder portions of the zone of Nulliporæ, perishing as the reef grows outwards, might be worn down by the surf. If this has not taken place, the reef can in no part have increased outwards in breadth since its formation, or at least since the Nulliporæ formed the convex mound on its margin; for the zone thus formed, and which stands between two and three feet above the other parts of the reef, is nowhere much above twenty yards in width.

Thus far we have considered facts, which indicate, with more or less probability, the increase of the atoll in its different parts: there are others having an opposite tendency. On the south-east side, Lieutenant Sulivan, to whose kindness I am indebted for many interesting observations, found the conglomerate projecting on the reef nearly fifty yards in front of the beach: we may infer from what we see in all other parts of the atoll, that the conglomerate was not originally so much exposed, but formed the base of an islet, the front and upper part of which has since been swept away. The degree to which the conglomerate, round nearly the whole atoll, has been scooped, broken up, and the fragments cast on the beach, is certainly very surprising, even on the view that it is the office of occasional gales to pile up fragments, and of the daily tides to wear them away. On the western side, also, of the atoll, where I have described a bed of sand and fragments with trees growing out of it, in front of an old beach, it struck both Lieutenant Sulivan and myself, from the manner in which the trees were being washed down, that the surf had lately recommenced an attack on this line of coast. Appearances indicating a slight encroachment of the water on the land, are plainer within the lagoon: I noticed in several places, both on its windward and leeward shores, old cocoa-nut trees falling with their roots undermined, and the rotten stumps of others on the beach, where the inhabitants assured us the cocoa-nut could not now grow. Captain Fitzroy pointed out to me, near the settlement, the foundation posts of a shed, now washed by every tide, but which the inhabitants stated, had seven years before stood above high watermark. In the calm waters of the lagoon, directly connected with a great, and therefore stable ocean, it seems very improbable that a change in the currents, sufficiently great to cause the water to eat into the land on all sides, should have taken place within a limited period. From these considerations I inferred, that probably the atoll had lately subsided to a small amount; and this inference was strengthened by the circumstance, that in 1834, two years before our visit, the island had been shaken by a severe earthquake, and by two slighter ones during the ten previous years. If, during these subterranean disturbances, the atoll did subside, the downward movement must have been very small, as we must conclude from the fields of dead coral still lipping the surface of the lagoon, and from the breakers on the western shore not having yet regained the line of their former action. The subsidence must, also, have been preceded by a long period of rest, during which the islets extended to their present size, and the living margin of the reef grew either upwards, or as I believe outwards, to its present distance from the beach.

Whether this view be correct or not, the above facts are worthy of attention, as showing how severe a struggle is in progress on these low coral formations between the two nicely balanced powers of land and water. With respect to the future state of Keeling atoll, if left undisturbed, we can see that the islets may still extend in length; but as they cannot resist the surf until broken by rolling over a wide space, their increase in breadth must depend on the increasing breadth of the reef; and this must be limited by the steepness of the submarine flanks, which can be added to only by sediment derived from the wear and tear of the coral. From the rapid growth of the coral in the channel cut for the schooner, and from the several agents at work in producing fine sediment, it might be thought that the lagoon would necessarily become quickly filled up. Some of this sediment, however, is transported into the open sea, as appears from the soundings off the mouth of the lagoon, instead of being deposited within it. The deposition, moreover, of sediment, checks the growth of coral-reefs, so that these two agencies cannot act together with full effect in filling it up. We know so little of the habits of the many different species of corals, which form the lagoon-reefs, that we have no more reasons for supposing that their whole surface would grow up as quickly as the coral did in the schooner-channel, than for supposing that the whole surface of a peat-moss would increase as quickly as parts are known to do in holes, where the peat has been cut away. These agencies, nevertheless, tend to fill up the lagoon; but in proportion as it becomes shallower, so must the polypifers be subject to many injurious agencies, such as impure water and loss of food. For instance, Mr. Liesk informed me, that some years before our visit unusually heavy rain killed nearly all the fish in the lagoon, and probably the same cause would likewise injure the corals. The reefs also, it must be remembered, cannot possibly rise above the level of the lowest spring-tide, so that the final conversion of the lagoon into land must be due to the accumulation of sediment; and in the midst of the clear water of the ocean, and with no surrounding high land, this process must be exceedingly slow.

Section II—GENERAL DESCRIPTION OF ATOLLS.

General form and size of atolls, their reefs and islets.—External slope.—Zone of Nulliporæ.—Conglomerate.—Depth of lagoons.—Sediment.—Reefs submerged wholly or in part.—Breaches in the reef.—Ledge-formed shores round certain lagoons.—Conversion of lagoons into land.

I will here give a sketch of the general form and structure of the many atolls and atoll-formed reefs which occur in the Pacific and Indian Oceans, comparing them with Keeling atoll. The Maldiva atolls and the Great Chagos Bank differ in so many respects, that I shall devote to them, besides occasional references, a third section of this chapter. Keeling atoll may be considered as of moderate dimensions and of regular form. Of the thirty-two islands surveyed by Captain Beechey in the Low Archipelago, the longest was found to be thirty miles, and the shortest less than a mile; but Vliegen atoll, situated in another part of the same group, appears to be sixty miles long and twenty broad. Most of the atolls in this group are of an elongated form; thus Bow Island is thirty miles in length, and on an average only six in width (See Fig. 4, Plate I), and Clermont Tonnere has nearly the same proportions. In the Marshall Archipelago (the Ralick and Radack group of Kotzebue) several of the atolls are more than thirty miles in length, and Rimsky Korsacoff is fifty-four long, and twenty wide, at the broadest part of its irregular outline. Most of the atolls in the Maldiva Archipelago are of great size, one of them (which, however, bears a double name) measured in a medial and slightly curved line, is no less than eighty-eight geographical miles long, its greatest width being under twenty, and its least only nine and a half miles. Some atolls have spurs projecting from them; and in the Marshall group there are atolls united together by linear reefs, for instance Menchikoff Island (See Fig. 3, Plate II), which is sixty miles in length, and consists of three loops tied together. In far the greater number of cases an atoll consists of a simple elongated ring, with its outline moderately regular.

The average width of the annular wreath may be taken as about a quarter of a mile. Captain Beechey[5] says that in the atolls of the Low Archipelago it exceeded in no instance half a mile. The description given of the structure and proportional dimensions of the reef and islets of Keeling atoll, appears to apply perfectly to nearly all the atolls in the Pacific and Indian Oceans. The islets are first formed some way back either on the projecting points of the reef, especially if its form be angular, or on the sides of the main entrances into the lagoon—that is in both cases, on points where the breakers can act during gales of wind in somewhat different directions, so that the matter thrown up from one side may accumulate against that before thrown up from another. In Lutké's chart of the Caroline atolls, we see many instances of the former case; and the occurrence of islets, as if placed for beacons, on the points where there is a gateway or breach through the reef, has been noticed by several authors. There are some atoll-formed reefs, rising to the surface of the sea and partly dry at low water, on which from some cause islets have never been formed; and there are others on which they have been formed, but have subsequently been worn away. In atolls of small dimensions the islets frequently become united into a single horse-shoe or ring-formed strip; but Diego Garcia, although an atoll of considerable size, being thirteen miles and a half in length, has its lagoon entirely surrounded, except at the northern end, by a belt of land, on an average a third of a mile in width. To show how small the total area of the annular reef and the land is in islands of this class, I may quote a remark from the voyage of Lutké, namely, that if the forty-three rings, or atolls, in the Caroline Archipelago, were put one within another, and over a steeple in the centre of St. Petersburg, the whole world would not cover that city and its suburbs.

[5] Beechey's "Voyage to the Pacific and Beering's Straits," chapter viii.

The form of the bottom off Keeling atoll, which gradually slopes to about twenty fathoms at the distance of between one and two hundred yards from the edge of the reef, and then plunges at an angle of 45° into unfathomable depths, is exactly the same[6] with that of the sections of the atolls in the Low Archipelago given by Captain Beechey. The nature, however, of the bottom seems to differ, for this officer[7] informs me that all the soundings, even the deepest, were on coral, but he does not know whether dead or alive. The slope round Christmas atoll (Lat. 1° 4′ N., 157° 45′ W.), described by Cook,[8] is considerably less, at about half a mile from the edge of the reef, the average depth was about fourteen fathoms on a fine sandy bottom, and at a mile, only between twenty and forty fathoms. It has no doubt been owing to this gentle slope, that the strip of land surrounding its lagoon, has increased in one part to the extraordinary width of three miles; it is formed of successive ridges of broken shells and corals, like those on the beach. I know of no other instance of such width in the reef of an atoll; but Mr. F. D. Bennett informs me that the inclination of the bottom round Caroline atoll in the Pacific, is like that off Christmas Island, very gentle. Off the Maldiva and Chagos atolls, the inclination is much more abrupt; thus at Heawandoo Pholo, Lieutenant Powell[9] found fifty and sixty fathoms close to the edge of the reef, and at 300 yards distance there was no bottom with a 300-yard line. Captain Moresby informs me, that at 100 fathoms from the mouth of the lagoon of Diego Garcia, he found no bottom with 150 fathoms; this is the more remarkable, as the slope is generally less abrupt in front of channels through a reef, owing to the accumulation of sediment. At Egmont Island, also, at 150 fathoms from the reef, soundings were struck with 150 fathoms. Lastly, at Cardoo atoll, only sixty yards from the reef, no bottom was obtained, as I am informed by Captain Moresby, with a line of 200 fathoms! The currents run with great force round these atolls, and where they are strongest, the inclination appears to be most abrupt. I am informed by the same authority, that wherever soundings were obtained off these islands, the bottom was invariably sandy: nor was there any reason to suspect the existence of submarine cliffs, as there was at Keeling Island.[10] Here then occurs a difficulty; can sand accumulate on a slope, which, in some cases, appears to exceed fifty-five degrees? It must be observed, that I speak of slopes where soundings were obtained, and not of such cases, as that of Cardoo, where the nature of the bottom is unknown, and where its inclination must be nearly vertical. M. Elie de Beaumont[11] has argued, and there is no higher authority on this subject, from the inclination at which snow slides down in avalanches, that a bed of sand or mud cannot be formed at a greater angle than thirty degrees. Considering the number of soundings on sand, obtained round the Maldiva and Chagos atolls, which appears to indicate a greater angle, and the extreme abruptness of the sand-banks in the West Indies, as will be mentioned in the Appendix, I must conclude that the adhesive property of wet sand counteracts its gravity, in a much greater ratio than has been allowed for by M. Elie de Beaumont. From the facility with which calcareous sand becomes agglutinated, it is not necessary to suppose that the bed of loose sand is thick.

[6] The form of the bottom round the Marshall atolls in the Northern Pacific is probably similar: Kotzebue ("First Voyage," vol. ii, p. 16) says: "We had at a small distance from the reef, forty fathoms depth, which increased a little further so much that we could find no bottom."

[7] I must be permitted to express my obligation to Captain Beechey, for the very kind manner in which he has given me information on several points, and to own the great assistance I have derived from his excellent published work.

[8] Cook's "Third Voyage," vol. ii, chap. 10.

[9] This fact is taken from a MS. account of these groups lent me by Captain Moresby. See also Captain Moresby's paper on the Maldiva atolls in the *Geographical Journal*, vol. v, p. 401.

[10] Off some of the islands in the Low Archipelago the bottom appears to descend by ledges. Off Elizabeth Island, which, however, consists of raised coral, Captain Beechey (page 45, 4to ed.) describes three ledges: the first had an easy slope from the beach to a distance of about fifty yards: the second extended two hundred yards with twenty-five fathoms on it, and then ended abruptly, like the first; and immediately beyond this there was no bottom with two hundred fathoms.

[11] "Memoires pour servir à une description Geolog. de France," tome iv, p. 216.

Captain Beechey has observed, that the submarine slope is much less at the extremities of the more elongated atolls in the Low Archipelago, than at their sides; in speaking of Ducie's Island he says[12] the buttress, as it may be called, which "has the most powerful enemy (the S.W. swell) to oppose, is carried out much further, and with less abruptness than the other." In some cases, the less inclination of a certain part of the external slope, for instance of the northern extremities of the two Keeling atolls, is caused by a prevailing current which there accumulates a bed of sand. Where the water is perfectly tranquil, as within a lagoon, the reefs generally grow up perpendicularly, and sometimes even overhang their bases; on the other hand, on the leeward side of Mauritius, where the water is generally tranquil, although not invariably so, the reef is very gently inclined. Hence it appears that the exterior angle varies much; nevertheless in the close similarity in form between the sections of Keeling atoll and of the atolls in the Low Archipelago, in the general steepness of the reefs of the Maldiva and Chagos atolls, and in the perpendicularity of those rising out of water always tranquil, we may discern the effects of uniform laws; but from the complex action of the surf and currents, on the growing powers of the coral and on the deposition of sediment, we can by no means follow out all the results.

[12] Beechey's "Voyage," 4to ed., p. 44.

Where islets have been formed on the reef, that part which I have sometimes called the "flat" and which is partly dry at low water, appears similar in every atoll. In the Marshall group in the North Pacific, it may be inferred from Chamisso's description, that the reef, where islets have not been formed on it, slopes gently from the external margin to the shores of the lagoon; Flinders states that the Australian barrier has a similar inclination inwards, and I have no doubt it is of general occurrence, although, according to Ehrenberg, the reefs of the Red Sea offer an exception. Chamisso observes that "the red colour of the reef (at the Marshall atolls) under the breakers is caused by a Nullipora, which covers the stone *wherever the waves beat*; and, under favourable circumstances, assumes a stalactical form,"—a description perfectly applicable to the margin of Keeling atoll.[13] Although Chamisso does not state that the masses of Nulliporæ form points or a mound, higher than the flat, yet I believe that this is the case; for Kotzebue,[14] in another part, speaks of the rocks on the edge of the reef "as visible for about two feet at low water," and these rocks we may feel quite certain are not formed of true coral,[15] Whether a smooth convex mound of Nulliporæ, like that which appears as if artificially constructed to protect the margin of Keeling Island, is of frequent occurrence round atolls, I know not; but we shall presently meet with it, under precisely the same form, on the outer edge of the "barrier-reefs" which encircle the Society Islands.

[13] Kotzebue's "First Voyage," vol. iii, p. 142. Near Porto Praya, in the Cape de Verde Islands, some basaltic rocks, lashed by no inconsiderable surf, were completely enveloped with a layer of Nulliporæ. The entire surface over many square inches, was coloured of a peach-blossomed red; the layer, however, was of no greater thickness than paper. Another kind, in the form of projecting knobs, grew in the same situation. These Nulliporæ are closely related to those described on the coral-reefs, but I believe are of different species.

[14] Kotzebue's "First Voyage," vol. ii, p. 16. Lieutenant Nelson, in his excellent memoir in the Geological Transactions (vol. ii, p. 105), alludes to the rocky points mentioned by Kotzebue, and infers that they consist of Serpulæ, which compose incrusting masses on the reefs of Bermudas, as they likewise do on a sandstone bar off the coast of Brazil (which I have described in *London Phil. Journal,* October 1841). These masses of Serpulæ hold the same position, relatively to the action of the sea, with the Nulliporæ on the coral-reefs in the Indian and Pacific Oceans.

[15] Captain Moresby, in his valuable paper "on the Northern atolls of Maldivas" (*Geographical Journal*, vol. v), says that the edges of the reefs there stand above water at low spring-tides.

There appears to be scarcely a feature in the structure of Keeling reef, which is not of common, if not of universal occurrence, in other atolls. Thus Chamisso describes[16] a layer of coarse conglomerate, outside the islets round the Marshall atolls which "appears on its upper surface uneven and eaten away." From drawings, with appended remarks, of Diego Garcia in the Chagos group and of several of the Maldiva atolls, shown me by Captain Moresby,[17] it is evident that their outer coasts are subject to the same round of decay and renovation as those of Keeling atoll. From the description of the atolls in the Low Archipelago, given in Captain Beechey's "Voyage," it is not apparent that any conglomerate coral-rock was there observed.

[16] Kotzebue's "First Voyage," vol. iii, p. 144.

[17] See also Moresby on the Northern atolls of the Maldivas, *Geographical Journal*, vol v, p. 400.

The lagoon in Keeling atoll is shallow; in the atolls of the Low Archipelago the depth varies from 20 to 38 fathoms, and in the Marshall Group, according to Chamisso, from 30 to 35; in the Caroline atolls it is only a little less. Within the Maldiva atolls there are large spaces with 45 fathoms, and some soundings are laid down of 49 fathoms. The greater part of the bottom in most lagoons, is formed of sediment; large spaces have exactly the same depth, or the depth varies so insensibly, that it is evident that no other means, excepting aqueous deposition, could have leveled the surface so equally. In the Maldiva atolls this is very conspicuous, and likewise in some of the Caroline and Marshall Islands. In the former large spaces consist of sand and *soft clay*; and Kotzebue speaks of clay having been found within one of the Marshall atolls. No doubt this clay is calcareous mud, similar to that at Keeling Island, and to that at Bermuda already referred to, as undistinguishable from disintegrated chalk, and which Lieutenant Nelson says is called there pipe-clay.[18]

[18] I may here observe that on the coast of Brazil, where there is much coral, the soundings near the land are described by Admiral Roussin, in the *Pilote du Brésil*, as siliceous sand, mingled with much finely comminuted particles of shells and coral. Further in the offing, for a space of 1,300 miles along the coast, from the Abrolhos Islands to Maranham, the bottom in many places is composed of "tuf blanc, mêlé ou formé de madrépores broyés." This white substance, probably, is analogous to that which occurs within the above-mentioned lagoons; it is sometimes, according to Roussin, firm, and he compares it to mortar.

Where the waves act with unequal force on the two sides of an atoll, the islets appear to be first formed, and are generally of greater continuity on the more exposed shore. The islets, also, which are placed to leeward, are in most parts of the Pacific liable to be occasionally swept entirely away by gales, equalling hurricanes in violence, which blow in an opposite direction to the ordinary trade-wind. The absence of the islets on the leeward side of atolls, or when present their lesser dimensions compared with those to windward, is a comparatively unimportant fact; but in several instances the reef itself on the leeward side, retaining its usual defined outline, does not rise to the surface by several fathoms. This is the case with the southern side of Peros Banhos (Plate 1, Fig. 9) in the Chagos group, with Mourileu atoll,[19] in the Caroline Archipelago, and with the barrier-reef (Plate I, Fig. 8) of the Gambier Islands. I allude to the latter reef, although belonging to another class, because Captain Beechey was first led by it to observe the peculiarity in the question. At Peros Banhos the submerged part is nine miles in length, and lies at an average depth of about five fathoms; its surface is nearly level, and consists of hard stone, with a thin covering of loose sand. There is scarcely any living coral on it, even on the outer margin, as I have been particularly assured by Captain Moresby; it is, in fact, a wall of dead coral-rock, having the same width and transverse section with the reef in its ordinary state, of which it is a continuous portion. The living and perfect parts terminate abruptly, and abut on the submerged portions, in the same manner as on the sides of an ordinary passage through the reef. The reef to leeward in other cases is nearly or quite obliterated, and one side of the lagoon is left open; for instance, at Oulleay (Caroline Archipelago), where a crescent-formed reef is fronted by an irregular bank, on which the other half of the annular reef probably once stood. At Namonouito, in the same Archipelago, both these modifications of the reef concur; it consists of a great flat bank, with from twenty to twenty-five fathoms water on it; for a length of more than forty miles on its southern side it is open and without any reef, whilst on the other sides it is bounded by a reef, in parts rising to the surface and perfectly characterised, in parts lying some fathoms submerged. In the Chagos group there are annular reefs, entirely submerged, which have the same structure as the submerged and defined portions just described. The Speaker's Bank offers an excellent example of this structure; its central expanse, which is about twenty-two fathoms deep, is twenty-four miles across; the external rim is of the usual width of annular reefs, and is well-defined; it lies between six and eight fathoms beneath the surface, and at the same depth there are scattered knolls in the lagoon. Captain Moresby believes the rim consists of dead rock, thinly covered with sand, and he is certain this is the case with the external rim of the Great Chagos Bank, which is also essentially a submerged atoll. In both these cases, as in the submerged portion of the reef at Peros Banhos, Captain Moresby feels sure that the quantity of living coral, even on the outer edge overhanging the deep-sea water, is quite insignificant. Lastly, in several parts of the Pacific and Indian Oceans there are banks, lying at greater depths than in the cases just mentioned, of the same form and size with the neighbouring atolls, but with their atoll-like structure wholly obliterated. It appears from the survey of Freycinet, that there are banks of this kind in the Caroline Archipelago, and, as is reported, in the Low Archipelago. When we discuss the origin of the different classes of coral formations, we shall see that the submerged state of the whole of some atoll-formed reefs, and of portions of others, generally but not invariably on the leeward side, and the existence of more deeply submerged banks now possessing little or no signs of their original atoll-like structure, are probably the effects of a uniform cause,—namely, the death of the coral, during the subsidence of the area, in which the atolls or banks are situated.

[19] Frederick Lutké's "Voyage autour du Monde," vol. ii, p. 291. See also his account of Namonouito, at pp. 97 and 105, and the chart of Oulleay in the Atlas.

There is seldom, with the exception of the Maldiva atolls, more than two or three channels, and generally only one leading into the lagoon, of sufficient depth for a ship to enter. in small atolls, there is usually not even one. Where there is deep water, for instance above twenty fathoms, in the middle of the lagoon, the channels through the reef are seldom as deep as the centre,—it may be said that the rim only of the saucer-shaped hollow forming the lagoon is notched. Mr. Lyell[20] has observed that the growth of the coral would tend to obstruct all the channels through a reef, except those kept open by discharging the water, which during high tide and the greater part of each ebb is thrown over its circumference. Several facts indicate that a considerable quantity of sediment is likewise discharged through these channels; and Captain Moresby informs me that he has observed, during the change of the monsoon, the sea discoloured to a distance off the entrances into the

Maldiva and Chagos atolls. This, probably, would check the growth of the coral in them, far more effectually than a mere current of water. In the many small atolls without any channel, these causes have not prevented the entire ring attaining the surface. The channels, like the submerged and effaced parts of the reef, very generally though not invariably occur on the leeward side of the atoll, or on that side, according to Beechey,[21] which, from running in the same direction with the prevalent wind, is not fully exposed to it. Passages between the islets on the reef, through which boats can pass at high water, must not be confounded with ship-channels, by which the annular reef itself is breached. The passages between the islets occur, of course, on the windward as well as on the leeward side; but they are more frequent and broader to leeward, owing to the lesser dimensions of the islets on that side.

[20] "Principles of Geology," vol. iii, p. 289.

[21] Beechey's "Voyage," 4to ed., vol. i, p. 189.

At Keeling atoll the shores of the lagoon shelve gradually, where the bottom is of sediment, and irregularly or abruptly where there are coral-reefs; but this is by no means the universal structure in other atolls. Chamisso,[22] speaking in general terms of the lagoons in the Marshall atolls, says the lead generally sinks "from a depth of two or three fathoms to twenty or twenty-four, and you may pursue a line in which on one side of the boat you may see the bottom, and on the other the azure-blue deep water." The shores of the lagoon-like channel within the barrier-reef at Vanikoro have a similar structure. Captain Beechey has described a modification of this structure (and he believes it is not uncommon) in two atolls in the Low Archipelago, in which the shores of the lagoon descend by a few, broad, slightly inclined ledges or steps: thus at Matilda atoll,[23] the great exterior reef, the surface of which is gently inclined towards and beneath the surface of the lagoon, ends abruptly in a little cliff three fathoms deep; at its foot, a ledge forty yards wide extends, shelving gently inwards like the surface-reef, and terminated by a second little cliff five fathoms deep; beyond this, the bottom of the lagoon slopes to twenty fathoms, which is the average depth of its centre. These ledges seem to be formed of coral-rock; and Captain Beechey says that the lead often descended several fathoms through holes in them. In some atolls, all the coral reefs or knolls in the lagoon come to the surface at low water; in other cases of rarer occurrence, all lie at nearly the same depth beneath it, but most frequently they are quite irregular,—some with perpendicular, some with sloping sides,—some rising to the surface, and others lying at all intermediate depths from the bottom upwards. I cannot, therefore, suppose that the union of such reefs could produce even one uniformly sloping ledge, and much less two or three, one beneath the other, and each terminated by an abrupt wall. At Matilda Island, which offers the best example of the step-like structure, Captain Beechey observes that the coral-knolls within the lagoon are quite irregular in their height. We shall hereafter see that the theory which accounts for the ordinary form of atolls, apparently includes this occasional peculiarity in their structure.

[22] Kotzebue's "First Voyage," vol. iii, p. 142.

[23] Beechey's "Voyage," 4to ed., vol. i, p. 160. At Whitsunday Island the bottom of the lagoon slopes gradually towards the centre, and then deepens suddenly, the edge of the bank being nearly perpendicular. This bank is formed of coral and dead shells.

In the midst of a group of atolls, there sometimes occur small, flat, very low islands of coral formation, which probably once included a lagoon, since filled up with sediment and coral-reefs. Captain Beechey entertains no doubt that this has been the case with the two small islands, which alone of thirty-one surveyed by him in the Low Archipelago, did not contain lagoons. Romanzoff Island (in lat. 15 deg S.) is described by Chamisso[24] as formed by a dam of madreporitic rock inclosing a flat space, thinly covered with trees, into which the sea on the leeward side occasionally breaks. North Keeling atoll appears to be in a rather less forward stage of conversion into land; it consists of a horse-shoe shaped strip of land surrounding a muddy flat, one mile in its longest axis, which is covered by the sea only at high water. When describing South Keeling atoll, I endeavoured to show how slow the final process of filling up a lagoon must be; nevertheless, as all causes do tend to produce this effect, it is very remarkable that not one instance, as I believe, is known of a moderately sized lagoon being filled up even to the low water-line at spring-tides, much less of such a one being converted into land. It is, likewise, in some degree remarkable, how few atolls, except small ones, are surrounded by a single linear strip of land, formed by the union of separate islets. We cannot suppose that the many atolls in the Pacific and Indian Oceans all have had a late origin, and yet should they remain at their present level, subjected only to the action of the sea and to the growing powers of the coral, during as many centuries as must have elapsed since any of the earlier tertiary epochs, it cannot, I think, be doubted that their lagoons and the islets on their reef, would present a totally different appearance from what they now do. This consideration leads to the suspicion that some renovating agency (namely subsidence) comes into play at intervals, and perpetuates their original structure.

[24] Kotzebue's "First Voyage," vol. iii, p. 221.

Section III—ATOLLS OF THE MALDIVA ARCHIPELAGO—GREAT CHAGOS BANK

Maldiva Archipelago.—Ring-formed reefs, marginal and central.—Great depths in the lagoons of the southern atolls.—Reefs in the lagoons all rising to the surface.—Position of islets and breaches in the reefs, with respect to the prevalent winds and action of the waves.—Destruction of islets.—Connection in the position and submarine foundation of distinct atolls.—The apparent disseverment of large atolls.—The Great Chagos Bank.—Its submerged condition and extraordinary structure.

Although occasional references have been made to the Maldiva atolls, and to the banks in the Chagos group, some points of their structure deserve further consideration. My description is derived from an examination of the admirable charts lately published from the survey of Captain Moresby and Lieutenant Powell, and more especially from information which Captain Moresby has communicated to me in the kindest manner.

The Maldiva Archipelago is 470 miles in length, with an average breadth of about 50 miles. The form and dimensions of the atolls, and their singular position in a double line, may be seen, but not well, in the greatly reduced chart (Fig. 6) in Plate II. The dimensions of the longest atoll in the group (called by the double name of Milla-dou-Madou and Tilla-dou-Matte) have already been given; it is 88 miles in a medial and slightly curved line, and is less than 20 miles in its broadest part. Suadiva, also, is a noble atoll, being 44 miles across in one direction, and 34 in another, and the great included expanse of water has a depth of between 250 and 300 feet. The smaller atolls in this group differ in no respect from ordinary ones; but the larger ones are remarkable from being breached by numerous deep-water channels leading into the lagoon; for instance, there are 42 channels, through which a ship could enter the lagoon of Suadiva. In the three southern large atolls, the separate portions of reef between these channels have the ordinary structure, and are linear; but in the other atolls, especially the more northern ones, these portions are ring-formed, like miniature atolls. Other ring-formed reefs rise out of the lagoons, in the place of those irregular ones which ordinarily occur there. In the reduction of the chart of Mahlos Mahdoo (Plate II, Fig. 4), it was not found easy to define the islets and the little lagoons within each reef, so that the ring-formed structure is very imperfectly shown; in the large published charts of Tilla-dou-Matte, the appearance of these rings, from standing further apart from each other, is very remarkable. The rings on the margin are generally elongated; many of them are three, and some even five miles, in diameter; those within the lagoon are usually smaller, few being more than two miles across, and the greater number rather less than one. The depth of the little lagoon within these small annular reefs is generally from five to seven fathoms, but occasionally more; and in Ari atoll many of the central ones are twelve, and some even more than twelve fathoms deep. These rings rise abruptly from the platform or bank, on which they are placed; their outer margin is invariably bordered by living coral[25] within which there is a flat surface of coral rock; of this flat, sand and fragments have in many cases accumulated and been converted into islets, clothed with vegetation. I can, in fact, point out no essential difference between these little ring-formed reefs (which, however, are larger, and contain deeper lagoons than many true atolls that stand in the open sea), and the most perfectly characterised atolls, excepting that the ring-formed reefs are based on a shallow foundation, instead of on the floor of the open sea, and that instead of being scattered irregularly, they are grouped closely together on one large platform, with the marginal rings arranged in a rudely formed circle.

> [25] Captain Moresby informs me that *Millepora complanata* is one of the commonest kinds on the outer margin, as it is at Keeling atoll.

The perfect series which can be traced from portions of simple linear reef, to others including long linear lagoons, and from these again to oval or almost circular rings, renders it probable that the latter are merely modifications of the linear or normal state. It is conformable with this view, that the ring-formed reefs on the margin, even where most perfect and standing furthest apart, generally have their longest axes directed in the line which the reef would have held, if the atoll had been bounded by an ordinary wall. We may also infer that the central ring-formed reefs are modifications of those irregular ones, which are found in the lagoons of all common atolls. It appears from the charts on a large scale, that the ring-like structure is contingent on the marginal channels or breaches being wide; and, consequently, on the whole interior of the atoll being freely exposed to the waters of the open sea. When the channels are narrow or few in number, although the lagoon be of great size and depth (as in Suadiva), there are no ring-formed reefs; where the channels are somewhat broader, the marginal portions of reef, and especially those close to the larger channels, are ring-formed, but the central ones are not so; where they are broadest, almost every reef throughout the atoll is more or less perfectly ring-formed. Although their presence is thus contingent on the openness of the marginal channels, the theory of their formation, as we shall hereafter see, is included in that of the parent atolls, of which they form the separate portions.

The lagoons of all the atolls in the southern part of the Archipelago are from ten to twenty fathoms deeper than those in the northern part. This is well exemplified in the case of Addoo, the southernmost atoll in the group, for although only nine miles in its longest diameter, it has a depth of thirty-nine fathoms, whereas all the other small atolls have comparatively shallow lagoons; I can assign no adequate cause for this difference in depth. In the central and deepest part of the lagoons, the bottom consists, as I am informed by Captain Moresby, of stiff clay (probably a calcareous mud); nearer the border it consists of sand, and in the channels through the reef, of hard sand-banks, sandstone, conglomerate rubble, and a little live coral. Close outside the reef and the line joining its detached portions (where intersected by many channels), the bottom is sandy, and it slopes abruptly into unfathomable depths. In most lagoons the depth is considerably greater in the centre than in the channels; but in Tilla-dou-Matte, where the marginal ring-formed reefs stand far apart, the same depth is carried across the entire atoll, from the deep-water line on one side to that on the other. I cannot refrain from once again remarking on the singularity of these atolls,—a great sandy and generally concave disc rises abruptly from the unfathomable ocean, with its central expanse studded and its border symmetrically fringed with oval basins of coral-rock, just lipping the surface of the sea, sometimes clothed with vegetation, and each containing a little lake of clear water!

In the southern Maldiva atolls, of which there are nine large ones, all the small reefs within the lagoons come to the surface, and are dry at low water spring-tides; hence in navigating them, there is no danger from submarine banks. This circumstance is very remarkable, as within some atolls, for instance those of the neighbouring Chagos group, not a single reef comes to the surface, and in most other cases a few only do, and the rest lie at all intermediate depths from the bottom upwards. When treating of the growth of coral I shall again refer to this subject.

Although in the neighbourhood of the Maldiva Archipelago the winds, during the monsoons, blow during nearly an equal time from opposite quarters, and although, as I am informed by Captain Moresby, the westerly winds are the strongest, yet the islets are almost all placed on the eastern side of the northern atolls, and on the south-eastern side of the southern atolls. That the formation of the islets is due to detritus thrown up from the outside, as in the ordinary manner, and not from the interior of the lagoons, may, I think be safely inferred from several considerations, which it is hardly worth while to detail. As the easterly winds are not the strongest, their action probably is aided by some prevailing swell or current.

In groups of atolls, exposed to a trade-wind, the ship-channels into the lagoons are almost invariably situated on the leeward or less exposed side of the reef, and the reef itself is sometimes either wanting there, or is submerged. A strictly analogous, but different fact, may be observed at the Maldiva atolls—namely, that where two atolls stand in front of each other, the breaches in the reef are the most numerous on their near, and therefore less exposed, sides. Thus on the near sides of Ari and the two Nillandoo atolls, which face S. Mãle, Phaleedoo, and Moloque atolls, there are seventy-three deep-water channels, and only twenty-five on their outer sides; on the near side of the three latter named atolls there are fifty-six openings, and only thirty-seven on their outsides. It is scarcely possible to attribute this difference to any other cause than the somewhat different action of the sea on the two sides, which would ensue from the protection afforded by the two rows of atolls to each other. I may here remark that in most cases, the conditions favourable to the greater accumulation of fragments on the reef and to its more perfect continuity on one side of the atoll than on the other, have concurred, but this has not been the case with the Maldivas; for we have seen that the islets are placed on the eastern or south-eastern sides, whilst the breaches in the reef occur indifferently on any side, where protected by an opposite atoll. The reef being more continuous on the outer and more exposed sides of those atolls which stand near each other, accords with the fact, that the reef of the southern atolls is more continuous than that of the northern ones; for the former, as I am informed by Captain Moresby, are more constantly exposed than the northern atolls to a heavy surf.

The date of the first formation of some of the islets in this Archipelago is known to the inhabitants; on the other hand, several islets, and even some of those which are believed to be very old, are now fast wearing away. The work of destruction has, in some instances, been completed in ten years. Captain Moresby found on one water-washed reef the marks of wells and graves, which were excavated when it supported an islet. In South Nillandoo atoll, the natives say that three of the islets were formerly larger: in North Nillandoo there is one now being washed away; and in this latter atoll Lieutenant Prentice found a reef, about six hundred yards in diameter, which the natives positively affirmed was lately an island covered with cocoa-nut trees. It is now only partially dry at low water spring-tides, and is (in Lieutenant Prentice's words) "entirely covered with live coral and madrepore." In the northern part, also, of the Maldiva Archipelago and in the Chagos group, it is known that some of the islets are disappearing. The natives attribute these effects to variations in the currents of the sea. For my own part I cannot avoid suspecting that there must be some further cause, which gives rise to such a cycle of change in the action of the currents of the great and open ocean.

Several of the atolls in this Archipelago are so related to each other in form and position, that at the first glance one is led to suspect that they have originated in the disseverment of a single one. Mãle consists of three perfectly characterised atolls, of which the shape and relative position are such, that a line drawn closely round all three, gives a symmetrical figure; to see this clearly, a larger chart is required than that of the Archipelago in Plate II; the channel separating the two northern Male atolls is only little more than a mile wide, and no bottom was found in it with 100 fathoms. Powell's Island is situated at the distance of two miles and a half off the northern end of Mahlos Mahdoo (see Fig. 4, Plate II), at the exact point where the two sides of the latter, if prolonged, would meet; no bottom, however, was found in the channel with 200 fathoms; in the wider channel between Horsburgh atoll and the southern end of Mahlos Mahdoo, no bottom was found with 250 fathoms. In these and similar cases, the relation consists only in the form and position of the atolls. But in the channel between the two Nillandoo atolls, although three miles and a quarter wide, soundings were struck at the depth of 200 fathoms; the channel between Ross and Ari atolls is four miles wide, and only 150 fathoms deep. Here then we have, besides the relation of form, a submarine connection. The fact of soundings having been obtained between two separate and perfectly characterised atolls is in itself interesting, as it has never, I believe, been effected in any of the many other groups of atolls in the Pacific and Indian seas. In continuing to trace the connection of adjoining atolls, if a hasty glance be taken at the chart (Fig. 4, Plate II) of Mahlos Mahdoo, and the line of unfathomable water be followed, no one will hesitate to consider it as one atoll. But a second look will show that it is divided by a bifurcating channel, of which the northern arm is about one mile and three-quarters in width, with an average depth of 125 fathoms, and the southern one three-quarters of a mile wide, and rather less deep. These channels resemble in the slope of their sides and general form, those which separate atolls in every respect distinct; and the northern arm is wider than that dividing two of the Mãle atolls. The ring-formed reefs on the sides of this bifurcating channel are elongated, so that the northern and southern portions of Mahlos Mahdoo may claim, as far as their external outline is concerned, to be considered as distinct and perfect atolls. But the intermediate portion, lying in the fork of the channel, is bordered by reefs less perfect than those which surround any other atoll in the group of equally small dimensions. Mahlos Mahdoo, therefore, is in every respect in so intermediate a condition, that it may be considered either as a single atoll nearly dissevered into three portions, or as three atolls almost perfect and intimately connected. This is an instance of a very early stage of the apparent disseverment of an atoll, but a still earlier one in many respects is exhibited at Tilla-dou-Matte. In one part of this atoll, the ring-formed reefs stand so far apart from each other, that the inhabitants have given different names to the northern and southern halves; nearly all the rings, moreover, are so perfect and stand so separate, and the space from which they rise is so level and unlike a true lagoon, that we can easily imagine the conversion of this one great atoll, not into two or three portions, but into a whole group of miniature atolls. A perfect series such as we have here traced, impresses the mind with an idea of actual change; and it will hereafter be seen, that the theory of subsidence, with the upward growth of the coral, modified by accidents of probable occurrence, will account for the occasional disseverment of large atolls.

Plate II—Great Chagos Bank, New Caledonia, Menchikoff Atoll, etc.

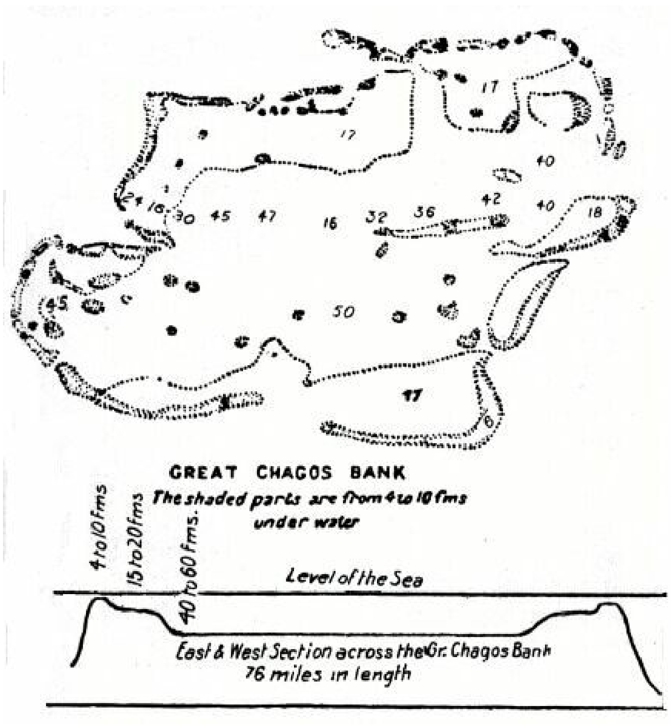


Fig. 1.—GREAT CHAGOS BANK, in the Indian Ocean; taken from the survey by Captain Moresby and Lieutenant Powell; the parts which are shaded, with the exception of two or three islets on the western and northern sides, do not rise to the surface, but are submerged from four to ten fathoms; the banks bounded by the dotted lines lie from fifteen to twenty fathoms beneath the surface, and are formed of sand; the central space is of mud, and from thirty to fifty fathoms deep.

Fig. 2.—A vertical section, on the same scale, in an eastern and western line across the Great Chagos Bank, given for the sake of exhibiting more clearly its structure.

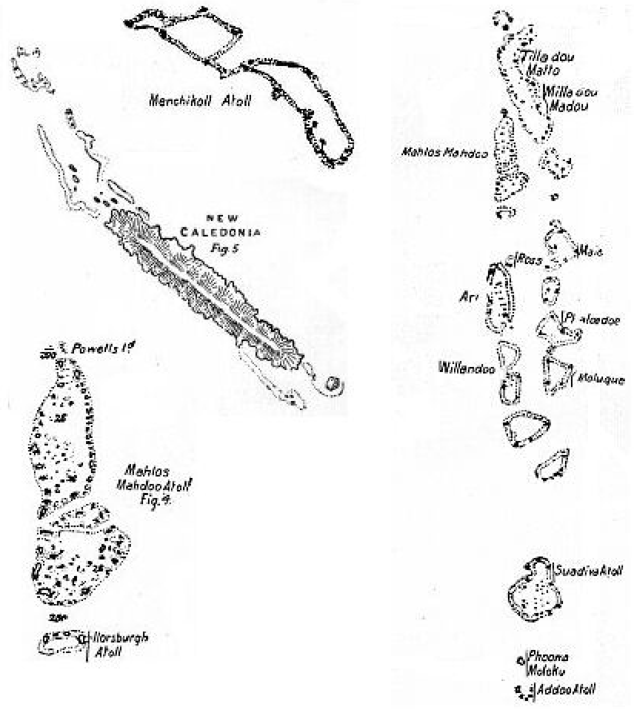


Fig. 3.—Menchikoff Atoll (or lagoon-island), in the Marshall Archipelago, Northern Pacific Ocean; from Krusenstern’s “Atlas of the Pacific;” originally surveyed by Captain Hagemeister; the depth within the lagoons is unknown.

Fig. 4.—Mahlos Mahdoo Atoll, together with Horsburgh atoll, in the Maldiva Archipelago; from the survey by Captain Moresby and Lieutenant Powell; the white spaces in the middle of the separate small reefs, both on the margin and in the middle part, are meant to represent little lagoons; but it was found not possible to distinguish them clearly from the small islets, which have been formed on these same small reefs; many of the smaller reefs could not be introduced; the nautical mark (dot over a dash) over the figures 250 and 200, between Mahlos Mahdoo and Horsburgh atoll and Powell’s island, signifies that soundings were not obtained at these depths.

Fig. 5.—New Caledonia, in the western part of the Pacific; from Krusenstern’s “Atlas,” compiled from several surveys; I have slightly altered the northern point of the reef, in accordance with the “Atlas of the Voyage of the *Astrolabe*.” In Krusenstern’s “Atlas,” the reef is represented by a single line with crosses; I have for the sake of uniformity added an interior line.

Fig. 6.—Maldiva Archipelago, in the Indian Ocean; from the survey by Captain Moresby and Lieutenant Powell.

The Great Chagos bank alone remains to be described. In the Chagos group there are some ordinary atolls, some annular reefs rising to the surface but without any islets on them, and some atoll-formed banks, either quite submerged, or nearly so. Of the latter, the Great Chagos Bank is much the largest, and differs in its structure from the others: a plan of it is given in Plate II, Fig. 1, in which, for the sake of clearness, I have had the parts under ten fathoms deep finely shaded: an east and west vertical section is given in Fig. 2, in which the vertical scale has been necessarily exaggerated. Its longest axis is ninety nautical miles, and another line drawn at right angles to the first, across the broadest part, is seventy. The central part consists of a level muddy flat, between forty and fifty fathoms deep, which is surrounded on all sides, with the exception of some breaches, by the steep edges of a set of banks, rudely arranged in a circle. These banks consist of sand, with a very little live coral; they vary in breadth from five to twelve miles, and on an average lie about sixteen fathoms beneath the surface; they are bordered by the steep edges of a third narrow and upper bank, which forms the rim to the whole. This rim is about a mile in width, and with the exception of two or three spots where islets have been formed, is submerged between five and ten fathoms. It consists of smooth hard rock, covered with a thin layer of sand, but with scarcely any live coral; it is steep on both sides, and outwards slopes abruptly into unfathomable depths. At the distance of less than half a mile from one part, no bottom was found with 190 fathoms; and off another point, at a somewhat greater distance, there was none with 210 fathoms. Small steep-sided banks or knolls, covered with luxuriantly growing coral, rise from the interior expanse to the same level with the external rim, which, as we have seen, is formed only of dead rock. It is impossible to look at the plan (Fig. 1, Plate II), although reduced to so small a scale, without at once perceiving that the Great Chagos Bank is, in the words of Captain Moresby,[26] "nothing more than a half-drowned atoll." But of what great dimensions, and of how extraordinary an internal structure? We shall hereafter have to consider both the cause of its submerged condition, a state common to other banks in the group, and the origin of the singular submarine terraces, which bound the central expanse: these, I think, it can be shown, have resulted from a cause analogous to that which has produced the bifurcating channel across Mahlos Mahdoo.

[26] This officer has had the kindness to lend me an excellent MS. account of the Chagos Islands; from this paper, from the published charts, and from verbal information communicated to me by Captain Moresby, the above account of the Great Chagos Bank is taken.

Chapter II
BARRIER REEFS

Closely resemble in general form and structure atoll-reefs.—Width and depth of the lagoon-channels.—Breaches through the reef in front of valleys, and generally on the leeward side.—Checks to the filling up of the lagoon-channels.—Size and constitution of the encircled islands.—Number of islands within the same reef.—Barrier-reefs of New Caledonia and Australia.—Position of the reef relative to the slope of the adjoining land.—Probable great thickness of barrier-reefs.

The term “barrier” has been generally applied to that vast reef which fronts the N.E. shore of Australia, and by most voyagers likewise to that on the western coast of New Caledonia. At one time I thought it convenient thus to restrict the term, but as these reefs are similar in structure, and in position relatively to the land, to those, which, like a wall with a deep moat within, encircle many smaller islands, I have classed them together. The reef, also, on the west coast of New Caledonia, circling round the extremities of the island, is an intermediate form between a small encircling reef and the Australian barrier, which stretches for a thousand miles in nearly a straight line.

The geographer Balbi has in effect described those barrier-reefs, which encircle moderately sized islands, by calling them atolls with high land rising from within their central expanse. The general resemblance between the reefs of the barrier and atoll classes may be seen in the small, but accurately reduced charts on Plate I,[1] and this resemblance can be further shown to extend to every part of the structure. Beginning with the outside of the reef; many scattered soundings off Gambier, Oualan, and some other encircled islands, show that close to the breakers there exists a narrow shelving margin, beyond which the ocean becomes suddenly unfathomable; but off the west coast of New Caledonia, Captain Kent[2] found no bottom with 150 fathoms, at two ships’ length from the reef; so that the slope here must be nearly as precipitous as off the Maldiva atolls.

[1] The authorities from which these charts have been reduced, together with some remarks on them are given in a separately appended page, descriptive of the Plates.

[2] Dalrymple, “Hydrog. Mem.” vol. iii.

I can give little information regarding the kinds of corals which live on the outer margin. When I visited the reef at Tahiti, although it was low water, the surf was too violent for me to see the living masses; but, according to what I heard from some intelligent native chiefs, they resemble in their rounded and branchless forms, those on the margin of Keeling atoll. The extreme verge of the reef, which was visible between the breaking waves at low water, consisted of a rounded, convex, artificial-like breakwater, entirely coated with Nulliporæ, and absolutely similar to that which I have described at Keeling atoll. From what I heard when at Tahiti, and from the writings of the Revs. W. Ellis and J. Williams, I conclude that this peculiar structure is common to most of the encircled islands of the Society Archipelago. The reef within this mound or breakwater, has an extremely irregular surface, even more so than between the islets on the reef of Keeling atoll, with which alone (as there are no islets on the reef of Tahiti) it can properly be compared. At Tahiti, the reef is very irregular in width; but round many other encircled islands, for instance, Vanikoro or Gambier Islands (Figs 1 and 8, Plate I), it is quite as regular, and of the same average width, as in true atolls. Most barrier-reefs on the inner side slope irregularly into the lagoon-channel (as the space of deep water separating the reef from the included land may be called), but at Vanikoro the reef slopes only for a short distance, and then terminates abruptly in a submarine wall, forty feet high,—a structure absolutely similar to that described by Chamisso in the Marshall atolls.

In the Society Archipelago, Ellis[3] states, that the reefs generally lie at the distance of from one to one and a half miles, and, occasionally, even at more than three miles, from the shore. The central mountains are generally bordered by a fringe of flat, and often marshy, alluvial land, from one to four miles in width. This fringe consists of coral-sand and detritus thrown up from the lagoon-channel, and of soil washed down from the hills; it is an encroachment on the channel, analogous to that low and inner part of the islets in many atolls which is formed by the accumulation of matter from the lagoon. At Hogoleu (Fig. 2, Plate I), in the Caroline Archipelago,[4] the reef on the south side is no less than twenty miles; on the east side, five; and on the north side, fourteen miles from the encircled high islands.

[3] Consult, on this and other points, the "Polynesian Researches," by the Rev. W. Ellis, an admirable work, full of curious information.

[4] See "Hydrographical Mem." and the "Atlas of the Voyage of the *Astrolabe*," by Captain Dumont D'Urville, p. 428.

The lagoon channels may be compared in every respect with true lagoons. In some cases they are open, with a level bottom of fine sand; in others they are choked up with reefs of delicately branched corals, which have the same general character as those within the Keeling atoll. These internal reefs either stand separately, or more commonly skirt the shores of the included high islands. The depth of the lagoon-channel round the Society Islands varies from two or three to thirty fathoms; in Cook's[5] chart of Ulieta, however, there is one sounding laid down of forty-eight fathoms; at Vanikoro there are several of fifty-four and one of fifty-six and a half fathoms (English), a depth which even exceeds by a little that of the interior of the great Maldiva atolls. Some barrier-reefs have very few islets on them; whilst others are surmounted by numerous ones; and those round part of Bolabola (Plate I, Fig. 5) form a single linear strip. The islets first appear either on the angles of the reef, or on the sides of the breaches through it, and are generally most numerous on the windward side. The reef to leeward retaining its usual width, sometimes lies submerged several fathoms beneath the surface; I have already mentioned Gambier Island as an instance of this structure. Submerged reefs, having a less defined outline, dead, and covered with sand, have been observed (see Appendix) off some parts of Huaheine and Tahiti. The reef is more frequently breached to leeward than to windward; thus I find in Krusenstern's "Memoir on the Pacific," that there are passages through the encircling reef on the leeward side of each of the seven Society Islands, which possess ship-harbours; but that there are openings to windward through the reef of only three of them. The breaches in the reef are seldom as deep as the interior lagoon-like channel; they generally occur in front of the main valleys, a circumstance which can be accounted for, as will be seen in the fourth chapter, without much difficulty. The breaches being situated in front of the valleys, which descend indifferently on all sides, explains their more frequent occurrence through the windward side of barrier-reefs than through the windward side of atolls,—for in atolls there is no included land to influence the position of the breaches.

[5] See the chart in vol. i of Hawkesworth's 4to ed. of "Cook's First Voyage."

It is remarkable, that the lagoon-channels round mountainous islands have not in every instance been long ago filled up with coral and sediment; but it is more easily accounted for than appears at first sight. In cases like that of Hogoleu and the Gambier Islands, where a few small peaks rise out of a great lagoon, the conditions scarcely differ from those of an atoll, and I have already shown, at some length, that the filling up of a true lagoon must be an extremely slow process. Where the channel is narrow, the agency, which on unprotected coasts is most productive of sediment, namely the force of the breakers, is here entirely excluded, and the reef being breached in the front of the main valleys, much of the finer mud from the rivers must be transported into the open sea. As a current is formed by the water thrown over the edge of atoll-formed reefs, which carries sediment with it through the deep-water breaches, the same thing probably takes place in barrier-reefs, and this would greatly aid in preventing the lagoon-channel from being filled up. The low alluvial border, however, at the foot of the encircled mountains, shows that the work of filling up is in progress; and at Maura (Plate I, Fig. 6), in the Society group, it has been almost effected, so that there remains only one harbour for small craft.

If we look at a set of charts of barrier-reefs, and leave out in imagination the encircled land, we shall find that, besides the many points already noticed of resemblance, or rather of identity in structure with atolls, there is a close general agreement in form, average dimensions, and grouping. Encircling barrier-reefs, like atolls, are generally elongated, with an irregularly rounded, though sometimes angular outline. There are atolls of all sizes, from less than two miles in diameter to sixty miles (excluding Tilla-dou-Matte, as it consists of a number of almost independent atoll-formed reefs); and there are encircling barrier-reefs from three miles and a half to forty-six miles in diameter,—Turtle Island being an instance of the former, and Hogoleu of the latter. At Tahiti the encircled island is thirty-six miles in its longest axis, whilst at Maurua it is only a little more than two miles. It will be shown, in the last chapter in this volume, that there is the strictest resemblance in the grouping of atolls and of common islands, and consequently there must be the same resemblance in the grouping of atolls and of encircling barrier-reefs.

The islands lying within reefs of this class, are of very various heights. Tahiti[6] is 7,000 feet; Maurua about 800; Aitutaki 360, and Manouai only 50. The geological nature of the included land varies: in most cases it is of ancient volcanic origin, owing apparently to the fact that islands of this nature are most frequent within all great seas; some, however, are of madreporitic limestone, and others of primary formation, of which latter kind New Caledonia offers the best example. The central land consists either of one island, or of several: thus, in the Society group, Eimeo stands by itself; while Taha and Raiatea (Fig. 3, Plate I), both moderately large islands of nearly equal size, are included in one reef. Within the reef of the Gambier group there are four large and some smaller islands (Fig. 8, Plate I); within that of Hogoleu (Fig. 2, Plate I) nearly a dozen small islands are scattered over the expanse of one vast lagoon.

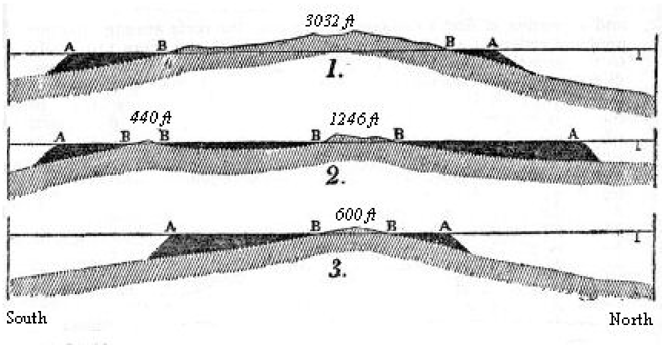
[6] The height of Tahiti is given from Captain Beechey; Maurua from Mr. F. D. Bennett (*Geograph. Journ.* vol. viii, p. 220); Aitutaki from measurements made on board the *Beagle*; and Manouai or Harvey Island, from an estimate by the Rev. J. Williams. The two latter islands, however, are not in some respects well characterised examples of the encircled class.

After the details now given, it may be asserted that there is not one point of essential difference between encircling barrier-reefs and atolls: the latter enclose a simple sheet of water, the former encircle an expanse with one or more islands rising from it. I was much struck with this fact, when viewing, from the heights of Tahiti, the distant island of Eimeo standing within smooth water, and encircled by a ring of snow-white breakers. Remove the central land, and an annular reef like that of an atoll in an early stage of its formation is left; remove it from Bolabola, and there remains a circle of linear coral-islets, crowned with tall cocoa-nut trees, like one of the many atolls scattered over the Pacific and Indian Oceans.

The barrier-reefs of Australia and of New Caledonia deserve a separate notice from their great dimensions. The reef on the west coast of New Caledonia (Fig. 5, Plate II) is 400 miles in length; and for a length of many leagues it seldom approaches within eight miles of the shore; and near the southern end of the island, the space between the reef and the land is sixteen miles in width. The Australian barrier extends, with a few interruptions, for nearly a thousand miles; its average distance from the land is between twenty and thirty miles; and in some parts from fifty to seventy. The great arm of the sea thus included, is from ten to twenty-five fathoms deep, with a sandy bottom; but towards the southern end, where the reef is further from the shore, the depth gradually increases to forty, and in some parts to more than sixty fathoms. Flinders[7] has described the surface of this reef as consisting of a hard white agglomerate of different kinds of coral, with rough projecting points. The outer edge is the highest part; it is traversed by narrow gullies, and at rare intervals is breached by ship-channels. The sea close outside is profoundly deep; but, in front of the main breaches, soundings can sometimes be obtained. Some low islets have been formed on the reef.

[7] Flinders' "Voyage to Terra Australis," vol. ii, p. 88.

There is one important point in the structure of barrier-reefs which must here be considered. The accompanying diagrams represent north and south vertical sections, taken through the highest points of Vanikoro, Gambier, and Maurua Islands, and through their encircling reefs. The scale both in the horizontal and vertical direction is the same, namely, a quarter of an inch to a nautical mile. The height and width of these islands is known; and I have attempted to represent the form of the land from the shading of the hills in the large published charts. It has long been remarked, even from the time of Dampier, that considerable degree of relation subsists between the inclination of that part of the land which is beneath water and that above it; hence the dotted line in the three sections, probably, does not widely differ in inclination from the actual submarine prolongation of the land. If we now look at the outer edge of the reef (AA), and bear in mind that the plummet on the right hand represents a depth of 1,200 feet, we must conclude that the vertical thickness of these barrier coral-reefs is very great.



1. VANIKORO, from the "Atlas of the Voyage of the *Astrolabe*," by D. D'Urville.
2. GAMBIER ISLAND, from Beechey.
3. MAURUA, from the "Atlas of the Voyage of the *Coquille*," by Duperrey.

The horizontal line is the level of the sea, from which on the right hand a plummet descends, representing a depth of 200 fathoms, or 1,200 feet. The vertical shading shows the section of the land, and the horizontal shading that of the encircling barrier-reef: from the smallness of the scale, the lagoon-channel could not be represented.
AA.—Outer edge of the coral-reefs, where the sea breaks.
BB.—The shore of the encircled islands.

I must observe that if the sections had been taken in any other direction across these islands, or across other encircled islands,[8] the result would have been the same. In the succeeding chapter it will be shown that reef-building polypifers cannot flourish at great depths,—for instance, it is highly improbable that they could exist at a quarter of the depth represented by the plummet on the right hand of the woodcut. Here there is a great *apparent* difficulty—how were the basal parts of these barrier-reef formed? It will, perhaps, occur to some, that the actual reefs formed of coral are not of great thickness, but that before their first growth, the coasts of these encircled islands were deeply eaten into, and a broad but shallow submarine ledge thus left, on the edge of which the coral grew; but if this had been the case, the shore would have been invariably bounded by lofty cliffs, and not have sloped down to the lagoon-channel, as it does in many instances. On this view,[9] moreover, the cause of the reef springing up at such a great distance from the land, leaving a deep and broad moat within, remains altogether unexplained. A supposition of the same nature, and appearing at first more probable is, that the reefs sprung up from banks of sediment, which had accumulated round the shore previously to the growth of the coral; but the extension of a bank to the same distance round an unbroken coast, and in front of those deep arms of the sea (as in Raiatea, see Plate II, Fig. 3) which penetrate nearly to the heart of some encircled islands, is exceedingly improbable. And why, again, should the reef spring up, in some cases steep on both sides like a wall, at a distance of two, three or more miles from the shore, leaving a channel often between two hundred and three hundred feet deep, and rising from a depth which we have reason to believe is destructive to the growth of coral? An admission of this nature cannot possibly be made. The existence, also, of the deep channel, utterly precludes the idea of the reef having grown outwards, on a foundation slowly formed on its outside, by the accumulation of sediment and coral detritus. Nor, again, can it be asserted, that the reef-building corals will not grow, excepting at a great distance from the land; for, as we shall soon see, there is a whole class of reefs, which take their name from growing closely attached (especially where the sea is deep) to the beach. At New Caledonia (see Plate II, Fig. 5) the reefs which run in front of the west coast are prolonged in the same line 150 miles beyond the northern extremity of the island, and this shows that some explanation, quite different from any of those just suggested, is required. The continuation of the reefs on each side of the submarine prolongation of New Caledonia, is an exceedingly interesting fact, if this part formerly existed as the northern extremity of the island, and before the attachment of the coral had been worn down by the action of the sea, or if it originally existed at its present height, with or without beds of sediment on each flank, how can we possibly account for the reefs, not growing on the crest of this submarine portion, but fronting its sides, in the same line with the reefs which front the shores of the lofty island? We shall hereafter see, that there is one, and I believe only one, solution of this difficulty.

[8] In the fifth chapter an east and west section across the Island of Bolabola and its barrier-reefs is given, for the sake of illustrating another point. The unbroken line in it (woodcut No. 5) is the section referred to. The scale is .57 of an inch to a mile; it is taken from the "Atlas of the Voyage of the *Coquille*," by Duperrey. The depth of the lagoon-channel is exaggerated.

[9] The Rev. D. Tyerman and Mr. Bennett ("Journal of Voyage and Travels," vol. i, p. 215) have briefly suggested this explanation of the origin of the encircling reefs of the Society Islands.

One other supposition to account for the position of encircling barrier-reefs remains, but it is almost too preposterous to be mentioned; namely, that they rest on enormous submarine craters, surrounding the included islands. When the size, height, and form of the islands in the Society group are considered, together with the fact that all are thus encircled, such a notion will be rejected by almost every one. New Caledonia, moreover, besides its size, is composed of primitive formations, as are some of the Comoro Islands;[10] and Aitutaki consists of calcareous rock. We must, therefore, reject these several explanations, and conclude that the vertical thickness of barrier-reefs, from their outer edges to the foundation on which they rest (from AA in the section to the dotted lines) is really great; but in this, there is no difficulty, for it is not necessary to suppose that the coral has sprung up from an immense depth, as will be evident when the theory of the upward growth of coral-reefs, during the slow subsidence of their foundation, is discussed.

[10] I have been informed that this is the case by Dr. Allan of Forres, who has visited this group.

Chapter III

FRINGING OR SHORE-REEFS

Reefs of Mauritius.—Shallow channel within the reef.—Its slow filling up.—Currents of water formed within it.—Upraised reefs.—Narrow fringing-reefs in deep seas.—Reefs on the coast of East Africa and of Brazil.—Fringing-reefs in very shallow seas, round banks of sediment and on worn-down islands.—Fringing-reefs affected by currents of the sea.—Coral coating the bottom of the sea, but not forming reefs.

Fringing-reefs, or, as they have been called by some voyagers, shore-reefs, whether skirting an island or part of a continent, might at first be thought to differ little, except in generally being of less breadth, from barrier-reefs. As far as the superficies of the actual reef is concerned this is the case; but the absence of an interior deep-water channel, and the close relation in their horizontal extension with the probable slope beneath the sea of the adjoining land, present essential points of difference.

The reefs which fringe the island of Mauritius offer a good example of this class. They extend round its whole circumference, with the exception of two or three parts,[1] where the coast is almost precipitous, and where, if as is probable the bottom of the sea has a similar inclination, the coral would have no foundation on which to become attached. A similar fact may sometimes be observed even in reefs of the barrier class, which follow much less closely the outline of the adjoining land; as, for instance, on the south-east and precipitous side of Tahiti, where the encircling reef is interrupted. On the western side of the Mauritius, which was the only part I visited, the reef generally lies at the distance of about half a mile from the shore; but in some parts it is distant from one to two, and even three miles. But even in this last case, as the coast-land is gently inclined from the foot of the mountains to the sea-beach, and as the soundings outside the reef indicate an equally gentle slope beneath the water, there is no reason for supposing that the basis of the reef, formed by the prolongation of the strata of the island, lies at a greater depth than that at which the polypifers could begin constructing the reef. Some allowance, however, must be made for the outward extension of the corals on a foundation of sand and detritus, formed from their own wear, which would give to the reef a somewhat greater vertical thickness, than would otherwise be possible.

[1] This fact is stated on the authority of the Officier du Roi, in his extremely interesting "Voyage à l'Isle de France," undertaken in 1768. According to Captain Carmichael (Hooker's *Bot. Misc.* vol. ii, p. 316) on one part of the coast there is a space for sixteen miles without a reef.

The outer edge of the reef on the western or leeward side of the island is tolerably well defined, and is a little higher than any other part. It chiefly consists of large strongly branched corals, of the genus Madrepora, which also form a sloping bed some way out to sea: the kinds of coral growing in this part will be described in the ensuing chapter. Between the outer margin and the beach, there is a flat space with a sandy bottom and a few tufts of living coral; in some parts it is so shallow, that people, by avoiding the deeper holes and gullies, can wade across it at low water; in other parts it is deeper, seldom however exceeding ten or twelve feet, so that it offers a safe coasting channel for boats. On the eastern and windward side of the island, which is exposed to a heavy surf, the reef was described to me as having a hard smooth surface, very slightly inclined inwards, just covered at low-water, and traversed by gullies; it appears to be quite similar in structure to the reefs of the barrier and atoll classes.

The reef of Mauritius, in front of every river and streamlet, is breached by a straight passage: at Grand Port, however, there is a channel like that within a barrier-reef; it extends parallel to the shore for four miles, and has an average depth of ten or twelve fathoms; its presence may probably be accounted for by two rivers which enter at each end of the channel, and bend towards each other. The fact of reefs of the fringing class being always breached in front of streams, even of those which are dry during the greater part of the year, will be explained, when the conditions unfavourable to the growth of coral are considered. Low coral-islets, like those on barrier-reefs and atolls, are seldom formed on reefs of this class, owing apparently in some cases to their narrowness, and in others to the gentle slope of the reef outside not yielding many fragments to the breakers. On the windward side, however, of the Mauritius, two or three small islets have been formed.

It appears, as will be shown in the ensuing chapter, that the action of the surf is favourable to the vigorous growth of the stronger corals, and that sand or sediment, if agitated by the waves, is injurious to them. Hence it is probable that a reef on a shelving shore, like that of Mauritius, would at first grow up, not attached to the actual beach, but at some little distance from it; and the corals on the outer margin would be the most vigorous. A shallow channel would thus be formed within the reef, and as the breakers are prevented acting on the shores of the island, and as they do not ordinarily tear up many fragments from the outside, and as every streamlet has its bed prolonged in a straight line through the reef, this channel could be filled up only very slowly with sediment. But a beach of sand and of fragments of the smaller kinds of coral seems, in the case of Mauritius, to be slowly encroaching on the shallow channel. On many shelving and sandy coasts, the breakers tend to form a bar of sand a little way from the beach, with a slight increase of depth within it; for instance, Captain Grey[2] states that the west coast of Australia, in latitude 24°, is fronted by a sand bar about two hundred yards in width, on which there is only two feet of water; but within it the depth increases to two fathoms. Similar bars, more or less perfect, occur on other coasts. In these cases I suspect that the shallow channel (which no doubt during storms is occasionally obliterated) is scooped out by the flowing away of the water thrown beyond the line, on which the waves break with the greatest force. At Pernambuco a bar of hard sandstone,[3] which has the same external form and height as a coral-reef, extends nearly parallel to the coast; within this bar currents, apparently caused by the water thrown over it during the greater part of each tide, run strongly, and are wearing away its inner wall. From these facts it can hardly be doubted, that within most fringing-reefs, especially within those lying some distance from the land, a return stream must carry away the water thrown over the outer edge; and the current thus produced, would tend to prevent the channel being filled up with sediment, and might even deepen it under certain circumstances. To this latter belief I am led, by finding that channels are almost universally present within the fringing-reefs of those islands which have undergone recent elevatory movements; and this could hardly have been the case, if the conversion of the very shallow channel into land had not been counteracted to a certain extent.

[2] Captain Grey's "Journal of Two Expeditions," vol. i, p. 369.

[3] I have described this singular structure in the *Lond. and Edin. Phil. Mag.,* October 1841.

A fringing-reef, if elevated in a perfect condition above the level of the sea, ought to present the singular appearance of a broad dry moat within a low mound. The author[4] of an interesting pedestrian tour round the Mauritius, seems to have met with a structure of this kind: he says "J'observai que là, où la mer étale, indépendamment des rescifs du large, il y à terre *une espèce d'effoncement* ou chemin couvert naturel. On y pourrait mettre du canon," etc. In another place he adds, "Avant de passer le Cap, on remarque un gros banc de corail élevé de plus de quinze pieds: c'est une espèce de rescif, que la mer abandonné, il regne au pied une longue flaque d'eau, dont on pourrait faire un bassin pour de petits vaisseaux." But the margin of the reef, although the highest and most perfect part, from being most exposed to the surf, would generally during a slow rise of the land be either partially or entirely worn down to that level, at which corals could renew their growth on its upper edge. On some parts of the coast-land of Mauritius there are little hillocks of coral-rock, which are either the last remnants of a continuous reef, or of low islets formed on it. I observed that two such hillocks between Tamarin Bay and the Great Black River; they were nearly twenty feet high, about two hundred yards from the present beach, and about thirty feet above its level. They rose abruptly from a smooth surface, strewed with worn fragments of coral. They consisted in their lower part of hard calcareous sandstone, and in their upper of great blocks of several species of Astræa and Madrepora, loosely aggregated; they were divided into irregular beds, dipping seaward, in one hillock at an angle of 8°, and in the other at 18°. I suspect that the superficial parts of the reefs, which have been upraised together with the islands they fringe, have generally been much more modified by the wearing action of the sea, than those of Mauritius.

[4] "Voyage à l'Isle de France, par un Officier du Roi," part i, pp. 192, 200.

Many islands[5] are fringed by reefs quite similar to those of Mauritius; but on coasts where the sea deepens very suddenly the reefs are much narrower, and their limited extension seems evidently to depend on the high inclination of the submarine slope; a relation, which, as we have seen, does not exist in reefs of the barrier class. The fringing-reefs on steep coasts are frequently not more than from fifty to one hundred yards in width; they have a nearly smooth, hard surface, scarcely uncovered at low water, and without any interior shoal channel, like that within those fringing-reefs, which lie at a greater distance from the land. The fragments torn up during gales from the outer margin are thrown over the reef on the shores of the island. I may give as instances, Wateeo, where the reef is described by Cook as being a hundred yards wide; and Mauti and Elizabeth[6] Islands, where it is only fifty yards in width: the sea round these islands is very deep.

[5] I may give Cuba, as another instance; Mr. Taylor (*Loudon's Mag. of Nat. Hist.,* vol. ix, p. 449) has described a reef several miles in length between Gibara and Vjaro, which extends parallel to the shore at the distance of between half and the third part of a mile, and encloses a space of shallow water, with a sandy bottom and tufts of coral. Outside the edge of the reef, which is formed of great branching corals, the depth is six and seven fathoms. This coast has been upheaved at no very distant geological period.

[6] Mauti is described by Lord Byron in the voyage of H.M.S. *Blonde*, and Elizabeth Island by Captain Beechey.

Fringing-reefs, like barrier-reefs, both surround islands, and front the shores of continents. In the charts of the eastern coast of Africa, by Captain Owen, many extensive fringing-reefs are laid down; thus, for a space of nearly forty miles, from latitude 1° 15′ to 1° 45′ S., a reef fringes the shore at an average distance of rather more than one mile, and therefore at a greater distance than is usual in reefs of this class; but as the coast-land is not lofty, and as the bottom shoals very gradually (the depth being only from eight to fourteen fathoms at a mile and a half outside the reef), its extension thus far from the land offers no difficulty. The external margin of this reef is described, as formed of projecting points, within which there is a space, from six to twelve feet deep, with patches of living coral on it. At Mukdeesha (lat. 2° 1′ N.) "the port is formed," it is said,[7] "by a long reef extending eastward, four or five miles, within which there is a narrow channel, with ten to twelve feet of water at low spring-tides;" it lies at the distance of a quarter of a mile from the shore. Again, in the plan of Mombas (lat. 4° S.), a reef extends for thirty-six miles, at the distance of from half a mile to one mile and a quarter from the shore; within it, there is a channel navigable "for canoes and small craft," between six and fifteen feet deep: outside the reef the depth is about thirty fathoms at the distance of nearly half a mile. Part of this reef is very symmetrical, and has a uniform breadth of two hundred yards.

[7] Owen's "Africa," vol. i, p. 357, from which work the foregoing facts are likewise taken.

The coast of Brazil is in many parts fringed by reefs. Of these, some are not of coral formation; for instance, those near Bahia and in front of Pernambuco; but a few miles south of this latter city, the reef follows[8] so closely every turn of the shore, that I can hardly doubt it is of coral; it runs at the distance of three-quarters of a mile from the land, and within it the depth is from ten to fifteen feet. I was assured by an intelligent pilot that at Ports Frances and Maceio, the outer part of the reef consists of living coral, and the inner of a white stone, full of large irregular cavities, communicating with the sea. The bottom of the sea off the coast of Brazil shoals gradually to between thirty and forty fathoms, at the distance of between nine and ten leagues from the land.

[8] See Baron Roussin's "Pilote du Brésil," and accompanying hydrographical memoir.

From the description now given, we must conclude that the dimensions and structure of fringing-reefs depend entirely on the greater or less inclination of the submarine slope, conjoined with the fact that reef-building polypifers can exist only at limited depths. It follows from this, that where the sea is very shallow, as in the Persian Gulf and in parts of the East Indian Archipelago, the reefs lose their fringing character, and appear as separate and irregularly scattered patches, often of considerable area. From the more vigorous growth of the coral on the outside, and from the conditions being less favourable in several respects within, such reefs are generally higher and more perfect in their marginal than in their central parts; hence these reefs sometimes assume (and this circumstance ought not to be overlooked) the appearance of atolls; but they differ from atolls in their central expanse being much less deep, in their form being less defined, and in being based on a shallow foundation. But when in a deep sea reefs fringe banks of sediment, which have accumulated beneath the surface, round either islands or submerged rocks, they are distinguished with difficulty on the one hand from encircling barrier-reefs, and on the other from atolls. In the West Indies there are reefs, which I should probably have arranged under both these classes, had not the existence of large and level banks, lying a little beneath the surface, ready to serve as the basis for the attachment of coral, been occasionally brought into view by the entire or partial absence of reefs on them, and had not the formation of such banks, through the accumulation of sediment now in progress, been sufficiently evident. Fringing-reefs sometimes coat, and thus protect the foundations of islands, which have been worn down by the surf to the level of the sea. According to Ehrenberg, this has been extensively the case with the islands in the Red Sea, which formerly ranged parallel to the shores of the mainland, with deep water within them: hence the reefs now coating their bases are situated relatively to the land like barrier-reefs, although not belonging to that class; but there are, as I believe, in the Red Sea some true barrier-reefs. The reefs of this sea and of the West Indies will be described in the Appendix. In some cases, fringing-reefs appear to be considerably modified in outline by the course of the prevailing currents. Dr. J. Allan informs me that on the east coast of Madagascar almost every headland and low point of sand has a coral-reef extending from it in a S.W. and N.E. line, parallel to the currents on that shore. I should think the influence of the currents chiefly consisted in causing an extension, in a certain direction, of a proper foundation for the attachment of the coral. Round many intertropical islands, for instance the Abrolhos on the coast of Brazil surveyed by Captain Fitzroy, and, as I am informed by Mr. Cuming, round the Philippines, the bottom of the sea is entirely coated by irregular masses of coral, which although often of large size, do not reach the surface and form proper reefs. This must be owing, either to insufficient growth, or to the absence of those kinds of corals which can withstand the breaking of the waves.

The three classes, atoll-formed, barrier, and fringing-reefs, together with the modifications just described of the latter, include all the most remarkable coral formations anywhere existing. At the commencement of the last chapter in the volume, where I detail the principles on which the map (Plate III) is coloured, the exceptional cases will be enumerated.

Chapter IV

ON THE DISTRIBUTION AND GROWTH OF CORAL-REEFS

In this chapter I will give all the facts which I have collected, relating to the distribution of coral-reefs,—to the conditions favourable to their increase,—to the rate of their growth,—and to the depth at which they are formed.

These subjects have an important bearing on the theory of the origin of the different classes of coral-reefs.

Section I—ON THE DISTRIBUTION OF CORAL-REEFS, AND ON THE CONDITIONS FAVOURABLE TO THEIR INCREASE

With regard to the limits of latitude, over which coral-reefs extend, I have nothing new to add. The Bermuda Islands, in 32° 15′ N., is the point furthest removed from the equator, in which they appear to exist; and it has been suggested that their extension so far northward in this instance is owing to the warmth of the Gulf Stream. In the Pacific, the Loo Choo Islands, in latitude 27° N., have reefs on their shores, and there is an atoll in 28° 30′, situated N.W. of the Sandwich Archipelago. In the Red Sea there are coral-reefs in latitude 30°. In the southern hemisphere coral-reefs do not extend so far from the equatorial sea. In the Southern Pacific there are only a few reefs beyond the line of the tropics, but Houtmans Abrolhos, on the western shores of Australia in latitude 29° S., are of coral formation.

The proximity of volcanic land, owing to the lime generally evolved from it, has been thought to be favourable to the increase of coral-reefs. There is, however, not much foundation for this view; for nowhere are coral-reefs more extensive than on the shores of New Caledonia, and of north-eastern Australia, which consist of primary formations; and in the largest groups of atolls, namely the Maldiva, Chagos, Marshall, Gilbert, and Low Archipelagoes, there is no volcanic or other kind of rock, excepting that formed of coral.

The entire absence of coral-reefs in certain large areas within the tropical seas, is a remarkable fact. Thus no coral-reefs were observed, during the surveying voyages of the *Beagle* and her tender on the west coast of South America south of the equator, or round the Galapagos Islands. It appears, also, that there are none[1] north of the equator; Mr. Lloyd, who surveyed the Isthmus of Panama, remarked to me, that although he had seen corals living in the Bay of Panama, yet he had never observed any reefs formed by them. I at first attributed this absence of reefs on the coasts of Peru and of the Galapagos Islands,[2] to the coldness of the currents from the south, but the Gulf of Panama is one of the hottest pelagic districts in the world.[3] In the central parts of the Pacific there are islands entirely free from reefs; in some few of these cases I have thought that this was owing to recent volcanic action; but the existence of reefs round the greater part of Hawaii, one of the Sandwich Islands, shows that recent volcanic action does not necessarily prevent their growth.

[1] I have been informed that this is the case, by Lieutenant Ryder, R.N., and others who have had ample opportunities for observation.

[2] The mean temperature of the surface sea from observations made by the direction of Captain Fitzroy on the shores of the Galapagos Islands, between the 16th of September and the 20th of October, 1835, was 68° Fahr. The lowest temperature observed was 58.5° at the south-west end of Albemarle Island; and on the west coast of this island, it was several times 62° and 63°. The mean temperature of the sea in the Low Archipelago of atolls, and near Tahiti, from similar observations made on board the *Beagle*, was (although further from the equator) 77.5°, the lowest any day being 76.5°. Therefore we have here a difference of 9.5° in mean temperature, and 18° in extremes; a difference doubtless quite sufficient to affect the distribution of organic beings in the two areas.

[3] Humboldt's "Personal Narrative," vol. vii, p. 434.

In the last chapter I stated that the bottom of the sea round some islands is thickly coated with living corals, which nevertheless do not form reefs, either from insufficient growth, or from the species not being adapted to contend with the breaking waves.

I have been assured by several people, that there are no coral-reefs on the west coast of Africa,[4] or round the islands in the Gulf of Guinea. This perhaps may be attributed, in part, to the sediment brought down by the many rivers debouching on that coast, and to the extensive mud-banks, which line great part of it. But the islands of St. Helena, Ascension, the Cape Verdes, St. Paul's, and Fernando Noronha, are, also, entirely without reefs, although they lie far out at sea, are composed of the same ancient volcanic rocks, and have the same general form, with those islands in the Pacific, the shores of which are surrounded by gigantic walls of coral-rock. With the exception of Bermuda, there is not a single coral-reef in the central expanse of the Atlantic Ocean. It will, perhaps, be suggested that the quantity of carbonate of lime in different parts of the sea, may regulate the presence of reefs. But this cannot be the case, for at Ascension, the waves charged to excess precipitate a thick layer of calcareous matter on the tidal rocks; and at St. Jago, in the Cape Verdes, carbonate of lime not only is abundant on the shores, but it forms the chief part of some upraised post-tertiary strata. The apparently capricious distribution, therefore, of coral-reefs, cannot be explained by any of these obvious causes; but as the study of the terrestrial and better known half of the world must convince every one that no station capable of supporting life is lost,—nay more, that there is a struggle for each station, between the different orders of nature,—we may conclude that in those parts of the intertropical sea, in which there are no coral-reefs, there are other organic bodies supplying the place of the reef-building polypifers. It has been shown in the chapter on Keeling atoll that there are some species of large fish, and the whole tribe of Holothuriæ which prey on the tenderer parts of the corals. On the other hand, the polypifers in their turn must prey on some other organic beings; the decrease of which from any cause would cause a proportionate destruction of the living coral. The relations, therefore, which determine the formation of reefs on any shore, by the vigorous growth of the efficient kinds of coral, must be very complex, and with our imperfect knowledge quite inexplicable. From these considerations, we may infer that changes in the condition of the sea, not obvious to our senses, might destroy all the coral-reefs in one area, and cause them to appear in another: thus, the Pacific or Indian Ocean might become as barren of coral-reefs as the Atlantic now is, without our being able to assign any adequate cause for such a change.

[4] It might be concluded, from a paper by Captain Owen (*Geograph. Journ.*, vol. ii, p. 89), that the reefs off Cape St. Anne and the Sherboro' Islands were of coral, although the author states that they are not purely coralline. But I have been assured by Lieutenant Holland, R.N., that these reefs are not of coral, or at least that they do not at all resemble those in the West Indies.

It has been a question with some naturalists, which part of a reef is most favourable to the growth of coral. The great mounds of living Porites and of Millepora round Keeling atoll occur exclusively on the extreme verge of the reef, which is washed by a constant succession of breakers; and living coral nowhere else forms solid masses. At the Marshall islands the larger kinds of coral (chiefly species of Astræa, a genus closely allied to Porites) "which form rocks measuring several fathoms in thickness," prefer, according to Chamisso,[5] the most violent surf. I have stated that the outer margin of the Maldiva atolls consists of living corals (some of which, if not all, are of the same species with those at Keeling atoll), and here the surf is so tremendous, that even large ships have been thrown, by a single heave of the sea, high and dry on the reef, all on board thus escaping with their lives.

Ehrenberg[6] remarks, that in the Red Sea the strongest corals live on the outer reefs, and appear to love the surf; he adds, that the more branched kinds abound a little way within, but that even these in still more protected places, become smaller. Many other facts having a similar tendency might be adduced.[7] It has, however, been doubted by MM. Quoy and Gaimard, whether any kind of coral can even withstand, much less flourish in, the breakers of an open sea:[8] they affirm that the saxigenous lithophytes flourish only where the water is tranquil, and the heat intense. This statement has passed from one geological work to another; nevertheless, the protection of the whole reef undoubtedly is due to those kinds of coral, which cannot exist in the situations thought by these naturalists to be most favourable to them. For should the outer and living margin perish, of any one of the many low coral-islands, round which a line of great breakers is incessantly foaming, the whole, it is scarcely possible to doubt, would be washed away and destroyed, in less than half a century. But the vital energies of the corals conquer the mechanical power of the waves; and the large fragments of reef torn up by every storm, are replaced by the slow but steady growth of the innumerable polypifers, which form the living zone on its outer edge.

[5] Kotzebue's "First Voyage" (Eng. Trans.), vol. iii, pp. 142, 143, 331.

[6] Ehrenberg, "Über die Natur und Bildung der Corallen Bänke im rothen Meere," p. 49.

[7] In the West Indies, as I am informed by Captain Bird Allen, R.N., it is the common belief of those, who are best acquainted with the reefs, that the coral flourishes most, where freely exposed to the swell of the open sea.

[8] "Annales des Sciences Naturelles," tome vi, pp. 276, 278.—"Là où les ondes sont agitées, les Lytophytés ne peuvent travailler, parce qu'elles détruiraient leurs fragiles édifices," etc.

From these facts, it is certain, that the strongest and most massive corals flourish, where most exposed. The less perfect state of the reef of most atolls on the leeward and less exposed side, compared with its state to windward; and the analogous case of the greater number of breaches on the near sides of those atolls in the Maldiva Archipelago, which afford some protection to each other, are obviously explained by this circumstance. If the question had been, under what conditions the greater number of species of coral, not regarding their bulk and strength, were developed, I should answer,—probably in the situations described by MM. Quoy and Gaimard, where the water is tranquil and the heat intense. The total number of species of coral in the circumtropical seas must be very great: in the Red Sea alone, 120 kinds, according to Ehrenberg,[9] have been observed.

[9] Ehrenberg, "Über die Natur," etc., p. 46.

The same author has observed that the recoil of the sea from a steep shore is injurious to the growth of coral, although waves breaking over a bank are not so. Ehrenberg also states, that where there is much sediment, placed so as to be liable to be moved by the waves there is little or no coral; and a collection of living specimens placed by him on a sandy shore died in the course of a few days.[10] An experiment, however, will presently be related in which some large masses of living coral increased rapidly in size, after having been secured by stakes on a sandbank. That loose sediment should be injurious to the living polypifers, appears, at first sight, probable; and accordingly, in sounding off Keeling atoll, and (as will hereafter be shown) off Mauritius, the arming of the lead invariably came up clean, where the coral was growing vigorously. This same circumstance has probably given rise to a strange belief, which, according to Captain Owen,[11] is general amongst the inhabitants of the Maldiva atolls, namely that corals have roots, and therefore that if merely broken down to the surface, they grow up again; but, if rooted out, they are permanently destroyed. By this means the inhabitants keep their harbours clear; and thus the French Governor of St. Mary's in Madagascar, "cleared out and made a beautiful little port at that place." For it is probable that sand would accumulate in the hollows formed by tearing out the corals, but not on the broken and projecting stumps, and therefore, in the former case, the fresh growth of the coral might be thus prevented.

[10] *Ibid.*, p. 49.

[11] Captain Owen on the Geography of the Maldiva Islands, *Geograph. Journal*, vol. ii, p. 88.

In the last chapter I remarked that fringing-reefs are almost universally breached, where streams enter the sea.[12] Most authors have attributed this fact to the injurious effects of the fresh water, even where it enters the sea only in small quantity, and during a part of the year. No doubt brackish water would prevent or retard the growth of coral; but I believe that the mud and sand which is deposited, even by rivulets when flooded, is a much more efficient check. The reef on each side of the channel leading into Port Louis at Mauritius, ends abruptly in a wall, at the foot of which I sounded and found a bed of thick mud. This steepness of the sides appears to be a general character in such breaches. Cook,[13] speaking of one at Raiatea, says, “like all the rest, it is very steep on both sides.” Now, if it were the fresh water mingling with the salt which prevented the growth of coral, the reef certainly would not terminate abruptly, but as the polypifers nearest the impure stream would grow less vigorously than those farther off, so would the reef gradually thin away. On the other hand, the sediment brought down from the land would only prevent the growth of the coral in the line of its deposition, but would not check it on the side, so that the reefs might increase till they overhung the bed of the channel. The breaches are much fewer in number, and front only the larger valleys in reefs of the encircling barrier class. They probably are kept open in the same manner as those into the lagoon of an atoll, namely, by the force of the currents and the drifting outwards of fine sediment. Their position in front of valleys, although often separated from the land by deep water lagoon-channels, which it might be thought would entirely remove the injurious effects both of the fresh water and the sediment, will receive a simple explanation when we discuss the origin of barrier-reefs.

> [12] Lieutenant Wellstead and others have remarked that this is the case in the Red Sea; Dr. Rüppell (“Reise in Abyss.” Band. i, p. 142) says that there are pear-shaped harbours in the upraised coral-coast, into which periodical streams enter. From this circumstance, I presume, we must infer that before the upheaval of the strata now forming the coast-land, fresh water and sediment entered the sea at these points; and the coral being thus prevented growing, the pear-shaped harbours were produced.

> [13] Cook’s “First Voyage,” vol. ii, p. 271 (Hawkesworth’s edit.)

In the vegetable kingdom every different station has its peculiar group of plants, and similar relations appear to prevail with corals. We have already described the great difference between the corals within the lagoon of an atoll and those on its outer margin. The corals, also, on the margin of Keeling Island occurred in zones; thus the *Porites* and *Millepora complanata* grow to a large size only where they are washed by a heavy sea, and are killed by a short exposure to the air; whereas, three species of Nullipora also live amidst the breakers, but are able to survive uncovered for a part of each tide; at greater depths, a strong Madrepora and *Millepora alcicornis* are the commonest kinds, the former appearing to be confined to this part, beneath the zone of massive corals, minute encrusting corallines and other organic bodies live. If we compare the external margin of the reef at Keeling atoll with that on the leeward side of Mauritius, which are very differently circumstanced, we shall find a corresponding difference in the appearance of the corals. At the latter place, the genus Madrepora is preponderant over every other kind, and beneath the zone of massive corals there are large beds of Seriatopora. There is also a marked difference, according to Captain Moresby,[14]between the great branching corals of the Red Sea, and those on the reefs of the Maldiva atolls.

> [14] Captain Moresby on the Northern Maldiva atolls, *Geograph. Journal*, vol. v, p. 401.

These facts, which in themselves are deserving of notice, bear, perhaps, not very remotely, on a remarkable circumstance which has been pointed out to me by Captain Moresby, namely, that with very few exceptions, none of the coral-knolls within the lagoons of Peros Banhos, Diego Garcia, and the Great Chagos Bank (all situated in the Chagos group), rise to the surface of the water; whereas all those, with equally few exceptions, within Solomon and Egmont atolls in the same group, and likewise within the large southern Maldiva atolls, reach the surface. I make these statements, after having examined the charts of each atoll. In the lagoon of Peros Banhos, which is nearly twenty miles across, there is only one single reef which rises to the surface; in Diego Garcia there are seven, but several of these lie close to the margin of the lagoon, and need scarcely have been reckoned; in the Great Chagos Bank there is not one. On the other hand, in the lagoons of some of the great southern Maldiva atolls, although thickly studded with reefs, every one without exception rises to the surface; and on an average there are less than two submerged reefs in each atoll; in the northern atolls, however, the submerged lagoon-reefs are not quite so rare. The submerged reefs in the Chagos atolls generally have from one to seven fathoms water on them, but some have from seven to ten. Most of them are small with very steep sides;[15] at Peros Banhos they rise from a depth of about thirty fathoms, and some of them in the Great Chagos Bank from above forty fathoms; they are covered, Captain Moresby informs me, with living and healthy coral, two and three feet high, consisting of several species. Why then have not these lagoon-reefs reached the surface, like the innumerable ones in the atolls above named? If we attempt to assign any difference in their external conditions, as the cause of this diversity, we are at once baffled. The lagoon of Diego Garcia is not deep, and is almost wholly surrounded by its reef; Peros Banhos is very deep, much larger, with many wide passages communicating with the open sea. On the other hand, of those atolls, in which all or nearly all the lagoon-reefs have reached the surface, some are small, others large, some shallow, others deep, some well-enclosed, and others open.

> [15] Some of these statements were not communicated to me verbally by Captain Moresby, but are taken from the MS. account before alluded to, of the Chagos Group.

Captain Moresby informs me that he has seen a French chart of Diego Garcia made eighty years before his survey, and apparently very accurate; and from it he infers, that during this interval there has not been the smallest change in the depth on any of the knolls within the lagoon. It is also known that during the last fifty-one years, the eastern channel into the lagoon has neither become narrower, nor decreased in depth; and as there are numerous small knolls of living coral within it, some change might have been anticipated. Moreover, as the whole reef round the lagoon of this atoll has been converted into land—an unparalleled case, I believe, in an atoll of such large size,—and as the strip of land is for considerable spaces more than half a mile wide—also a very unusual circumstance,—we have the best possible evidence, that Diego Garcia has remained at its present level for a very long period. With this fact, and with the knowledge that no sensible change has taken place during eighty years in the coral-knolls, and considering that every single reef has reached the surface in other atolls, which do not present the smallest appearance of being older than Diego Garcia and Peros Banhos, and which are placed under the same external conditions with them, one is led to conclude that these submerged reefs, although covered with luxuriant coral, have no tendency to grow upwards, and that they would remain at their present levels for an almost indefinite period.

From the number of these knolls, from their position, size, and form, many of them being only one or two hundred yards across, with a rounded outline, and precipitous sides,—it is indisputable that they have been formed by the growth of coral; and this makes the case much more remarkable. In Peros Banhos and in the Great Chagos Bank, some of these almost columnar masses are 200 feet high, and their summits lie only from two to eight fathoms beneath the surface; therefore, a small proportional amount more of growth would cause them to attain the surface, like those numerous knolls, which rise from an equally great depth within the Maldiva atolls. We can hardly suppose that time has been wanting for the upward growth of the coral, whilst in Diego Garcia, the broad annular strip of land, formed by the continued accumulation of detritus, shows how long this atoll has remained at its present level. We must look to some other cause than the rate of growth; and I suspect it will be found in the reefs being formed of different species of corals, adapted to live at different depths. The Great Chagos Bank is situated in the centre of the Chagos Group, and the Pitt and Speaker Banks at its two extreme points. These banks resemble atolls, except in their external rim being about eight fathoms submerged, and in being formed of dead rock, with very little living coral on it: a portion nine miles long of the annular reef of Peros Banhos atoll is in the same condition. These facts, as will hereafter be shown, render it very probable that the whole group at some former period subsided seven or eight fathoms; and that the coral perished on the outer margin of those atolls which are now submerged, but that it continued alive, and grew up to the surface on those which are now perfect. If these atolls did subside, and if from the suddenness of the movement or from any other cause, those corals which are better adapted to live at a certain depth than at the surface, once got possession of the knolls, supplanting the former occupants, they would exert little or no tendency to grow upwards. To illustrate this, I may observe, that if the corals of the upper zone on the outer edge of Keeling atoll were to perish, it is improbable that those of the lower zone would grow to the surface, and thus become exposed to conditions for which they do not appear to be adapted. The conjecture, that the corals on the submerged knolls within the Chagos atolls have analogous habits with those of the lower zone outside Keeling atoll, receives some support from a remark by Captain Moresby, namely, that they have a different appearance from those on the reefs in the Maldiva atolls, which, as we have seen, all rise to the surface: he compares the kind of difference to that of the vegetation under different climates. I have entered at considerable length into this case, although unable to throw much light on it, in order to show that an equal tendency to upward growth ought not to be attributed to all coral-reefs,—to those situated at different depths,—to those forming the ring of an atoll or those on the knolls within a lagoon,—to those in one area and those in another. The inference, therefore, that one reef could not grow up to the surface within a given time, because another, not known to be covered with the same species of corals, and not known to be placed under conditions exactly the same, has not within the same time reached the surface, is unsound.

Section II—ON THE RATE OF GROWTH OF CORAL-REEFS

The remark made at the close of the last section, naturally leads to this division of our subject, which has not, I think, hitherto been considered under a right point of view. Ehrenberg[16] has stated, that in the Red Sea, the corals only coat other rocks in a layer from one to two feet in thickness, or at most to a fathom and a half; and he disbelieves that, in any case, they form, by their own proper growth, great masses, stratum over stratum. A nearly similar observation has been made by MM. Quoy and Gaimard,[17] with respect to the thickness of some upraised beds of coral, which they examined at Timor and some other places. Ehrenberg[18] saw certain large massive corals in the Red Sea, which he imagines to be of such vast antiquity, that they might have been beheld by Pharaoh; and according to Mr. Lyell[19] there are certain corals at Bermuda, which are known by tradition, to have been living for centuries. To show how slowly coral-reefs grow upwards, Captain Beechey[20] has adduced the case of the Dolphin Reef off Tahiti, which has remained at the same depth beneath the surface, namely about two fathoms and a half, for a period of sixty-seven years. There are reefs in the Red Sea, which certainly do not appear[21] to have increased in dimensions during the last half-century, and from the comparison of old charts with recent surveys, probably not during the last two hundred years. These, and other similar facts, have so strongly impressed many with the belief of the extreme slowness of the growth of corals, that they have even doubted the possibility of islands in the great oceans having been formed by their agency. Others, again, who have not been overwhelmed by this difficulty, have admitted that it would require thousands, and tens of thousands of years, to form a mass, even of inconsiderable thickness; but the subject has not, I believe, been viewed in the proper light.

[16] Ehrenberg, as before cited, pp. 39, 46, and 50.

[17] “Annales des Sciences Nat.” tom. vi, p. 28.

[18] Ehrenberg, *ut sup.*, p. 42.

[19] Lyell’s “Principles of Geology,” book iii, ch. xviii.

[20] Beechey’s “Voyage to the Pacific,” ch. viii.

[21] Ehrenberg, *ut sup.*, p. 43.

That masses of considerable thickness have been formed by the growth of coral, may be inferred with certainty from the following facts. In the deep lagoons of Peros Banhos and of the Great Chagos Bank, there are, as already described, small steep-sided knolls covered with living coral. There are similar knolls in the southern Maldiva atolls, some of which, as Captain Moresby assures me, are less than a hundred yards in diameter, and rise to the surface from a depth of between two hundred and fifty and three hundred feet. Considering their number, form, and position, it would be preposterous to suppose that they are based on pinnacles of any rock, not of coral formation; or that sediment could have been heaped up into such small and steep isolated cones. As no kind of living coral grows above the height of a few feet, we are compelled to suppose that these knolls have been formed by the successive growth and death of many individuals,—first one being broken off or killed by some accident, and then another, and one set of species being replaced by another set with different habits, as the reef rose nearer the surface, or as other changes supervened. The spaces between the corals would become filled up with fragments and sand, and such matter would probably soon be consolidated, for we learn from Lieutenant Nelson,[22] that at Bermuda a process of this kind takes place beneath water, without the aid of evaporation. In reefs, also, of the barrier class, we may feel sure, as I have shown, that masses of great thickness have been formed by the growth of the coral; in the case of Vanikoro, judging only from the depth of the moat between the land and the reef, the wall of coral-rock must be at least three hundred feet in vertical thickness.

[22] "Geological Transactions," vol. v, p. 113.

It is unfortunate that the upraised coral-islands in the Pacific have not been examined by a geologist. The cliffs of Elizabeth Island, in the Low Archipelago, are eighty feet high, and appear, from Captain Beechey's description, to consist of a homogeneous coral-rock. From the isolated position of this island, we may safely infer that it is an upraised atoll, and therefore that it has been formed by masses of coral, grown together. Savage Island seems, from the description of the younger Forster,[23] to have a similar structure, and its shores are about forty feet high: some of the Cook Islands also appear[24] to be similarly composed. Captain Belcher, R.N., in a letter which Captain Beaufort showed me at the admiralty, speaking of Bow atoll, says, "I have succeeded in boring forty-five feet through coral-sand, when the auger became jammed by the falling in of the surrounding *creamy* matter." On one of the Maldiva atolls, Captain Moresby bored to a depth of twenty-six feet, when his auger also broke: he has had the kindness to give me the matter brought up; it is perfectly white, and like finely triturated coral-rock.

[23] Forster's "Voyage round the World with Cook," vol. ii, pp. 163, 167.

[24] Williams's "Narrative of Missionary Enterprise," p. 30.

In my description of Keeling atoll, I have given some facts, which show that the reef probably has grown outwards; and I have found, just within the outer margin, the great mounds of Porites and of Millepora, with their summits lately killed, and their sides subsequently thickened by the growth of the coral: a layer, also, of Nullipora had already coated the dead surface. As the external slope of the reef is the same round the whole of this atoll, and round many other atolls, the angle of inclination must result from an adaption between the growing powers of the coral, and the force of the breakers, and their action on the loose sediment. The reef, therefore, could not increase outwards, without a nearly equal addition to every part of the slope, so that the original inclination might be preserved, and this would require a large amount of sediment, all derived from the wear of corals and shells, to be added to the lower part. Moreover, at Keeling atoll, and probably in many other cases, the different kinds of corals would have to encroach on each other; thus the Nulliporæ cannot increase outwards without encroaching on the Porites and *Millepora complanata,* as is now taking place; nor these latter without encroaching on the strongly branched Madreporet, the *Millepora alcicornis,* and some Astræas; nor these again without a foundation being formed for them within the requisite depth, by the accumulation of sediment. How slow, then, must be the ordinary lateral or outward growth of such reefs. But off Christmas atoll, where the sea is much more shallow than is usual, we have good reason to believe that, within a period not very remote, the reef has increased considerably in width. The land has the extraordinary breadth of three miles; it consists of parallel ridges of shells and broken corals, which furnish "an incontestable proof," as observed by Cook,[25] "that the island has been produced by accessions from the sea, and is in a state of increase." The land is fronted by a coral-reef, and from the manner in which islets are known to be formed, we may feel confident that the reef was not three miles wide, when the first, or most backward ridge, was thrown up; and, therefore, we must conclude that the reef has grown outwards during the accumulation of the successive ridges. Here then, a wall of coral-rock of very considerable breadth has been formed by the outward growth of the living margin, within a period during which ridges of shells and corals, lying on the bare surface, have not decayed. There can be little doubt, from the account given by Captain Beechey, that Matilda atoll, in the Low Archipelago, has been converted in the space of thirty-four years, from being, as described by the crew of a wrecked whaling vessel, a "reef of rocks" into a lagoon-island, fourteen miles in length, with "one of its sides covered nearly the whole way with high trees."[26] The islets, also, on Keeling atoll, it has been shown, have increased in length, and since the construction of an old chart, several of them have become united into one long islet; but in this case, and in that of Matilda atoll, we have no proof, and can only infer as probable, that the reef, that is the foundation of the islets, has increased as well as the islets themselves.

[25] Cook’s “Third Voyage,” book III, ch. x.

[26] Beechey’s “Voyage to the Pacific,” ch. vii and viii.

After these considerations, I attach little importance, as indicating the ordinary and still less the possible rate of *outward* growth of coral-reefs, to the fact that certain reefs in the Red Sea have not increased during a long interval of time; or to other such cases, as that of Ouluthy atoll in the Caroline group, where every islet, described a thousand years before by Cantova was found in the same state by Lutké,[27]—without it could be shown that, in these cases, the conditions were favourable to the vigorous and unopposed growth of the corals living in the different zones of depth, and that a proper basis for the extent of the reef was present. The former conditions must depend on many contingencies, and in the deep oceans where coral formations most abound, a basis within the requisite depth can rarely be present.

[27] F. Lutké’s “Voyage autour du Monde.” In the group Elato, however, it appears that what is now the islet Falipi, is called in Cantova’s Chart, the Banc de Falipi. It is not stated whether this has been caused by the growth of coral, or by the accumulation of sand.

Nor do I attach any importance to the fact of certain submerged reefs, as those off Tahiti, or those within Diego Garcia not now being nearer the surface than they were many years ago, as an indication of the rate under favourable circumstances of the *upward* growth of reefs; after it has been shown, that all the reefs have grown to the surface in some of the Chagos atolls, but that in neighbouring atolls which appear to be of equal antiquity and to be exposed to the same external conditions, every reef remains submerged; for we are almost driven to attribute this to a difference, not in the rate of growth, but in the habits of the corals in the two cases.

In an old-standing reef, the corals, which are so different in kind on different parts of it, are probably all adapted to the stations they occupy, and hold their places, like other organic beings, by a struggle one with another, and with external nature; hence we may infer that their growth would generally be slow, except under peculiarly favourable circumstances. Almost the only natural condition, allowing a quick upward growth of the whole surface of a reef, would be a slow subsidence of the area in which it stood; if, for instance, Keeling atoll were to subside two or three feet, can we doubt that the projecting margin of live coral, about half an inch in thickness, which surrounds the dead upper surfaces of the mounds of Porites, would in this case form a concentric layer over them, and the reef thus increase upwards, instead of, as at present, outwards? The Nulliporæ are now encroaching on the Porites and Millepora, but in this case might we not confidently expect that the latter would, in their turn, encroach on the Nulliporæ? After a subsidence of this kind, the sea would gain on the islets, and the great fields of dead but upright corals in the lagoon, would be covered by a sheet of clear water; and might we not then expect that these reefs would rise to the surface, as they anciently did when the lagoon was less confined by islets, and as they did within a period of ten years in the schooner-channel, cut by the inhabitants? In one of the Maldiva atolls, a reef, which within a very few years existed as an islet bearing cocoa-nut trees, was found by Lieutenant Prentice “*entirely covered with live coral and Madrepore.*” The natives believe that the islet was washed away by a change in the currents, but if, instead of this, it had quietly subsided, surely every part of the island which offered a solid foundation, would in a like manner have become coated with living coral.

Through steps such as these, any thickness of rock, composed of a singular intermixture of various kinds of corals, shells, and calcareous sediment, might be formed; but without subsidence, the thickness would necessarily be determined by the depth at which the reef-building polypifers can exist. If it be asked, at what rate in years I suppose a reef of coral favourably circumstanced could grow up from a given depth; I should answer, that we have no precise evidence on this point, and comparatively little concern with it. We see, in innumerable points over wide areas, that the rate has been sufficient, either to bring up the reefs from various depths to the surface, or, as is more probable, to keep them at the surface, during progressive subsidences; and this is a much more important standard of comparison than any cycle of years.

It may, however, be inferred from the following facts, that the rate in years under favourable circumstances would be very far from slow. Dr. Allan, of Forres, has, in his MS. Thesis deposited in the library of the Edinburgh University (extracts from which I owe to the kindness of Dr. Malcolmson), the following account of some experiments, which he tried during his travels in the years 1830 to 1832 on the east coast of Madagascar. "To ascertain the rise and progress of the coral-family, and fix the number of species met with at Foul Point (latitude 17° 40′) twenty species of coral were taken off the reef and planted apart on a sand-bank *three feet deep at low water.* Each portion weighed ten pounds, and was kept in its place by stakes. Similar quantities were placed in a clump and secured as the rest. This was done in December 1830. In July following, each detached mass was nearly level with the sea at low water, quite immovable, and several feet long, stretching as the parent reef, with the coast current from north to south. The masses accumulated in a clump were found equally increased, but some of the species in such unequal ratios, as to be growing over each other." The loss of Dr. Allan's magnificent collection by shipwreck, unfortunately prevents its being known to what genera these corals belonged; but from the numbers experimented on, it is certain that all the more conspicuous kinds must have been included. Dr. Allan informs me, in a letter, that he believes it was a Madrepora, which grew most vigorously. One may be permitted to suspect that the level of the sea might possibly have been somewhat different at the two stated periods; nevertheless, it is quite evident that the growth of the ten-pound masses, during the six or seven months, at the end of which they were found immovably fixed[28] and several feet in length, must have been very great. The fact of the different kinds of coral, when placed in one clump, having increased in extremely unequal ratios, is very interesting, as it shows the manner in which a reef, supporting many species of coral, would probably be affected by a change in the external conditions favouring one kind more than another. The growth of the masses of coral in N. and S. lines parallel to the prevailing currents, whether due to the drifting of sediment or to the simple movement of the water, is, also, a very interesting circumstance.

[28] It is stated by De la Beche ("Geological Manual," p. 143), on the authority of Mr. Lloyd, who surveyed the Isthmus of Panama, that some specimens of Polypifers, placed by him in a sheltered pool of water, were found in the course of a few days firmly fixed by the secretion of a stony matter, to the bottom.

A fact, communicated to me by Lieutenant Wellstead, I.N., in some degree corroborates the result of Dr. Allan's experiments: it is, that in the Persian Gulf a ship had her copper bottom encrusted in the course of twenty months with a layer of coral, *two feet* in thickness, which it required great force to remove, when the vessel was docked: it was not ascertained to what order this coral belonged. The case of the schooner-channel choked up with coral in an interval of less than ten years, in the lagoon of Keeling atoll, should be here borne in mind. We may also infer, from the trouble which the inhabitants of the Maldiva atolls take to root out, as they express it, the coral-knolls from their harbours, that their growth can hardly be very slow.[29]

[29] Mr. Stutchbury (*West of England Journal*, No. I, p. 50.) has described a specimen of Agaricia, "weighing 2 lbs. 9 oz., which surrounds a species of oyster, whose age could not be more than two years, and yet is completely enveloped by this dense coral." I presume that the oyster was living when the specimen was procured; otherwise the fact tells nothing. Mr. Stutchbury also mentions an anchor, which had become entirely encrusted with coral in fifty years; other cases, however, are recorded of anchors which have long remained amidst coral-reefs without having become coated. The anchor of the *Beagle*, in 1832, after having been down exactly one month at Rio de Janeiro, was so thickly coated by two species of Tubularia, that large spaces of the iron were entirely concealed; the tufts of this horny zoophyte were between two and three inches in length. It has been attempted to compute, but I believe erroneously, the rate of growth of a reef, from the fact mentioned by Captain Beechey, of the *Chama gigas* being embedded in coral-rock. But it should be remembered, that some species of this genus invariably live, both whilst young and old, in cavities, which the animal has the power of enlarging with its growth. I saw many of these shells thus embedded in the outer "flat" of Keeling atoll, which is composed of dead rock; and therefore the cavities in this case had no relation whatever with the growth of coral. M. Lesson, also, speaking of this shell (Partie Zoolog. "Voyage de la *Coquille*"), has remarked, "que constamment ses valves étaient engagés complétement dans la masse des Madrepores."

From the facts given in this section, it may be concluded, first, that considerable thicknesses of rock have certainly been formed within the present geological area by the growth of coral and the accumulation of its detritus; and, secondly, that the increase of individual corals and of reefs, both outwards or horizontally and upwards or vertically, under the peculiar conditions favourable to such increase, is not slow, when referred either to the standard of the average oscillations of level in the earth's crust, or to the more precise but less important one of a cycle of years.

Section III—ON THE DEPTHS AT WHICH REEF-BUILDING POLYPIFERS CAN LIVE

I have already described in detail, which might have appeared trivial, the nature of the bottom of the sea immediately surrounding Keeling atoll; and I will now describe with almost equal care the soundings off the fringing-reefs of Mauritius. I have preferred this arrangement, for the sake of grouping together facts of a similar nature. I sounded with the wide bell-shaped lead which Captain Fitzroy used at Keeling Island, but my examination of the bottom was confined to a few miles of coast (between Port Louis and Tomb Bay) on the leeward side of the island. The edge of the reef is formed of great shapeless masses of branching Madrepores, which chiefly consist of two species,—apparently *M. corymbosa* and *pocillifera*,—mingled with a few other kinds of coral. These masses are separated from each other by the most irregular gullies and cavities, into which the lead sinks many feet. Outside this irregular border of Madrepores, the water deepens gradually to twenty fathoms, which depth generally is found at the distance of from half to three-quarters of a mile from the reef. A little further out the depth is thirty fathoms, and thence the bank slopes rapidly into the depths of the ocean. This inclination is very gentle compared with that outside Keeling and other atolls, but compared with most coasts it is steep. The water was so clear outside the reef, that I could distinguish every object forming the rugged bottom. In this part, and to a depth of eight fathoms, I sounded repeatedly, and at each cast pounded the bottom with the broad lead, nevertheless the arming invariably came up perfectly clean, but deeply indented. From eight to fifteen fathoms a little calcareous sand was occasionally brought up, but more frequently the arming was simply indented. In all this space the two Madrepores above mentioned, and two species of Astræa, with rather large[30] stars, seemed the commonest kinds; and it must be noticed that twice at the depth of fifteen fathoms, the arming was marked with a clean impression of an Astræa. Besides these lithophytes, some fragments of the *Millepora alcicornis,* which occurs in the same relative position at Keeling Island, were brought up; and in the deeper parts there were large beds of a Seriatopora, different from *S. subulata*, but closely allied to it. On the beach within the reef, the rolled fragments consisted chiefly of the corals just mentioned, and of a massive Porites, like that at Keeling atoll, of a Meandrina, *Pocillopora verrucosa*, and of numerous fragments of Nullipora. From fifteen to twenty fathoms the bottom was, with few exceptions, either formed of sand, or thickly covered with Seriatopora: this delicate coral seems to form at these depths extensive beds unmingled with any other kind. At twenty fathoms, one sounding brought up a fragment of Madrepora apparently *M. pocillifera*, and I believe it is the same species (for I neglected to bring specimens from both stations) which mainly forms the upper margin of the reef; if so, it grows in depths varying from 0 to 20 fathoms. Between 20 and 23 fathoms I obtained several soundings, and they all showed a sandy bottom, with one exception at 30 fathoms, when the arming came up scooped out, as if by the margin of a large Caryophyllia. Beyond 33 fathoms I sounded only once; and from 86 fathoms, at the distance of one mile and a third from the edge of the reef, the arming brought up calcareous sand with a pebble of volcanic rock. The circumstance of the arming having invariably come up quite clean, when sounding within a certain number of fathoms off the reefs of Mauritius and Keeling atoll (eight fathoms in the former case, and twelve in the latter) and of its having always come up (with one exception) smoothed and covered with sand, when the depth exceeded twenty fathoms, probably indicates a criterion, by which the limits of the vigorous growth of coral might in all cases be readily ascertained. I do not, however, suppose that if a vast number of soundings were obtained round these islands, the limit above assigned would be found never to vary, but I conceive the facts are sufficient to show, that the exceptions would be few. The circumstance of a *gradual* change, in the two cases, from a field of clean coral to a smooth sandy bottom, is far more important in indicating the depth at which the larger kinds of coral flourish than almost any number of separate observations on the depth, at which certain species have been dredged up. For we can understand the gradation, only as a prolonged struggle against unfavourable conditions. If a person were to find the soil clothed with turf on the banks of a stream of water, but on going to some distance on one side of it, he observed the blades of grass growing thinner and thinner, with intervening patches of sand, until he entered a desert of sand, he would safely conclude, especially if changes of the same kind were noticed in other places, that the presence of the water was absolutely necessary to the formation of a thick bed of turf: so may we conclude, with the same feeling of certainty, that thick beds of coral are formed only at small depths beneath the surface of the sea.

[30] Since the preceding pages were printed off, I have received from Mr. Lyell a very interesting pamphlet, entitled "Remarks upon Coral Formations," etc., by J. Couthouy, Boston, United States, 1842. There is a statement (p. 6), on the authority of the Rev. J. Williams, corroborating the remarks made by Ehrenberg and Lyell (p. 71 of this volume), on the antiquity of certain individual corals in the Red Sea and at Bermuda; namely, that at Upolu, one of the Navigator Islands, "particular clumps of coral are known to the fishermen by name, derived from either some particular configuration or tradition attached to them, and handed down from time immemorial." With respect to the thickness of masses of coral-rock, it clearly appears, from the descriptions given by Mr. Couthouy (pp. 34, 58) that Mangaia and Aurora Islands are upraised atolls, composed of coral rock: the level summit of the former is about three hundred feet, and that of Aurora Island is two hundred feet above the sea-level.

I have endeavoured to collect every fact, which might either invalidate or corroborate this conclusion. Captain Moresby, whose opportunities for observation during his survey of the Maldiva and Chagos Archipelagoes have been unrivalled, informs me, that the upper part or zone of the steep-sided reefs, on the inner and outer coasts of the atolls in both groups, invariably consists of coral, and the lower parts of sand. At seven or eight fathoms depth, the bottom is formed, as could be seen through the clear water, of great living masses of coral, which at about ten fathoms generally stand some way apart from each other, with patches of white sand between them, and at a little greater depth these patches become united into a smooth steep slope, without any coral. Captain Moresby, also, informs me in support of his statement, that he found only decayed coral on the Padua Bank (northern part of the Laccadive group) which has an average depth between twenty-five and thirty-five fathoms, but that on some other banks in the same group with only ten or twelve fathoms water on them (for instance, the Tillacapeni bank), the coral was living. With regard to the coral-reefs in the Red Sea, Ehrenberg has the following passage:—"The living corals do not descend there into great depths. On the edges of islets and near reefs, where the depth was small, very many lived; but we found no more even at six fathoms. The pearl-fishers at Yemen and Massaua asserted that there was no coral near the pearl-banks at nine fathoms depth, but only sand. We were not able to institute any more special researches."[31] I am, however, assured both by Captain Moresby and Lieutenant Wellstead, that in the more northern parts of the Red Sea, there are extensive beds of living coral at a depth of twenty-five fathoms, in which the anchors of their vessels were frequently entangled. Captain Moresby attributes the less depth, at which the corals are able to live in the places mentioned by Ehrenberg, to the greater quantity of sediment there; and the situations, where they were flourishing at the depth of twenty-five fathoms, were protected, and the water was extraordinarily limpid. On the leeward side of Mauritius where I found the coral growing at a somewhat greater depth than at Keeling atoll, the sea, owing apparently to its tranquil state, was likewise very clear. Within the lagoons of some of the Marshall atolls, where the water can be but little agitated, there are, according to Kotzebue, living beds of coral in twenty-five fathoms. From these facts, and considering the manner in which the beds of clean coral off Mauritius, Keeling Island, the Maldiva and Chagos atolls, graduated into a sandy slope, it appears very probable that the depth, at which reef-building polypifers can exist, is partly determined by the extent of inclined surface, which the currents of the sea and the recoiling waves have the power to keep free from sediment.

[31] Ehrenberg, "Über die Natur," etc., p. 50.

MM. Quoy and Gaimard[32] believe that the growth of coral is confined within very limited depths; and they state that they never found any fragment of an Astræa (the genus they consider most efficient in forming reefs) at a depth above twenty-five or thirty feet. But we have seen that in several places the bottom of the sea is paved with massive corals at more than twice this depth; and at fifteen fathoms (or twice this depth) off the reefs of Mauritius, the arming was marked with the distinct impression of a living Astræa. *Millepora alcicornis* lives in from 0 to 12 fathoms, and the genera Madrepora and Seriatopora from 0 to 20 fathoms. Captain Moresby has given me a specimen of *Sideropora scabra* (Porites of Lamarck) brought up alive from 17 fathoms. Mr. Couthouy[33] states that he has dredged up on the Bahama banks considerable masses of Meandrina from 16 fathoms, and he has seen this coral growing in 20 fathoms. A Caryophyllia, half an inch in diameter, was dredged up alive from 80 fathoms off Juan Fernandez (latitude 33° S.) by Captain P. P. King:[34] this is the most remarkable fact with which I am acquainted, showing the depth at which a genus of corals often found on reefs, can exist.[35] We ought, however, to feel less surprise at this fact, as Caryophyllia alone of the lamelliform genera, ranges far beyond the tropics; it is found in Zetland[36] in Lat. 60° N. in deep water, and I procured a small species from Tierra del Fuego in Lat. 53° S. Captain Beechey informs me, that branches of pink and yellow coral were frequently brought up from between twenty and twenty-five fathoms off the Low atolls; and Lieutenant Stokes, writing to me from the N.W. coast of Australia, says that a strongly branched coral was procured there from thirty fathoms; unfortunately it is not known to what genera these corals belong.

[32] “Annales des Sci. Nat.” tom. vi.

[33] “Remarks on Coral Formations,” p. 12.

[34] I am indebted to Mr. Stokes for having kindly communicated this fact to me, together with much other valuable information.

[35] I will record in the form of a note all the facts that I have been able to collect on the depths, both within and without the tropics, at which those corals and corallines can live, which there is no reason to suppose ever materially aid in the construction of a reef.

Ellis (“Nat. Hist. of Coralline,” p. 96) states that Ombellularia was procured in latitude 79° N. *sticking* to a *line* from the depth of 236 fathoms; hence this coral either must have been floating loose, or was entangled in stray line at the bottom. Off Keeling atoll a compound Ascidia (Sigillina) was brought up from 39 fathoms, and a piece of sponge, apparently living, from 70, and a fragment of Nullipora also apparently living from 92 fathoms. At a greater depth than 90 fathoms off this coral island, the bottom was thickly strewed with joints of Halimeda and small fragments of other Nulliporæ, but all dead. Captain B. Allen, R.N., informs me that in the survey of the West Indies it was noticed that between the depth of 10 and 200 fathoms, the sounding lead very generally came up coated with the dead joints of a Halimeda, of which he showed me specimens. Off Pernambuco, in Brazil, in about twelve fathoms, the bottom was covered with fragments dead and alive of a dull red Nullipora, and I infer from Roussin’s chart, that a bottom of this kind extends over a wide area. On the beach, within the coral-reefs of Mauritius, vast quantities of fragments of Nulliporæ were piled up. From these facts it appears, that these simply organized bodies are amongst the most abundant productions of the sea.

[36] Fleming’s “British Animals,” genus Caryophyllia.

Name of Zoophyte	Depth in Fathoms	Country and S. Latitude	Authority
Sertularia	40	Cape Horn 66°	(Where none is given, the observation is my own.)
Cellaria	Ditto	Ditto	
Cellaria. A minute scarlet encrusted species, found living	190	Keeling Atoll 12°	
Cellaria. An allied, small stony sub-generic form	48	S. Cruz River 50°	

A coral allied to Vincularia, with eight rows of cells	40	Cape Horn	
Tubulipora, near to T. patima	Ditto	Ditto	
Ditto	94	East Chiloe 43°	
Cellepora, several species, and allied sub-generic forms	40	Cape Horn	
Ditto	40 and 57	Chonos Arch. 45°	
Ditto	48	S. Cruz 50°	
Eschara	30	Tierra del Fuego 53°	
Ditto	48	S. Cruz R. 50°	
Retepora	40	Cape Horn	
Ditto	100	C. Good Hope 34°	Quoy and Gaimard, *Ann. Scien. Nat.,* t. vi, p. 284.
Millepora, a strong coral with cylindrical branches, of a pink colour, abut two inches high, resembling in the form of its orifices M. aspera of Lamarck	94 and 30	E. Chiloe 43° Tierra del Fuego 53°	
Coralium	120	Barbary 33° N.	Peyssonel in paper read to Royal society May 1752.
Antipathes	16	Chonos 45°	
Gorgonia (or an allied form)	160	Abrolhos on the coast of Brazil 18°	Capt. Beechey informed me of this fact in a letter.

Although the limit of depth, at which each particular kind of coral ceases to exist, is far from being accurately known; yet when we bear in mind the manner in which the clumps of coral gradually became infrequent at about the same depth, and wholly disappeared at a greater depth than twenty fathoms, on the slope round Keeling atoll, on the leeward side of the Mauritius, and at rather less depth, both without and within the atolls of the Maldiva and Chagos Archipelagoes; and when we know that the reefs round these islands do not differ from other coral formations in their form and structure, we may, I think, conclude that in ordinary cases, reef- building polypifers do not flourish at greater depths than between twenty and thirty fathoms.

It has been argued[37] that reefs may possibly rise from very great depths through the means of small corals, first making a platform for the growth of the stronger kinds. This, however, is an arbitrary supposition: it is not always remembered, that in such cases there is an antagonist power in action, namely, the decay of organic bodies, when not protected by a covering of sediment, or by their own rapid growth. We have, moreover, no right to calculate on unlimited time for the accumulation of small organic bodies into great masses. Every fact in geology proclaims that neither the land, nor the bed of the sea retain for indefinite periods the same level. As well might it be imagined that the British Seas would in time become choked up with beds of oysters, or that the numerous small corallines off the inhospitable shores of Tierra del Fuego would in time form a solid and extensive coral-reef.

[37] *Journal of the Royal Geographical Society,* 1831, p. 218.

Chapter V

THEORY OF THE FORMATION OF THE DIFFERENT CLASSES OF CORAL-REEFS

The atolls of the larger archipelagoes are not formed on submerged craters, or on banks of sediment.—Immense areas interspersed with atolls.—Their subsidence.—The effects of storms and earthquakes on atolls.—Recent changes in their state.—The origin of barrier-reefs and of atolls.—Their relative forms.—The step-formed ledges and walls round the shores of some lagoons.—The ring-formed reefs of the Maldiva atolls.—The submerged condition of parts or of the whole of some annular reefs.—The disseverment of large atolls.—The union of atolls by linear reefs.—The Great Chagos Bank.—Objections from the area and amount of subsidence required by the theory, considered.—The probable composition of the lower parts of atolls.

The naturalists who have visited the Pacific, seem to have had their attention riveted by the lagoon-islands, or atolls,—those singular rings of coral-land which rise abruptly out of the unfathomable ocean—and have passed over, almost unnoticed, the scarcely less wonderful encircling barrier-reefs. The theory most generally received on the formation of atolls, is that they are based on submarine craters; but where can we find a crater of the shape of Bow atoll, which is five times as long as it is broad (Plate I, Fig. 4); or like that of Menchikoff Island (Plate II, Fig. 3), with its three loops, together sixty miles in length; or like Rimsky Korsacoff, narrow, crooked, and fifty-four miles long; or like the northern Maldiva atolls, made up of numerous ring-formed reefs, placed on the margin of a disc,—one of which discs is eighty-eight miles in length, and only from ten to twenty in breadth? It is, also, not a little improbable, that there should have existed as many craters of immense size crowded together beneath the sea, as there are now in some parts atolls. But this theory lies under a greater difficulty, as will be evident, when we consider on what foundations the atolls of the larger archipelagoes rest: nevertheless, if the rim of a crater afforded a basis at the proper depth, I am far from denying that a reef like a perfectly characterised atoll might not be formed; some such, perhaps, now exist; but I cannot believe in the possibility of the greater number having thus originated.

An earlier and better theory was proposed by Chamisso;[1] he supposes that as the more massive kinds of corals prefer the surf, the outer portions, in a reef rising from a submarine basis, would first reach the surface and consequently form a ring. But on this view it must be assumed, that in every case the basis consists of a flat bank; for if it were conically formed, like a mountainous mass, we can see no reason why the coral should spring up from the flanks, instead of from the central and highest parts: considering the number of the atolls in the Pacific and Indian Oceans, this assumption is very improbable. As the lagoons of atolls are sometimes even more than forty fathoms deep, it must, also, be assumed on this view, that at a depth at which the waves do not break, the coral grows more vigorously on the edges of a bank than on its central part; and this is an assumption without any evidence in support of it. I remarked, in the third chapter, that a reef, growing on a detached bank, would tend to assume an atoll-like structure; if, therefore, corals were to grow up from a bank, with a level surface some fathoms submerged, having steep sides and being situated in a deep sea, a reef not to be distinguished from an atoll, might be formed: I believe some such exist in the West Indies. But a difficulty of the same kind with that affecting the crater theory, runners, as we shall presently see, this view inapplicable to the greater number of atolls.

[1] Kotzebue's "First Voyage," vol. iii, p. 331.

No theory worthy of notice has been advanced to account for those barrier-reefs, which encircle islands of moderate dimensions. The great reef which fronts the coast of Australia has been supposed, but without any special facts, to rest on the edge of a submarine precipice, extending parallel to the shore. The origin of the third class or of fringing-reefs presents, I believe, scarcely any difficulty, and is simply consequent on the polypifers not growing up from great depths, and their not flourishing close to gently shelving beaches where the water is often turbid.

What cause, then, has given to atolls and barrier-reefs their characteristic forms? Let us see whether an important deduction will not follow from the consideration of these two circumstances, first, the reef-building corals flourishing only at limited depths; and secondly, the vastness of the areas interspersed with coral-reefs and coral-islets, none of which rise to a greater height above the level of the sea, than that attained by matter thrown up by the waves and winds. I do not make this latter statement vaguely; I have carefully sought for descriptions of every island in the intertropical seas; and my task has been in some degree abridged by a map of the Pacific, corrected in 1834 by MM. D'Urville and Lottin, in which the low islands are distinguished from the high ones (even from those much less than a hundred feet in height) by being written without a capital letter; I have detected a few errors in this map, respecting the height of some of the islands, which will be noticed in the Appendix, where I treat of coral formations in geographical order. To the Appendix, also, I must refer for a more particular account of the data on which the statements on the next page are grounded. I have ascertained, and chiefly from the writings of Cook, Kotzebue, Bellinghausen, Duperrey, Beechey, and Lutké, regarding the Pacific; and from Moresby[2] with respect to the Indian Ocean, that in the following cases the term "low island" strictly means land of the height commonly attained by matter thrown up by the winds and the waves of an open sea. If we draw a line (the plan I have always adopted) joining the external atolls of that part of the Low Archipelago in which the islands are numerous, the figure will be a pointed ellipse (reaching from Hood to Lazaref Island), of which the longer axis is 840 geographical miles, and the shorter 420 miles; in this space[3] none of the innumerable islets united into great rings rise above the stated level. The Gilbert group is very narrow, and 300 miles in length. In a prolonged line from this group, at the distance of 240 miles, is the Marshall Archipelago, the figure of which is an irregular square, one end being broader than the other; its length is 520 miles, with an average width of 240; these two groups together are 1,040 miles in length, and all their islets are low. Between the southern end of the Gilbert and the northern end of Low Archipelago, the ocean is thinly strewed with islands, all of which, as far as I have been able to ascertain, are low; so that from nearly the southern end of the Low Archipelago, to the northern end of the Marshall Archipelago, there is a narrow band of ocean, more than 4,000 miles in length, containing a great number of islands, all of which are low. In the western part of the Caroline Archipelago, there is a space of 480 miles in length, and about 100 broad, thinly interspersed with low islands. Lastly, in the Indian Ocean, the archipelago of the Maldivas is 470 miles in length, and 60 in breadth; that of the Laccadives is 150 by 100 miles; as there is a low island between these two groups, they may be considered as one group of 1,000 miles in length. To this may be added the Chagos group of low islands, situated 280 miles distant, in a line prolonged from the southern extremity of the Maldivas. This group, including the submerged banks, is 170 miles in length and 80 in breadth. So striking is the uniformity in direction of these three archipelagoes, all the islands of which are low, that Captain Moresby, in one of his papers, speaks of them as parts of one great chain, nearly 1,500 miles long. I am, then, fully justified in repeating, that enormous spaces, both in the Pacific and Indian Oceans, are interspersed with islands, of which not one rises above that height, to which the waves and winds in an open sea can heap up matter. On what foundations, then, have these reefs and islets of coral been constructed? A foundation must originally have been present beneath each atoll at that limited depth, which is indispensable for the first growth of the reef-building polypifers. A conjecture will perhaps be hazarded, that the requisite bases might have been afforded by the accumulation of great banks of sediment, which owing to the action of superficial currents (aided possibly by the undulatory movement of the sea) did not quite reach the surface,—as actually appears to have been the case in some parts of the West Indian Sea. But in the form and disposition of the groups of atolls, there is nothing to countenance this notion; and the assumption without any proof, that a number of immense piles of sediment have been heaped on the floor of the great Pacific and Indian Oceans, in their central parts far remote from land, and where the dark blue colour of the limpid water bespeaks its purity, cannot for one moment be admitted.

[2] See also Captain Owen's and Lieutenant Wood's papers in the *Geographical Journal*, on the Maldiva and Laccadive Archipelagoes. These officers particularly refer to the lowness of the islets; but I chiefly ground my assertion respecting these two

groups, and the Chagos group, from information communicated to me by Captain Moresby.

[3] I find from Mr. Couthouy's pamphlet (p. 58) that Aurora Island is about two hundred feet in height; it consists of coral-rock, and seems to have been formed by the elevation of an atoll. It lies north-east of Tahiti, close without the line bounding the space coloured dark blue in the map appended to this volume. Honden Island, which is situated in the extreme north-west part of the Low Archipelago, according to measurements made on board the *Beagle*, whilst sailing by, is 114 feet from the *summit of the trees* to the water's edge. This island appeared to resemble the other atolls of the group.

The many widely-scattered atolls must, therefore, rest on rocky bases. But we cannot believe that the broad summit of a mountain lies buried at the depth of a few fathoms beneath every atoll, and nevertheless throughout the immense areas above-named, with not one point of rock projecting above the level of the sea; for we may judge with some accuracy of mountains beneath the sea, by those on the land; and where can we find a single chain several hundred miles in length and of considerable breadth, much less several such chains, with their many broad summits attaining the same height, within from 120 to 180 feet? If the data be thought insufficient, on which I have grounded my belief, respecting the depth at which the reef-building polypifers can exist, and it be assumed that they can flourish at a depth of even one hundred fathoms, yet the weight of the above argument is but little diminished, for it is almost equally improbable, that as many submarine mountains, as there are low islands in the several great and widely separated areas above specified, should all rise within six hundred feet of the surface of the sea and not one above it, as that they should be of the same height within the smaller limit of one or two hundred feet. So highly improbable is this supposition, that we are compelled to believe, that the bases of the many atolls did never at any one period all lie submerged within the depth of a few fathoms beneath the surface, but that they were brought into the requisite position or level, some at one period and some at another, through movements in the earth's crust. But this could not have been effected by elevation, for the belief that points so numerous and so widely separated were successively uplifted to a certain level, but that not one point was raised above that level, is quite as improbable as the former supposition, and indeed differs little from it. It will probably occur to those who have read Ehrenberg's account of the Reefs of the Red Sea, that many points in these great areas may have been elevated, but that as soon as raised, the protuberant parts were cut off by the destroying action of the waves: a moment's reflection, however, on the basin-like form of the atolls, will show that this is impossible; for the upheaval and subsequent abrasion of an island would leave a flat disc, which might become coated with coral, but not a deeply concave surface; moreover, we should expect to see, in some parts at least, the rock of the foundation brought to the surface. If, then, the foundations of the many atolls were not uplifted into the requisite position, they must of necessity have subsided into it; and this at once solves every difficulty,[4] for we may safely infer, from the facts given in the last chapter, that during a gradual subsidence the corals would be favourably circumstanced for building up their solid frame works and reaching the surface, as island after island slowly disappeared. Thus areas of immense extent in the central and most profound parts of the great oceans, might become interspersed with coral-islets, none of which would rise to a greater height than that attained by detritus heaped up by the sea, and nevertheless they might all have been formed by corals, which absolutely required for their growth a solid foundation within a few fathoms of the surface.

[4] The additional difficulty on the crater hypothesis before alluded to, will now be evident; for on this view the volcanic action must be supposed to have formed within the areas specified a vast number of craters, all rising within a few fathoms of the surface, and not one above it. The supposition that the craters were at different times upraised above the surface, and were there abraded by the surf and subsequently coated by corals, is subject to nearly the same objections with those given above in this paragraph; but I consider it superfluous to detail all the arguments opposed to such a notion. Chamisso's theory, from assuming the existence of so many banks, all lying at the proper depth beneath the water, is also vitally defective. The same observation applies to an hypothesis of Lieutenant Nelson's ("Geolog. Trans." vol. v, p. 122), who supposes that the ring-formed structure is caused by a greater number of germs of corals becoming attached to the

declivity, than to the central plateau of a submarine bank: it likewise applies to the notion formerly entertained (Forster's "Observ.," p. 151), that lagoon-islands owe their peculiar form to the instinctive tendencies of the polypifers. According to this latter view, the corals on the outer margin of the reef instinctively expose themselves to the surf in order to afford protection to corals living in the lagoon, which belong to other genera, and to other families!

It would be out of place here to do more than allude to the many facts, showing that the supposition of a gradual subsidence over large areas is by no means improbable. We have the clearest proof that a movement of this kind is possible, in the upright trees buried under the strata many thousand feet in thickness; we have also every reason for believing that there are now large areas gradually sinking, in the same manner as others are rising. And when we consider how many parts of the surface of the globe have been elevated within recent geological periods, we must admit that there have been subsidences on a corresponding scale, for otherwise the whole globe would have swollen. It is very remarkable that Mr. Lyell,[5] even in the first edition of his "Principles of Geology," inferred that the amount of subsidence in the Pacific must have exceeded that of elevation, from the area of land being very small relatively to the agents there tending to form it, namely, the growth of coral and volcanic action. But it will be asked, are there any direct proofs of a subsiding movement in those areas, in which subsidence will explain a phenomenon otherwise inexplicable? This, however, can hardly be expected, for it must ever be most difficult, excepting in countries long civilised, to detect a movement, the tendency of which is to conceal the part affected. In barbarous and semi-civilised nations how long might not a slow movement, even of elevation such as that now affecting Scandinavia, have escaped attention!

[5] "Principles of Geology," sixth edition, vol. iii, p. 386.

Mr. Williams[6] insists strongly that the traditions of the natives, which he has taken much pains in collecting, do not indicate the appearance of any new islands: but on the theory of a gradual subsidence, all that would be apparent would be, the water sometimes encroaching slowly on the land, and the land again recovering by the accumulation of detritus its former extent, and perhaps sometimes the conversion of an atoll with coral islets on it, into a bare or into a sunken annular reef. Such changes would naturally take place at the periods when the sea rose above its usual limits, during a gale of more than ordinary strength; and the effects of the two causes would be hardly distinguishable. In Kotzebue's "Voyage" there are accounts of islands, both in the Caroline and Marshall Archipelagoes, which have been partly washed away during hurricanes; and Kadu, the native who was on board one of the Russian vessels, said "he saw the sea at Radack rise to the feet of the cocoa-nut trees; but it was conjured in time."[7] A storm lately entirely swept away two of the Caroline islands, and converted them into shoals; it partly, also, destroyed two other islands.[8] According to a tradition which was communicated to Captain Fitzroy, it is believed in the Low Archipelago, that the arrival of the first ship caused a great inundation, which destroyed many lives. Mr. Stutchbury relates, that in 1825, the western side of Chain Atoll, in the same group, was completely devastated by a hurricane, and not less than 300 lives lost: "in this instance it was evident, even to the natives, that the hurricane alone was not sufficient to account for the violent agitation of the ocean."[9] That considerable changes have taken place recently in some of the atolls in the Low Archipelago, appears certain from the case already given of Matilda Island: with respect to Whitsunday and Gloucester Islands in this same group, we must either attribute great inaccuracy to their discoverer, the famous circumnavigator Wallis, or believe that they have undergone a considerable change in the period of fifty-nine years, between his voyage and that of Captain Beechey's. Whitsunday Island is described by Wallis as "about four miles long, and three wide," now it is only one mile and a half long. The appearance of Gloucester Island, in Captain Beechey's words,[10] "has been accurately described by its discoverer, but its present form and extent differ materially." Blenheim reef, in the Chagos group, consists of a water-washed annular reef, thirteen miles in circumference, surrounding a lagoon ten fathoms deep: on its surface there were a few worn patches of conglomerate coral-rock, of about the size of hovels; and these Captain Moresby considered as being, without doubt, the last remnants of islets; so that here an atoll has been converted into an atoll-formed reef. The inhabitants of the Maldiva Archipelago, as long ago as 1605, declared, "that the high tides and violent currents were diminishing the number of the islands:"[11] and I have already shown, on the authority of Captain Moresby, that the work of destruction is still in progress; but that on the other hand the first formation of some islets is known to the present inhabitants. In such cases, it would be exceedingly difficult to detect a gradual subsidence of the foundation, on which these mutable structures rest.

[6] Williams's "Narrative of Missionary Enterprise," p. 31.

[7] Kotzebue's "First Voyage," vol. iii, p. 168.

[8] M. Desmoulins in "Comptes Rendus," 1840, p. 837.

[9] *West of England Journal*, No. I, p. 35.

[10] Beechey's "Voyage to the Pacific," chap. vii, and Wallis's "Voyage in the *Dolphin*," chap. iv.

[11] See an extract from Pyrard's Voyage in Captain Owen's paper on the Maldiva Archipelago, in the *Geographical Journal*, vol. ii, p. 84.

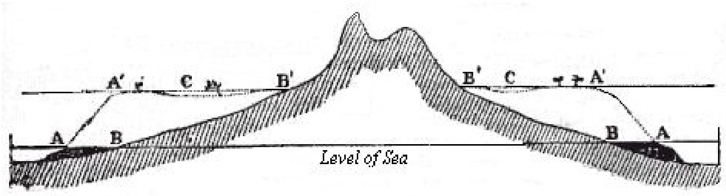
Some of the archipelagoes of low coral-islands are subject to earthquakes: Captain Moresby informs me that they are frequent, though not very strong, in the Chagos group, which occupies a very central position in the Indian Ocean, and is far from any land not of coral formation. One of the islands in this group was formerly covered by a bed of mould, which, after an earthquake, disappeared, and was believed by the residents to have been washed by the rain through the broken masses of underlying rock; the island was thus rendered unproductive. Chamisso[12] states, that earthquakes are felt in the Marshall atolls, which are far from any high land, and likewise in the islands of the Caroline Archipelago. On one of the latter, namely Oulleay atoll, Admiral Lutké, as he had the kindness to inform me, observed several straight fissures about a foot in width, running for some hundred yards obliquely across the whole width of the reef. Fissures indicate a stretching of the earth's crust, and, therefore, probably changes in its level; but these coral-islands, which have been shaken and fissured, certainly have not been elevated, and, therefore, probably they have subsided. In the chapter on Keeling atoll, I attempted to show by direct evidence, that the island underwent a movement of subsidence, during the earthquakes lately felt there.

[12] See Chamisso, in Kotzebue's "First Voyage," vol. iii, p. 182 and 136.

The facts stand thus;—there are many large tracts of ocean, without any high land, interspersed with reefs and islets, formed by the growth of those kinds of corals, which cannot live at great depths; and the existence of these reefs and low islets, in such numbers and at such distant points, is quite inexplicable, excepting on the theory, that the bases on which the reefs first became attached, slowly and successively sank beneath the level of the sea, whilst the corals continued to grow upwards. No positive facts are opposed to this view, and some general considerations render it probable. There is evidence of change in form, whether or not from subsidence, on some of these coral-islands; and there is evidence of subterranean disturbances beneath them. Will then the theory, to which we have thus been led, solve the curious problem,—what has given to each class of reef its peculiar form?

Let us in imagination place within one of the subsiding areas, an island surrounded by a "fringing-reef,"—that kind, which alone offers no difficulty in the explanation of its origin. Let the unbroken lines, and the oblique shading in the woodcut (No. 4) represent a vertical section through such an island; and the horizontal shading will represent the section of the reef. Now, as the island sinks down, either a few feet at a time or quite insensibly, we may safely infer from what we know of the conditions favourable to the growth of coral, that the living masses bathed by the surf on the margin of the reef, will soon regain the surface. The water, however, will encroach, little by little, on the shore, the island becoming lower and smaller, and the space between the edge of the reef and the beach proportionately broader. A section of the reef and island in this state, after a subsidence of several hundred feet, is given by the dotted lines: coral-islets are supposed to have been formed on the new reef, and a ship is anchored in the lagoon-channel. This section is in every respect that of an encircling barrier-reef; it is, in fact, a section taken[13] east and west through the highest point of the encircled island of Bolabola; of which a plan is given in Plate I, Fig. 5. The same section is more clearly shown in the following woodcut (No. 5) by the unbroken lines. The width of the reef, and its slope, both on the outer and inner side, will have been determined by the growing powers of the coral, under the conditions (for instance the force of the breakers and of the currents) to which it has been exposed; and the lagoon-channel will be deeper or shallower, in proportion to the growth of the delicately branched corals within the reef, and to the accumulation of sediment, relatively, also, to the rate of subsidence and the length of the intervening stationary periods.

[13] The section has been made from the chart given in the "Atlas of the Voyage of the *Coquille*." The scale is .57 of an inch to a mile. The height of the island, according to M. Lesson, is 4,026 feet. The deepest part of the lagoon-channel is 162 feet; its depth is exaggerated in the woodcut for the sake of clearness.



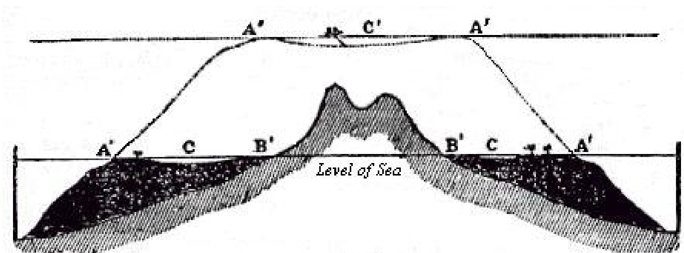
No. 4

AA—Outer edge of the reef at the level of the sea.
BB—Shores of the island.
A′A′—Outer edge of the reef, after its upward growth during a period of subsidence.
CC—The lagoon-channel between the reef and the shores of the now encircled land.
B′B′—The shores of the encircled island.

N.B.—In this, and the following woodcut, the subsidence of the land could only be represented by an apparent rise in the level of the sea.

It is evident in this section, that a line drawn perpendicularly down from the outer edge of the new reef to the foundation of solid rock, exceeds by as many feet as there have been feet of subsidence, that small limit of depth at which the effective polypifers can live—the corals having grown up, as the whole sank down, from a basis formed of other corals and their consolidated fragments. Thus the difficulty on this head, which before seemed so great, disappears.

As the space between the reef and the subsiding shore continued to increase in breadth and depth, and as the injurious effects of the sediment and fresh water borne down from the land were consequently lessened, the greater number of the channels, with which the reef in its fringing state must have been breached, especially those which fronted the smaller streams, will have become choked up with the growth of coral: on the windward side of the reef, where the coral grows most vigorously, the breaches will probably have first been closed. In barrier-reefs, therefore, the breaches kept open by draining the tidal waters of the lagoon-channel, will generally be placed on the leeward side, and they will still face the mouths of the larger streams, although removed beyond the influence of their sediment and fresh water;—and this, it has been shown, is commonly the case.



No. 5

A′A′—Outer edges of the barrier-reef at the level of the sea. The cocoa-nut trees represent coral-islets formed on the reef.
CC—The lagoon-channel.
B′B′—The shores of the island, generally formed of low alluvial land and of coral detritus from the lagoon-channel.
A″A″—The outer edges of the reef now forming an atoll.
C′—The lagoon of the newly formed atoll. According to the scale, the depth of the lagoon and of the lagoon-channel is

exaggerated.

Referring to the diagram shown above, in which the newly formed barrier-reef is represented by unbroken lines, instead of by dots as in the former woodcut, let the work of subsidence go on, and the doubly pointed hill will form two small islands (or more, according to the number of the hills) included within one annular reef. Let the island continue subsiding, and the coral-reef will continue growing up on its own foundation, whilst the water gains inch by inch on the land, until the last and highest pinnacle is covered, and there remains a perfect atoll. A vertical section of this atoll is shown in the woodcut by the dotted lines;—a ship is anchored in its lagoon, but islets are not supposed yet to have been formed on the reef. The depth of the lagoon and the width and slope of the reef, will depend on the circumstances just referred to under barrier-reefs. Any further subsidence will produce no change in the atoll, except perhaps a diminution in its size, from the reef not growing vertically upwards; but should the currents of the sea act violently upon it, and should the corals perish on part or on the whole of its margin, changes would result during subsidence which will be presently noticed. I may here observe, that a bank either of rock or of hardened sediment, level with the surface of the sea, and fringed with living coral, would (if not so small as to allow the central space to be quickly filled up with detritus) by subsidence be converted immediately into an atoll, without passing, as in the case of a reef fringing the shore of an island, through the intermediate form of a barrier-reef. If such a bank lay a few fathoms submerged, the simple growth of the coral (as remarked in the third chapter) without the aid of subsidence, would produce a structure scarcely to be distinguished from a true atoll; for in all cases the corals on the outer margin of a reef, from having space and being freely exposed to the open sea, will grow vigorously and tend to form a continuous ring whilst the growth of the less massive kinds on the central expanse, will be checked by the sediment formed there, and by that washed inwards by the breakers; and as the space becomes shallower, their growth will, also, be checked by the impurities of the water, and probably by the small amount of food brought by the enfeebled currents, in proportion to the surface of living reefs studded with innumerable craving mouths: the subsidence of a reef based on a bank of this kind, would give depth to its central expanse or lagoon, steepness to its flanks, and through the free growth of the coral, symmetry to its outline:—I may here repeat that the larger groups of atolls in the Pacific and Indian Oceans cannot be supposed to be founded on banks of this nature.

If, instead of the island in the diagram, the shore of a continent fringed by a reef had subsided, a great barrier-reef, like that on the north-east coast of Australia, would have necessarily resulted; and it would have been separated from the main land by a deep-water channel, broad in proportion to the amount of subsidence, and to the less or greater inclination of the neighbouring coast-line. The effect of the continued subsidence of a great barrier-reef of this kind, and its probable conversion into a chain of separate atolls, will be noticed, when we discuss the apparent progressive disseverment of the larger Maldiva atolls.

We now are able to perceive that the close similarity in form, dimensions, structure, and relative position (which latter point will hereafter be more fully noticed) between fringing and encircling barrier-reefs, and between these latter and atolls, is the necessary result of the transformation, during subsidence of the one class into the other. On this view, the three classes of reefs ought to graduate into each other. Reefs having intermediate character between those of the fringing and barrier classes do exist; for instance, on the south-west coast of Madagascar, a reef extends for several miles, within which there is a broad channel from seven to eight fathoms deep, but the sea does not deepen abruptly outside the reef. Such cases, however, are open to some doubts, for an old fringing-reef, which had extended itself a little on a basis of its own formation, would hardly be distinguishable from a barrier-reef, produced by a small amount of subsidence, and with its lagoon-channel nearly filled up with sediment during a long stationary period. Between barrier-reefs, encircling either one lofty island or several small low ones, and atolls including a mere expanse of water, a striking series can be shown: in proof of this, I need only refer to the first plate in this volume, which speaks more plainly to the eye, than any description could to the ear. The authorities from which the charts have been engraved, together with some remarks on them and descriptive of the plates, are given above. At New Caledonia (Plate II, Fig. 5.) the barrier-reefs extend for 150 miles on each side of the submarine prolongation of the island; and at their northern extremity they appear broken up and converted into a vast atoll-formed reef, supporting a few low coral-islets: we may imagine that we here see the effects of subsidence actually in progress, the water always encroaching on the northern end of the island, towards which the mountains slope down, and the reefs steadily building up their massive fabrics in the lines of their ancient growth.

We have as yet only considered the origin of barrier-reefs and atolls in their simplest form; but there remain some peculiarities in structure and some special cases, described in the two first chapters, to be accounted for by our theory. These consist—in the inclined ledge terminated by a wall, and sometimes succeeded by a second ledge with a wall, round the shores of certain lagoons and lagoon-channels; a structure which cannot, as I endeavoured to show, be explained by the simple growing powers of the corals,—in the ring or basin-like forms of the central reefs, as well as of the separate marginal portions of the northern Maldiva atolls,—in the submerged condition of the whole, or of parts of certain barrier and atoll-formed reefs; where only a part is submerged, this being generally to leeward,—in the apparent progressive disseverment of some of the Maldiva atolls,—in the existence of irregularly formed atolls, some being tied together by linear reefs, and others with spurs projecting from them,—and, lastly, in the structure and origin of the Great Chagos Bank.

Step-formed ledges round certain lagoons.—If we suppose an atoll to subside at an extremely slow rate, it is difficult to follow out the complex results. The living corals would grow up on the outer margin; and likewise probably in the gullies and deeper parts of the bare surface of the annular reef; the water would encroach on the islets, but the accumulation of fresh detritus might possibly prevent their entire submergence. After a subsidence of this very slow nature, the surface of the annular reef sloping gently into the lagoon, would probably become united with the irregular reefs and banks of sand, which line the shores of most lagoons. Should, however, the atoll be carried down by a more rapid movement, the whole surface of the annular reef, where there was a foundation of solid matter, would be favourably circumstanced for the fresh growth of coral; but as the corals grew upwards on its exterior margin, and the waves broke heavily on this part, the increase of the massive polypifers on the inner side would be checked from the want of water. Consequently, the exterior parts would first reach the surface, and the new annular reef thus formed on the old one, would have its summit inclined inwards, and be terminated by a subaqueous wall, formed by the upward growth of the coral (before being much checked), from the inner edge of the solid parts of the old reef. The inner portion of the new reef, from not having grown to the surface, would be covered by the waters of the lagoon. Should a subsidence of the same kind be repeated, the corals would again grow up in a wall, from all the solid parts of the resunken reef, and, therefore, not from within the sandy shores of the lagoon; and the inner part of the new annular reef would, from being as before checked in its upward growth, be of less height than the exterior parts, and therefore would not reach the surface of the lagoon. In this case the shores of the lagoon would be surrounded by two inclined ledges, one beneath the other, and both abruptly terminated by subaqueous cliffs.[14]

[14] According to Mr. Couthouy (p. 26) the external reef round many atolls descends by a succession of ledges or terraces. He attempts, I doubt whether successfully, to explain this structure somewhat in the same manner as I have attempted, with respect to the internal ledges round the lagoons of some atolls. More facts are wanted regarding the nature both of the interior and exterior step-like ledges: are all the ledges, or only the upper ones, covered with living coral? If they are all covered, are the kinds different on the ledges according to the depth? Do the interior and exterior ledges occur together in the same atolls; if so, what is their total width, and is the intervening surface-reef narrow, etc.?

The ring or basin-formed reefs of the northern Maldiva atolls.—I may first observe, that the reefs within the lagoons of atolls and within lagoon-channels, would, if favourably circumstanced, grow upwards during subsidence in the same manner as the annular rim; and, therefore, we might expect that such lagoon- reefs, when not surrounded and buried by an accumulation of sediment more rapid than the rate of subsidence, would rise abruptly from a greater depth than that at which the efficient polypifers can flourish: we see this well exemplified in the small abruptly-sided reefs, with which the deep lagoons of the Chagos and Southern Maldiva atolls are studded. With respect to the ring or basin-formed reefs of the Northern Maldiva atolls, it is evident, from the perfectly continuous series which exists that the marginal rings, although wider than the exterior or bounding reef of ordinary atolls, are only modified portions of such a reef; it is also evident that the central rings, although wider than the knolls or reefs which commonly occur in lagoons, occupy their place. The ring-like structure has been shown to be contingent on the breaches into the lagoon being broad and numerous, so that all the reefs which are bathed by the waters of the lagoon are placed under nearly the same conditions with the outer coast of an atoll standing in the open sea. Hence the exterior and living margins of these reefs must have been favourably circumstanced for growing outwards, and increasing beyond the usual breadth; and they must likewise have been favourably circumstanced for growing vigorously upwards, during the subsiding movements, to which by our theory the whole archipelago has been subjected; and subsidence with this upward growth of the margins would convert the central space of each little reef into a small lagoon. This, however, could only take place with those reefs, which had increased to a breadth sufficient to prevent their central spaces from being almost immediately filled up with the sand and detritus driven inwards from all sides: hence it is that few reefs, which are less than half a mile in diameter, even in the atolls where the basin-like structure is most strikingly exhibited, include lagoons. This remark, I may add, applies to all coral-reefs wherever found. The basin-formed reefs of the Maldiva Archipelago may, in fact, be briefly described, as small atolls formed during subsidence over the separate portions of large and broken atolls, in the same manner as these latter were formed over the barrier-reefs, which encircled the islands of a large archipelago now wholly submerged.

Submerged and dead reefs.—In the second section of the first chapter, I have shown that there are in the neighbourhood of atolls, some deeply submerged banks, with level surfaces; that there are others, less deeply but yet wholly submerged, having all the characters of perfect atolls, but consisting merely of dead coral-rock; that there are barrier-reefs and atolls with merely a portion of their reef, generally on the leeward side, submerged; and that such portions either retain their perfect outline, or they appear to be quite effaced, their former place being marked only by a bank, conforming in outline with that part of the reef which remains perfect. These several cases are, I believe, intimately related together, and can be explained by the same means. There, perhaps, exist some submerged reefs, covered with living coral and growing upwards, but to these I do not here refer. As we see that in those parts of the ocean, where coral-reefs are most abundant, one island is fringed and another neighbouring one is not fringed; as we see in the same archipelago, that all the reefs are more perfect in one part of it than in another, for instance, in the southern half compared with the northern half of the Maldiva Archipelago, and likewise on the outer coasts compared with the inner coasts of the atolls in this same group, which are placed in a double row; as we know that the existence of the innumerable polypifers forming a reef, depends on their sustenance, and that they are preyed on by other organic beings; and, lastly, as we know that some inorganic causes are highly injurious to the growth of coral, it cannot be expected that during the round of change to which earth, air, and water are exposed, the reef-building polypifers should keep alive for perpetuity in any one place; and still less can this be expected, during the progressive subsidences, perhaps at some periods more rapid than at others, to which by our theory these reefs and islands have been subjected and are liable. It is, then, not improbable that the corals should sometimes perish either on the whole or on part of a reef; if on part, the dead portion, after a small amount of subsidence, would still retain its proper outline and position beneath the water. After a more prolonged subsidence, it would probably form, owing to the accumulation of sediment, only the margin of a flat bank, marking the limits of the former lagoon. Such dead portions of reef would generally lie on the leeward side,[15] for the impure water and fine sediment would more easily flow out from the lagoon over this side of the reef, where the force of the breakers is less than to windward; and therefore the corals would be less vigorous on this side, and be less able to resist any destroying agent. It is likewise owing to this same cause, that reefs are more frequently breached to leeward by narrow channels, serving as by ship-channels, than to windward. If the corals perished entirely, or on the greater part of the circumference of an atoll, an atoll-shaped bank of dead rock, more or less entirely submerged, would be produced; and further subsidence, together with the accumulation of sediment, would often obliterate its atoll-like structure, and leave only a bank with a level surface.

[15] Mr. Lyell, in the first edition of his "Principles of Geology,"

offered a somewhat different explanation of this structure. He supposes that there has been subsidence; but he was not aware that the submerged portions of reef were in most cases, if not in all, dead; and he attributes the difference in height in the two sides of most atolls, chiefly to the greater accumulation of detritus to windward than to leeward. But as matter is accumulated only on the backward part of the reef, the front part would remain of the same height on both sides. I may here observe that in most cases (for instance, at Peros Banhos, the Gambier group and the Great Chagos Bank), and I suspect in all cases, the dead and submerged portions do not blend or slope into the living and perfect parts, but are separated from them by an abrupt line. In some instances small patches of living reef rise to the surface from the middle of the submerged and dead parts.

In the Chagos group of atolls, within an area of 160 miles by 60, there are two atoll-formed banks of dead rock (besides another very imperfect one), entirely submerged; a third, with merely two or three very small pieces of living reef rising to the surface; and a fourth, namely, Peros Banhos (Plate I, Fig. 9), with a portion nine miles in length dead and submerged. As by our theory this area has subsided, and as there is nothing improbable in the death, either from changes in the state of the surrounding sea or from the subsidence being great or sudden, of the corals on the whole, or on portions of some of the atolls, the case of the Chagos group presents no difficulty. So far indeed are any of the above-mentioned cases of submerged reefs from being inexplicable, that their occurrence might have been anticipated on our theory, and as fresh atolls are supposed to be in progressive formation by the subsidence of encircling barrier-reefs, a weighty objection, namely that the number of atolls must be increasing infinitely, might even have been raised, if proofs of the occasional destruction and loss of atolls could not have been adduced.

The disseverment of the larger Maldiva atolls.—The apparent progressive disseverment in the Maldiva Archipelago of large atolls into smaller ones, is, in many respects, an important consideration, and requires an explanation. The graduated series which marks, as I believe, this process, can be observed only in the northern half of the group, where the atolls have exceedingly imperfect margins, consisting of detached basin-formed reefs. The currents of the sea flow across these atolls, as I am informed by Captain Moresby, with considerable force, and drift the sediment from side to side during the monsoons, transporting much of it seaward; yet the currents sweep with greater force round their flanks. It is historically known that these atolls have long existed in their present state; and we can believe, that even during a very slow subsidence they might thus remain, the central expanse being kept at nearly its original depth by the accumulation of sediment. But in the action of such nicely balanced forces during a progressive subsidence (like that, to which by our theory this archipelago has been subjected), it would be strange if the currents of the sea should never make a direct passage across some one of the atolls, through the many wide breaches in their margins. If this were once effected, a deep-water channel would soon be formed by the removal of the finer sediment, and the check to its further accumulation; and the sides of the channel would be worn into a slope like that on the outer coasts, which are exposed to the same force of the currents. In fact, a channel precisely like that bifurcating one which divides Mahlos Mahdoo (Plate II, Fig. 4), would almost necessarily be formed. The scattered reefs situated near the borders of the new ocean-channel, from being favourably placed for the growth of coral, would, by their extension, tend to produce fresh margins to the dissevered portions; such a tendency is very evident (as may be seen in the large published chart) in the elongated reefs on the borders of the two channels intersecting Mahlos Mahdoo. Such channels would become deeper with continued subsidence, and probably from the reefs not growing up perpendicularly, somewhat broader. In this case, and more especially if the channels had been formed originally of considerable breadth, the dissevered portions would become perfect and distinct atolls, like Ari and Ross atolls (Plate II, Fig. 6), or like the two Nillandoo atolls, which must be considered as distinct, although related in form and position, and separated from each other by channels, which though deep have been sounded. Further subsidence would render such channels unfathomable, and the dissevered portions would then resemble Phaleedoo and Moluque atolls, or Mahlos Mahdoo and Horsburgh atolls (Plate II, Fig. 4), which are related to each other in no respect except in proximity and position. Hence, on the theory of subsidence, the disseverment of large atolls, which have imperfect margins (for otherwise their disseverment would be scarcely possible), and which are exposed to strong currents, is far from being an improbable event; and the several stages, from close relation to entire isolation in the atolls of the Maldiva Archipelago, are readily explicable.

We might go even further, and assert as not improbable, that the first formation of the Maldiva Archipelago was due to a barrier-reef, of nearly the same dimensions with that of New Caledonia (Plate II, Fig. 5), for if, in imagination, we complete the subsidence of that great island, we might anticipate from the present broken condition of the northern portion of the reef, and from the almost entire absence of reefs on the eastern coast, that the barrier-reef after repeated subsidences, would become during its upward growth separated into distinct portions; and these portions would tend to assume an atoll-like structure, from the coral growing with vigour round their entire circumferences, when freely exposed to an open sea. As we have some large islands partly submerged with barrier-reefs marking their former limits, such as New Caledonia, so our theory makes it probable that there should be other large islands wholly submerged; and these, we may now infer, would be surmounted, not by one enormous atoll, but by several large elongated ones, like the atolls in the Maldiva group; and these again, during long periods of subsidence, would sometimes become dissevered into smaller atolls. I may add, that both in the Marshall and Caroline Archipelagoes, there are atolls standing close together, which have an evident relationship in form: we may suppose, in such cases, either that two or more encircled islands originally stood close together, and afforded bases for two or more atolls, or that one atoll has been dissevered. From the position, as well as form, of three atolls in the Caroline Archipelago (the Namourrek and Elato group), which are placed in an irregular circle, I am strongly tempted to believe that they have originated by the process of disseverment.[16]

[16] The same remark is, perhaps, applicable to the islands of Ollap, Fanadik, and Tamatam in the Caroline Archipelago, of which charts are given in the atlas of Duperrey's voyage: a line drawn through the linear reefs and lagoons of these three islands forms a semicircle. Consult also, the atlas of Lutké's voyage; and for the Marshall group that of Kotzebue; for the Gilbert group consult the atlas of Duperrey's voyage. Most of the points here referred to may, however, be seen in Krusenstern's general Atlas of the Pacific.

Irregularly formed atolls.—In the Marshall group, Musquillo atoll consists of two loops united in one point; and Menchikoff atoll is formed of three loops, two of which (as may be seen in Fig. 3, Plate II) are connected by a mere ribbon-shaped reef, and the three together are sixty miles in length. In the Gilbert group some of the atolls have narrow strips of reef, like spurs, projecting from them. There occur also in parts of the open sea, a few linear and straight reefs, standing by themselves; and likewise some few reefs in the form of crescents, with their extremities more or less curled inwards. Now, the upward growth of a barrier-reef which fronted only one side of an island, or one side of an elongated island with its extremities (of which cases exist), would produce after the complete subsidence of the land, mere strips or crescent or hook-formed reefs: if the island thus partially fronted became divided during subsidence into two or more islands, these islands would be united together by linear reefs; and from the further growth of the coral along their shores together with subsidence, reefs of various forms might ultimately be produced, either atolls united together by linear reefs, or atolls with spurs projecting from them. Some, however, of the more simple forms above specified, might, as we have seen, be equally well produced by the coral perishing during subsidence on part of the circumference of an atoll, whilst on the other parts it continued to grow up till it reached the surface.

The Great Chagos Bank.—I have already shown that the submerged condition of the Great Chagos Bank (Plate II, Fig. 1, with its section Fig. 2), and of some other banks in the Chagos group, may in all probability be attributed to the coral having perished before or during the movements of subsidence, to which this whole area by our theory has been subjected. The external rim or upper ledge (shaded in the chart), consists of dead coral-rock thinly covered with sand; it lies at an average depth of between five and eight fathoms, and perfectly resembles in form the annular reef of an atoll. The banks of the second level, the boundaries of which are marked by dotted lines in the chart, lie from about fifteen to twenty fathoms beneath the surface; they are several miles broad, and terminate in a very steep slope round the central expanse. This central expanse I have already described, as consisting of a level muddy flat between thirty and forty fathoms deep. The banks of the second level, might at first sight be thought analogous to the internal step-like ledge of coral-rock which borders the lagoons of some atolls, but their much greater width, and their being formed of sand, are points of essential difference. On the eastern side of the atoll some of the banks are linear and parallel, resembling islets in a great river, and pointed directly towards a great breach on the opposite side of the atoll; these are best seen in the large published chart. I inferred from this circumstance, that strong currents sometimes set directly across this vast bank; and I have since heard from Captain Moresby that this is the case. I observed, also, that the channels or breaches through the rim, were all of the same depth as the central lagoon-like space into which they lead; whereas the channels into the other atolls of the Chagos group, and as I believe into most other large atolls, are not nearly as deep as their lagoons: for instance at Peros Banhos, the channels are only of the same depth, namely between ten and twenty fathoms, as the bottom of the lagoon for a space about a mile and a half in width round its shores, whilst the central expanse of the lagoon is from thirty-five to forty fathoms deep. Now, if an atoll during a gradual subsidence once became entirely submerged, like the Great Chagos Bank, and therefore no longer exposed to the surf, very little sediment could be formed from it; and consequently the channels leading into the lagoon from not being filled up with drifted sand and coral detritus, would continue increasing in depth, as the whole sank down. In this case, we might expect that the currents of the open sea, instead of any longer sweeping round the submarine flanks, would flow directly through the breaches across the lagoon, removing in their course the finer sediment, and preventing its further accumulation. We should then have the submerged reef forming an external and upper rim of rock, and beneath this portion of the sandy bottom of the old lagoon, intersected by deep-water channels or breaches, and thus formed into separate marginal banks; and these would be cut off by steep slopes, overhanging the central space, worn down by the passage of the oceanic currents.

By these means, I have scarcely any doubt that the Great Chagos Bank has originated,—a structure which at first appeared to me far more anomalous than any I had met with. The process of formation is nearly the same with that, by which Mahlos Mahdoo had been trisected; but in the Chagos Bank the channels of the oceanic currents entering at several different quarters, have united in a central space.

This great atoll-formed bank appears to be in an early stage of disseverment; should the work of subsidence go on, from the submerged and dead condition of the whole reef, and the imperfection of the south-east quarter a mere wreck would probably be left. The Pitt’s Bank, situated not far southward, appears to be precisely in this state; it consists of a moderately level, oblong bank of sand, lying from 10 to 20 fathoms beneath the surface, with two sides protected by a narrow ledge of rock which is submerged between 5 and 8 fathoms. A little further south, at about the same distance as the southern rim of the Great Chagos Bank is from the northern rim, there are two other small banks with from 10 to 20 fathoms on them; and not far eastward soundings were struck on a sandy bottom, with between 110 and 145 fathoms. The northern portion with its ledge-like margin, closely resembles any one segment of the Great Chagos Bank, between two of the deep-water channels, and the scattered banks, southward appear to be the last wrecks of less perfect portions.

I have examined with care the charts of the Indian and Pacific Oceans, and have now brought before the reader all the examples, which I have met with, of reefs differing from the type of the class to which they belong; and I think it has been satisfactorily shown, that they are all included in our theory, modified by occasional accidents which might have been anticipated as probable. In this course we have seen, that in the lapse of ages encircling barrier-reefs are occasionally converted into atolls, the name of atoll being properly applicable, at the moment when the last pinnacle of encircled land sinks beneath the surface of the sea. We have, also, seen that large atolls during the progressive subsidence of the areas in which they stand, sometimes become dissevered into smaller ones; at other times, the reef-building polypifers having entirely perished, atolls are converted into atoll-formed banks of dead rock; and these again through further subsidence and the accumulation of sediment modified by the force of the oceanic currents, pass into level banks with scarcely any distinguishing character. Thus may the history of an atoll be followed from its first origin, through the occasional accidents of its existence, to its destruction and final obliteration.

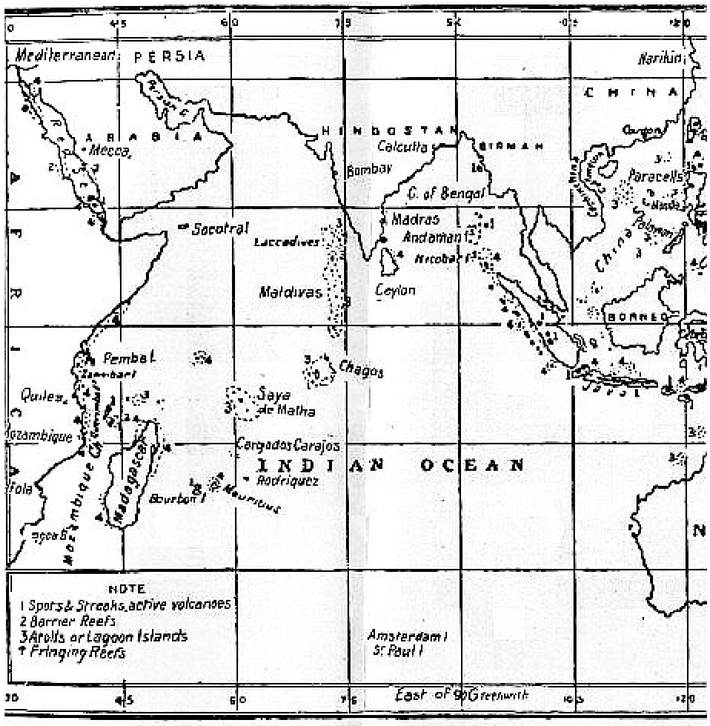
Objections to the theory of the formation of atolls and barrier-reefs.— The vast amount of subsidence, both horizontally or in area, and vertically or in depth, necessary to have submerged every mountain, even the highest, throughout the immense spaces of ocean interspersed with atolls, will probably strike most people as a formidable objection to my theory. But as continents, as large as the spaces supposed to have subsided, have been raised above the level of the sea,—as whole regions are now rising, for instance, in Scandinavia and South America,—and as no reason can be assigned, why subsidences should not have occurred in some parts of the earth's crust on as great a scale both in extent and amount as those of elevation, objections of this nature strike me as of little force. The remarkable point is that movements to such an extent should have taken place within a period, during which the polypifers have continued adding matter on and above the same reefs. Another and less obvious objection to the theory will perhaps be advanced from the circumstance, of the lagoons within atolls and within barrier-reefs never having become in any one instance during prolonged subsidences of a greater depth than sixty fathoms, and seldom more than forty fathoms; but we already admit, if the theory be worth considering, that the rate of subsidence has not exceeded that of the upward growth of the coral on the exterior margin; we are, therefore, only further required to admit, that the subsidence has not exceeded in rate the filling up of the interior spaces by the growth of the corals living there, and by the accumulation of sediment. As this filling up must take place very slowly within barrier-reefs lying far from the land, and within atolls which are of large dimensions and which have open lagoons with very few reefs, we are led to conclude that the subsidence thus counter-balanced, must have been slow in an extraordinary degree; a conclusion which accords with our only means, namely, with what is known of the rate and manner of recent elevatory movements, of judging by analogy what is the probable rate of subsidence.

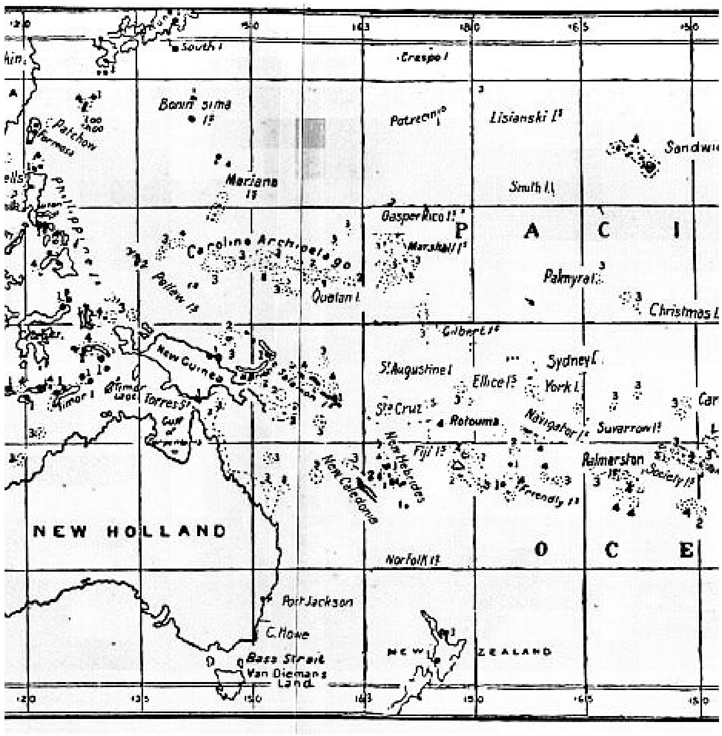
In this chapter it has, I think, been shown, that the theory of subsidence, which we were compelled to receive from the necessity of giving to the corals, in certain large areas, foundations at the requisite depth, explains both the normal structure and the less regular forms of those two great classes of reefs, which have justly excited the astonishment of all persons who have sailed through the Pacific and Indian Oceans. But further to test the truth of the theory, a crowd of questions will occur to the reader: Do the different kinds of reefs, which have been produced by the same kind of movement, generally lie within the same areas? What is their relation of form and position,—for instance, do adjoining groups of atolls, and the separate atolls in these groups, bear the same relation to each other which islands do in common archipelagoes? Have we reason to believe, that where there are fringing-reefs, there has not lately been subsidence; or, for it is almost our only way of ascertaining this point, are there frequently proofs of recent elevation? Can we by this means account for the presence of certain classes of reefs in some large areas, and their entire absence in others? Do the areas which have subsided, as indicated by the presence of atolls and barrier-reefs, and the areas which have remained stationary or have been upraised, as shown by fringing-reefs, bear any determinate relation to each other; and are the dimensions of these areas such as harmonise with the greatness of the subterranean changes, which, it must be supposed, have lately taken place beneath them? Is there any connection between the movements thus indicated, and recent volcanic action? All these questions ought to receive answers in accordance with the theory; and if this can be satisfactorily shown, not only is the theory confirmed, but as deductions, the answers are in themselves important. Under this latter point of view, these questions will be chiefly considered in the following chapter.[17]

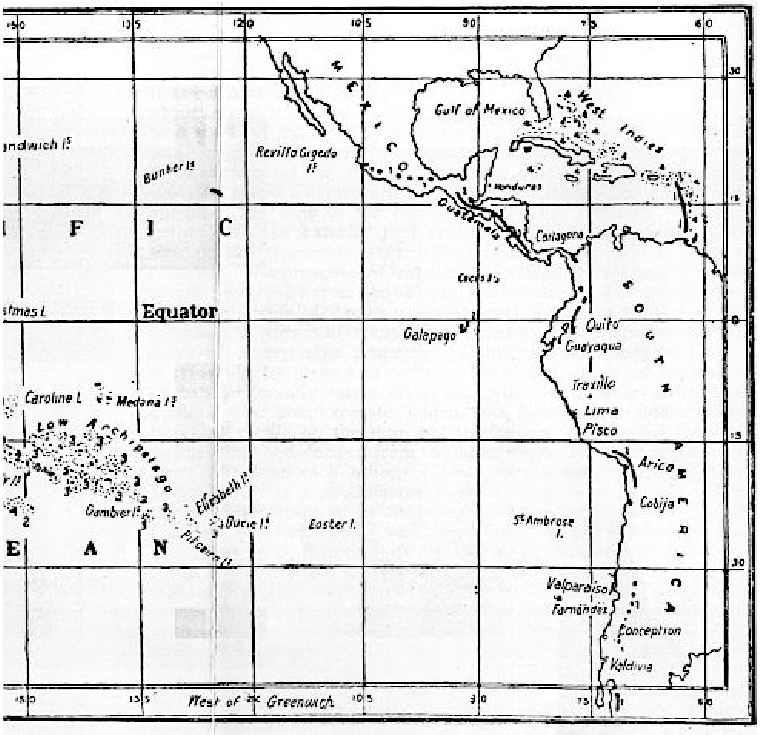
[17] I may take this opportunity of briefly considering the appearances, which would probably be presented by a vertical and deep section across a coral formation (referring chiefly to an atoll), formed by the upward growth of coral during successive subsidences. This is a subject worthy of attention, as a means of comparison with ancient coral-strata. The circumferential parts would consist of massive species, in a vertical position, with their interstices filled up with detritus; but this would be the part most subject to subsequent denudation and removal. It is useless to speculate how large a portion of the exterior annular reef would consist of upright coral, and how much of fragmentary rock, for this would depend on many contingencies,—such as on the rate of subsidence, occasionally allowing a fresh growth of coral to cover the whole surface, and on the breakers having force sufficient to throw fragments over this same space. The conglomerate which composes the base of the islets, would (if not removed by denudation together with the exterior reef on which it rests) be

conspicuous from the size of the fragments,—the different degrees in which they have been rounded,—the presence of fragments of conglomerate torn up, rounded, and recemented,—and from the oblique stratification. The corals which lived in the lagoon-reefs at each successive level, would be preserved upright, and they would consist of many kinds, generally much branched. In this part, however, a very large proportion of the rock (and in some cases nearly all of it) would be formed of sedimentary matter, either in an excessively fine, or in a moderately coarse state, and with the particles almost blended together. The conglomerate which was formed of rounded pieces of the branched corals, on the shores of the lagoon, would differ from that formed on the islets and derived from the outer coast; yet both might have accumulated very near each other. I have seen a conglomerate limestone from Devonshire like a conglomerate now forming on the shores of the Maldiva atolls. The stratification taken as a whole, would be horizontal; but the conglomerate beds resting on the exterior reef, and the beds of sandstone on the shores of the lagoon (and no doubt on the external flanks) would probably be divided (as at Keeling atoll and at Mauritius) by numerous layers dipping at considerable angles in different directions. The calcareous sandstone and coral-rock would almost necessarily contain innumerable shells, echini, and the bones of fish, turtle, and perhaps of birds; possibly, also, the bones of small saurians, as these animals find their way to the islands far remote from any continent. The large shells of some species of Tridacna would be found vertically imbedded in the solid rock, in the position in which they lived. We might expect also to find a mixture of the remains of pelagic and littoral animals in the strata formed in the lagoon, for pumice and the seeds of plants are floated from distant countries into the lagoons of many atolls: on the outer coast of Keeling atoll, near the mouth of the lagoon, the case of a pelagic Pteropodous animal was brought up on the arming of the sounding lead. All the loose blocks of coral on Keeling atoll were burrowed by vermiform animals; and as every cavity, no doubt, ultimately becomes filled with spathose limestone, slabs of the rock taken from a considerable depth, would, if polished, probably exhibit the excavations of such burrowing animals. The conglomerate and fine-grained beds of coral-rock would be hard, sonorous, white and composed of nearly pure calcareous matter; in some few parts, judging from the specimens at Keeling atoll, they would probably contain a small quantity of iron. Floating pumice and scoriæ, and occasionally stones transported in the root of trees (see my "Journal of Researches," page 549) appear the only sources, through which foreign matter is brought to coral-formations standing in the open ocean. The area over which sediment is transported from coral-reefs must be considerable: Captain Moresby informs me that during the change of monsoons the sea is discoloured to a considerable distance off the Maldiva and Chagos atolls. The sediment of fringing and barrier coral-reefs must be mingled with the mud, which is brought down from the land, and is transported seaward through the breaches, which occur in front of almost every valley. If the atolls of the larger archipelagoes were upraised, the bed of the ocean being converted into land, they would form flat-topped mountains, varying in diameter from a few miles (the smallest atolls being worn away) to sixty miles; and from being horizontally stratified and of similar composition, they would, as Mr. Lyell has remarked, falsely appear as if they had originally been united into one vast continuous mass. Such great strata of coral-rock would rarely be associated with erupted volcanic matter, for this could only take place, as may be inferred from what follows in the next chapter, when the area, in which they were situated, commenced to rise, or at least ceased to subside. During the enormous period necessary to effect an elevation of the kind just alluded to, the surface would necessarily be denuded to a great thickness; hence it is highly improbable that any fringing-reef, or even any barrier-reef, at least of those encircling small islands, would be preserved. From this same cause, the strata which were formed within the lagoons of atolls and lagoon-channels of barrier-reefs, and which must consist in a large part of sedimentary matter, would more often be preserved to future ages, than the exterior solid reef, composed of massive corals in an upright position; although it is on this exterior part that the present existence and further growth of atolls and barrier-reefs entirely depend.

Plate III—Map showing the distribution of coral-reefs and active volcanoes.


Mediterranean
PERSIA
ARABIA
Mecca
HINDOSTAN
Calcutta
Bombay
BIRMAH
CHINA
Nankin
Canton
Paracells
C. of Bengal
Madras
Andaman I.s
Nicobar I.s
Socotra I.
Laccadives
Maldivas
Ceylon
BORNEO
JAVA
Pemba I.
Zanzibar
Quiles
Mozambique
Saya de Matha
Chagos
Cargados Carajos
INDIAN OCEAN
Rodriquez
Mauritius
Bourbon I.
Madagascar
Mozambique Channel
NOTE
1 Spots & Streaks, active volcanoes
2 Barrier Reefs
3 Atolls or Lagoon Islands
4 Fringing Reefs
Amsterdam I.
St Paul I.
East of Greenwich


South I.
Crespo I.
Bonin sima I.s
Patrecinio I.
Lisianski I.s
Sandwich
Mariana I.s
Smith I.
Gaspar Rico I.s
PACIFIC
Caroline Archipelago
Marshall I.s
Philippine I.s
Pellew I.s
Qualan I.
Palmyra I.
Christmas I.
Gilbert I.s
New Guinea
St Augustine I.
Sydney I.
Ellice I.s
York I.
Timor I.
Torres St.
St Cruz
Rotouma
Navigator I.s
Suvarrow I.s
Gulf of Carpentaria
New Hebrides
Fiji I.s
Palmerston
Society I.s
New Caledonia
Friendly I.s
NEW HOLLAND
Norfolk I.s
OCEAN
Port Jackson
C. Howe
Bass Strait
Van Diemans Land
NEW ZEALAND



The principles, on which this map was coloured, are explained in the beginning of Chapter VI; and the authorities for each particular spot are detailed in the Appendix to *Coral Reefs.* The names not printed in upper case in the Index refer to the Appendix.

Chapter VI

ON THE DISTRIBUTION OF CORAL-REEFS WITH REFERENCE TO THE THEORY OF THEIR FORMATION

Description of the coloured map.—Proximity of atolls and barrier-reefs.—Relation in form and position of atolls with ordinary islands.—Direct evidence of subsidence difficult to be detected.—Proofs of recent elevation where fringing-reefs occur.—Oscillations of level.—Absence of active volcanoes in the areas of subsidence.—Immensity of the areas which have been elevated and have subsided.—Their relation to the present distribution of the land.—Areas of subsidence elongated, their intersection and alternation with those of elevation.—Amount and slow rate of the subsidence.—Recapitulation.

It will be convenient to give here a short account of the appended map (Plate III):[1] a fuller one, with the data for colouring each spot, is reserved for the Appendix; and every place there referred to may be found in the Index. A larger chart would have been desirable; but, small as the adjoined one is, it is the result of many months' labour. I have consulted, as far as I was able, every original voyage and map; and the colours were first laid down on charts on a larger scale. The same blue colour, with merely a difference in the depth of tint, is used for atolls or lagoon-islands, and barrier-reefs, for we have seen, that as far as the actual coral-formation is concerned, they have no distinguishing character. Fringing-reefs have been coloured red, for between them on the one hand, and barrier-reefs and atolls on the other, there is an important distinction with respect to the depth beneath the surface, at which we are compelled to believe their foundations lie. The two distinct colours, therefore, mark two great types of structure.

[1] Inasmuch as the coloured map would have proved too costly to be given in this series, the indications of colour have been replaced by numbers referring to the dotted groups of reefs, etc. The author's original wording, however, is retained in full, as it will be easy to refer to the map by the numbers, and thus the flow of the narrative is undisturbed.

The *dark blue colour* [represented by (3) in our plate] represents atolls and submerged annular reefs, with deep water in their centres. I have coloured as atolls, a few low and small coral-islands, without lagoons; but this has been done only when it clearly appeared that they originally contained lagoons, since filled up with sediment: when there were not good grounds for this belief, they have been left uncoloured.

The *pale blue colour* [represented by (2)] represents barrier-reefs. The most obvious character of reefs of this class is the broad and deep-water moat within the reef: but this, like the lagoons of small atolls, is liable to become filled up with detritus and with reefs of delicately branched corals: when, therefore, a reef round the entire circumference of an island extends very far into a profoundly deep sea, so that it can hardly be confounded with a fringing-reef which must rest on a foundation of rock within a small depth, it has been coloured pale blue, although it does not include a deep-water moat: but this has only been done rarely, and each case is distinctly mentioned in the Appendix.

The *red colour* (4) represents reefs fringing the land quite closely where the sea is deep, and where the bottom is gently inclined extending to a moderate distance from it, but not having a deep-water moat or lagoon-like space parallel to the shore. It must be remembered that fringing-reefs are frequently *breached* in front of rivers and valleys by deepish channels, where mud has been deposited. A space of thirty miles in width has been coloured round or in front of the reefs of each class, in order that the colours might be conspicuous on the appended map, which is reduced to so small a scale.

The *vermillion spots*, and streaks (1) represent volcanoes now in action, or historically known to have been so. They are chiefly laid down from Von Buch's work on the Canary Islands; and my reasons for making a few alterations are given in the note below.[2]

[2] I have also made considerable use of the geological part of Berghaus' "Physical Atlas." Beginning at the eastern side of the

Pacific, I have added to the number of the volcanoes in the southern part of the Cordillera, and have coloured Juan Fernandez according to observations collected during the voyage of the *Beagle* (“Geol. Trans.,” vol. v, p. 601). I have added a volcano to Albemarle Island, one of the Galapagos Archipelago (the author’s “Journal of Researches,” p. 457). In the Sandwich group there are no active volcanoes, except at Hawaii; but the Rev. W. Ellis informs me, there are streams of lava apparently modern on Maui, having a very recent appearance, which can be traced to the craters whence they flowed. The same gentleman informs me, that there is no reason to believe that any active volcano exists in the Society Archipelago; nor are there any known in the Samoa or Navigator group, although some of the streams of lava and craters there appear recent. In the Friendly group, the Rev. J. Williams says (“Narrative of Missionary Enterprise,” p. 29) that Toofoa and Proby Islands are active volcanoes. I infer from Hamilton’s “Voyage in the *Pandora*” (p. 95), that Proby Island is synonymous with Onouafou, but I have not ventured to colour it. There can be no doubt respecting Toofoa, and Captain Edwards (Von Buch, p. 386) found the lava of recent eruption at Amargura still smoking. Berghaus marks four active volcanoes actually within the Friendly group; but I do not know on what authority: I may mention that Maurelle describes Latte as having a burnt-up appearance: I have marked only Toofoa and Amargura. South of the New Hebrides lies Matthews Rock, which is drawn and described as an active crater in the “Voyage of the *Astrolabe*.” Between it and the volcano on the eastern side of New Zealand, lies Brimstone Island, which from the high temperature of the water in the crater, may be ranked as active (Berghaus “Vorbemerk,” II Lief. S. 56). Malte Brun, vol. xii, p. 231, says that there is a volcano near port St. Vincent in New Caledonia. I believe this to be an error, arising from a smoke seen on the *opposite* coast by Cook (“Second Voyage,” vol. ii, p. 23) which smoke went out at night. The Mariana Islands, especially the northern ones, contain many craters (see Freycinet’s “Hydrog. Descript.”) which are not active. Von Buch, however, states (p. 462) on the authority of La Peyrouse, that there are no less than seven volcanoes between these islands and Japan. Gemelli Creri (Churchill’s “Collect.” vol. iv, p. 458), says there are two active volcanoes in latitude 23° 30′, and in latitude 24°: but I have not coloured them. From the statements in Beechey’s “Voyage” (p. 518, 4to edit.) I have coloured one in the northern part of the Bonin group. M. S. Julien has clearly made out from Chinese manuscripts not very ancient (“Comptes Rendus,” 1840, p. 832), that there are two active volcanoes on the eastern side of Formosa. In Torres Straits, on Cap Island (9° 48′ S., 142° 39′ E.) a volcano was seen burning with great violence in 1793 by Captain Bampton (see Introduction to Flinders’ “Voyage,” p. 41). Mr. M’Clelland (Report of Committee for investigating Coal in India, p. 39) has shown that the volcanic band passing through Barren Island must be extended northwards. It appears by an old chart, that Cheduba was once an active volcano (see also *Silliman’s North American Journal*, vol. xxxviii, p. 385). In Berghaus’ “Phys. Atlas,” 1840, No. 7 of Geological Part, a volcano on the coast of Pondicherry is said to have burst forth in 1757. Ordinaire (“Hist. Nat. des Volcans,” p. 218) says that there is one at the mouth of the Persian Gulf, but I have not coloured it, as he gives no particulars. A volcano in Amsterdam, or St. Paul’s, in the southern part of the Indian Ocean, has been seen (*Naut. Mag.* 1838, p. 842) in action. Dr. J. Allan, of Forres, informs me in a letter, that when he was at Joanna, he saw at night flames apparently volcanic, issuing from the chief Comoro Island, and that the Arabs assured him that they were volcanic, adding that the volcano burned more during the wet season. I have marked this as a volcano, though with some hesitation, on account of the possibility of the flame arising from gaseous sources.

The uncoloured coasts consist, first and chiefly, of those, where there are no coral-reefs, or such small portions as to be quite insignificant. Secondly, of those coasts where there are reefs, but where the sea is very shallow, for in this case the reefs generally lie far from the land, and become very irregular, in their forms: where they have not become irregular, they have been coloured. thirdly, if I had the means of ascertaining the fact, I should not colour a reef merely coating the edges of a submarine crater, or of a level submerged bank; for such superficial formations differ essentially, even when not in external appearance, from reefs whose foundations as well as superficies have been wholly formed by the growth of coral. Fourthly, in the Red Sea, and within some parts of the East Indian Archipelago (if the imperfect charts of the latter can be trusted), there are many scattered reefs, of small size, represented in the chart by mere dots, which rise out of deep water: these cannot be arranged under either of the three classes: in the Red Sea, however, some of these little reefs, from their position, seem once to have formed parts of a continuous barrier. There exist, also, scattered in the open ocean, some linear and irregularly formed strips of coral-reef, which, as shown in the last chapter, are probably allied in their origin to atolls; but as they do not belong to that class, they have not been coloured; they are very few in number and of insignificant dimensions. Lastly, some reefs are left uncoloured from the want of information respecting them, and some because they are of an intermediate structure between the barrier and fringing classes. The value of the map is lessened, in proportion to the number of reefs which I have been obliged to leave uncoloured, although, in a theoretical point of view, few of them present any great difficulty: but their number is not very great, as will be found by comparing the map with the statements in the Appendix. I have experienced more difficulty in colouring fringing-reefs than in colouring barrier-reefs, as the former, from their much less dimensions, have less attracted the attention of navigators. As I have had to seek my information from all kinds of sources, and often from indirect ones, I do not venture to hope that the map is free from many errors. Nevertheless, I trust it will give an approximately correct view of the general distribution of the coral-reefs over the whole world (with the exception of some fringing-reefs on the coast of Brazil, not included within the limits of the map), and of their arrangement into the three great classes, which, though necessarily very imperfect from the nature of the objects classified, have been adopted by most voyagers. I may further remark, that the dark blue colour represents land entirely composed of coral-rock; the pale blue, land with a wide and thick border of coral-rock; and the red, a mere narrow fringe of coral-rock.

Looking now at the map under the theoretical point of view indicated in the last chapter, the two blue tints signify that the foundations of the reefs thus coloured have subsided to a considerable amount, at a slower rate than that of the upward growth of the corals, and that probably in many cases they are still subsiding. The red signifies that the shores which support fringing-reefs have not subsided (at least to any considerable amount, for the effects of a subsidence on a small scale would in no case be distinguishable); but that they have remained nearly stationary since the period when they first became fringed by reefs; or that they are now rising or have been upraised, with new lines of reefs successively formed on them: these latter alternatives are obviously implied, as newly formed lines of shore, after elevations of the land, would be in the same state with respect to the growth of fringing-reefs, as stationary coasts. If during the prolonged subsidence of a shore, coral-reefs grew for the first time on it, or if an old barrier-reef were destroyed and submerged, and new reefs became attached to the land, these would necessarily at first belong to the fringing class, and, therefore, be coloured red, although the coast was sinking: but I have no reason to believe, that from this source of error, any coast has been coloured wrongly with respect to movement indicated. Well characterised atolls and encircling barrier-reefs, where several occur in a group, or a single barrier-reef if of large dimensions, leave scarcely any doubt on the mind respecting the movement by which they have been produced; and even a small amount of subsequent elevation is soon betrayed. The evidence from a single atoll or a single encircling barrier-reef, must be received with some caution, for the former may possibly be based upon a submerged crater or bank, and the latter on a submerged margin of sediment, or of worn-down rock. From these remarks we may with greater certainty infer that the spaces, especially the larger ones, tinted blue in the map, have subsided, than that the red spaces have remained stationary, or have been upraised.

On the grouping of the different classes of reefs.—Having made these preliminary remarks, I will consider first how far the grouping of the different kinds of coral-islands and reefs is corroborative of the truth of the theory. A glance at the map shows that the reefs, coloured blue and red, produced under widely different conditions, are not indiscriminately mixed together. Atolls and barrier-reefs, on the other hand, as may be seen by the two blue tints, generally lie near each other; and this would be the natural result of both having been produced during the subsidence of the areas in which they stand. Thus, the largest group of encircled islands is that of the Society Archipelago; and these islands are surrounded by atolls, and only separated by a narrow space from the large group of Low atolls. In the midst of the Caroline atolls, there are three fine encircled islands. The northern point of the barrier-reef of New Caledonia seems itself, as before remarked, to form a complete large atoll. The great Australian barrier is described as including both atolls and small encircled islands. Captain King[3] mentions many atoll-formed and encircling coral-reefs, some of which lie within the barrier, and others may be said (for instance between lat. 16° and 13°) to form part of it. Flinders[4] has described an atoll-formed reef in lat. 10°, seven miles long and from one to three broad, resembling a boot in shape, with apparently very deep water within. Eight miles westward of this, and forming part of the barrier, lie the Murray Islands, which are high and are encircled. In the Corallian Sea, between the two great barriers of Australia and New Caledonia, there are many low islets and coral-reefs, some of which are annular, or horse-shoe shaped. Observing the smallness of the scale of the map, the parallels of latitude being nine hundred miles apart, we see that none of the large groups of reefs and islands supposed to have been produced by long-continued subsidence, lie near extensive lines of coast coloured red, which are supposed to have remained stationary since the growth of their reefs, or to have been upraised and new lines of reefs formed on them. Where the red and blue circles do occur near each other, I am able, in several instances, to show that there have been oscillations of level, subsidence having preceded the elevation of the red spots; and elevation having preceded the subsidence of the blue spots: and in this case the juxtaposition of reefs belonging to the two great types of structure is little surprising. We may, therefore, conclude that the proximity in the same areas of the two classes of reefs, which owe their origin to the subsidence of the earth's crust, and their separation from those formed during its stationary or uprising condition, holds good to the full extent, which might have been anticipated by our theory.

[3] Sailing directions, appended to vol. ii of his "Surveying Voyage to Australia."

[4] "Voyage to Terra Australis," vol. ii, p. 336.

As groups of atolls have originated in the upward growth, at each fresh sinking of the land, of those reefs which primarily fringed the shores of one great island, or of several smaller ones; so we might expect that these rings of coral-rock, like so many rude outline charts, will still retain some traces of the general form, or at least general range, of the land, round which they were first modelled. That this is the case with the atolls in the Southern Pacific as far as their range is concerned, seems highly probable, when we observe that the three principal groups are directed in north-west and south-east lines, and that nearly all the land in the S. Pacific ranges in this same direction; namely, N. Western Australia, New Caledonia, the northern half of New Zealand, the New Hebrides, Saloman, Navigator, Society, Marquesas, and Austral archipelagoes: in the Northern Pacific, the Caroline atolls abut against the north-west line of the Marshall atolls, much in the same manner as the east and west line of islands from Ceram to New Britain do on New Ireland: in the Indian Ocean the Laccadive and Maldiva atolls extend nearly parallel to the western and mountainous coast of India. In most respects, there is a perfect resemblance with ordinary islands in the grouping of atolls and in their form: thus the outline of all the larger groups is elongated; and the greater number of the individual atolls are elongated in the same direction with the group, in which they stand. The Chagos group is less elongated than is usual with other groups, and the individual atolls in it are likewise but little elongated; this is strikingly seen by comparing them with the neighbouring Maldiva atolls. In the Marshall and Maldiva archipelagoes, the atolls are ranged in two parallel lines, like the mountains in a great double mountain-chain. Some of the atolls, in the larger archipelagoes, stand so near to each other, and have such an evident relationship in form, that they compose little sub-groups: in the Caroline Archipelago, one such sub-group consists of Pouynipete, a lofty island encircled by a barrier-reef, and separated by a channel only four miles and a half wide from Andeema atoll, with a second atoll a little further off. In all these respects an examination of a series of charts will show how perfectly groups of atolls resemble groups of common islands.

On the direct evidence of the blue spaces in the map having subsided during the upward growth of the reefs so coloured, and of the red spaces having remained stationary, or having been upraised.—With respect to subsidence, I have shown in the last chapter, that we cannot expect to obtain in countries inhabited only by semi-civilised races, demonstrative proofs of a movement, which invariably tends to conceal its own evidence. But on the coral-islands supposed to have been produced by subsidence, we have proofs of changes in their external appearance—of a round of decay and renovation—of the last vestiges of land on some—of its first commencement on others: we hear of storms desolating them to the astonishment of their inhabitants: we know by the great fissures with which some of them are traversed, and by the earthquakes felt under others, that subterranean disturbances of some kind are in progress. These facts, if not directly connected with subsidence, as I believe they are, at least show how difficult it would be to discover proofs of such movement by ordinary means. At Keeling atoll, however, I have described some appearances, which seem directly to show that subsidence did take place there during the late earthquakes. Vanikoro, according to Chevalier Dillon,[5] is often violently shaken by earthquakes, and there, the unusual depth of the channel between the shore and the reef,—the almost entire absence of islets on the reef,—its wall-like structure on the inner side, and the small quantity of low alluvial land at the foot of the mountains, all seem to show that this island has not remained long at its present level, with the lagoon-channel subjected to the accumulation of sediment, and the reef to the wear and tear of the breakers. At the Society Archipelago, on the other hand, where a slight tremor is only rarely felt, the shoaliness of the lagoon-channels round some of the islands, the number of islets formed on the reefs of others, and the broad belt of low land at the foot of the mountains, indicate that, although there must have been great subsidence to have produced the barrier-reefs, there has since elapsed a long stationary period.[6]

[5] See Captain Dillon's "Voyage in search of La Peyrouse." M. Cordier in his "Report on the Voyage of the 'Astrolabe'" (p. cxi, vol. i), speaking of Vanikoro, says the shores are surrounded by reefs of madrepore, "qu'on assure etre de formation tout-a-fait moderne." I have in vain endeavoured to learn some further particulars about this remarkable passage. I may here add, that according to our theory, the island of Pouynipete (Plate I, Fig. 7), in the Caroline Archipelago, being encircled by a barrier-reef, must have subsided. In the *New S. Wales Lit. Advert.* February 1835 (which I have seen through the favour of Dr. Lloghtsky), there is an account of this island (subsequently confirmed by Mr. Campbell), in which it is said, "At the N.E. end, at a place called Tamen, there are ruins of a town, *now only* accessible by boats, the waves *reaching to the steps of the houses.*" Judging from this passage, one would be tempted to conclude that the island must have subsided, since these houses were built. I may, also, here append a statement in Malte Brun (vol. ix, p. 775, given without any authority), that the sea gains in an extraordinary manner on the coast of Cochin China, which lies in front and near the subsiding coral-reefs in the China Sea: as the coast is granitic, and not alluvial, it is scarcely possible that the encroachment of the sea can be owing to the washing away of the land; and if so, it must be due to subsidence.

[6] Mr. Couthouy states ("Remarks," p. 44) that at Tahiti and Eimeo the space between the reef and the shore has been nearly filled up by the extension of those coral-reefs, which within most barrier-reefs merely fringe the land. From this circumstance, he arrives at the same conclusion as I have done, that the Society Islands since their subsidence, have remained stationary during a long period; but he further believes that they have recently commenced rising, as well as the whole area of the Low Archipelago. He does not give any detailed proofs regarding the elevation of the Society Islands, but I shall refer to this subject in another part of this chapter. Before making some further comments, I may observe how satisfactory it is to me, to find Mr. Couthouy affirming, that "having personally examined a large number of coral-islands, and also residing eight months among the volcanic class, having shore and partially encircling reefs, I may be permitted to state that my own observations have impressed a conviction of the correctness of the theory of Mr. Darwin."

This gentleman believes, that subsequently to the subsidence by which the atolls in the Low Archipelago were produced, the whole area has been elevated to the amount of a few feet; this would indeed be a remarkable fact; but as far as I am able to judge, the grounds of his conclusion are not sufficiently strong. He states that he found in almost every atoll which he visited, the shores of the lagoon raised from eighteen to thirty inches above the sea-level, and containing imbedded Tridacnæ and corals standing as they grew; some of the corals were dead in their upper parts, but below a certain line they continued to flourish. In the lagoons, also, he frequently met with clusters of Madrepore, with their extremities standing from one inch to a foot above the surface of the water. Now, these appearances are exactly what I should have expected, without any subsequent elevation having taken place; and I think Mr. Couthouy has not borne in mind the indisputable fact, that corals, when constantly bathed by the surf, can exist at a higher level than in quite tranquil water, as in a lagoon. As long, therefore, as the waves continued at low water to break entirely over parts of the annular reef of an atoll, submerged to a small depth, the corals and shells attached on these parts might continue living at a level above the smooth surface of the lagoon, into which the waves rolled; but as soon as the outer edge of the reef grew up to its utmost possible height, or if the reef were very broad nearly to that height, the force of the breakers would be checked, and the corals and shells on the inner parts near the lagoon would occasionally be left dry, and thus be partially or wholly destroyed. Even in atolls, which have not lately subsided, if the outer margin of the reef continued to increase in breadth seaward (each fresh zone of corals rising to the same vertical height as at Keeling atoll), the line where the waves broke most heavily would advance outwards, and therefore the corals, which when living near the margin, were washed by the breaking waves during the whole of each tide, would cease being so, and would therefore be left on the backward part of the reef standing exposed and dead. The case of the madrepores in the lagoons with the tops of their branches exposed, seems to be an analogous fact, to the great fields of dead but upright corals in the lagoon of Keeling atoll; a condition of things which I have endeavoured to show, has resulted from the lagoon having become more and more enclosed and choked up with reefs, so that during high winds, the rising of the tide (as observed by the inhabitants) is checked, and the corals, which had formerly grown to the greatest possible height, are occasionally exposed, and thus are killed: and this is a condition of things, towards which almost every atoll in the intervals of its subsidence must be tending. Or if we look to the state of an atoll directly after a subsidence of some fathoms, the waves would roll heavily over the entire circumference of the reef, and the surface of the lagoon would, like the ocean, never be quite at rest, and therefore the corals in the lagoon, from being constantly laved by the rippling water, might extend their branches to a little greater height than they could, when the lagoon became enclosed and protected. Christmas atoll (2° N. lat.) which has a very shallow lagoon, and differs in several respects from most atolls, possibly may have been elevated recently; but its highest part appears (Couthouy, p. 46) to be only ten feet above the sea-level. The facts of a second class, adduced by Mr. Couthouy, in support of the alleged recent elevation of the Low Archipelago, are not all (especially those referring to a shelf of rock) quite intelligible to me; he believes that certain enormous fragments of rock on the reef, must have been moved into their present position, when the reef was at a lower level; but here again the force of the breakers on any inner point of the reef being diminished by its outward growth without any change in its level, has not, I think, been borne in mind. We should, also, not overlook the occasional agency of waves caused by earthquakes and hurricanes. Mr. Couthouy further argues, that since these great fragments were deposited and fixed on the reef, they have been elevated; he infers this from the greatest amount of erosion not being near their bases, where they are unceasingly washed by the reflux of the tides, but at some height on their sides, near the line of high-water mark, as shown in an accompanying diagram. My former remark again applies here, with this further observation, that as the waves have to roll over a wide space of reef before they reach the fragments, their force must be greatly increased with the increasing depth of water as the tide rises, and therefore I should have expected that the chief line of present erosion would have coincided with the line of high-water mark; and if the reef had grown outwards, that there would have been lines of erosion at greater heights. The conclusion, to which I am finally led by the interesting observations of Mr. Couthouy is, that the atolls in the Low Archipelago have, like the Society Islands, remained at a stationary level for a long period: and this probably is the ordinary course of events, subsidence supervening after long intervals of rest.

Turning now to the red colour; as on our map, the areas which have sunk slowly downwards to great depths are many and large, we might naturally have been led to conjecture, that with such great changes of level in progress, the coasts which have been fringed probably for ages (for we have no reason to believe that coral-reefs are of short duration), would not have remained all this time stationary, but would frequently have undergone movements of elevation. This supposition, we shall immediately see, holds good to a remarkable extent; and although a stationary condition of the land can hardly ever be open to proof, from the evidence being only negative, we are, in some degree, enabled to ascertain the correctness of the parts coloured red on the map, by the direct testimony of upraised organic remains of a modern date. Before going into the details on this head (printed in small type), I may mention, that when reading a memoir on coral formations by MM. Quoy and Gaimard[7] I was astonished to find, for I knew that they had crossed both the Pacific and Indian Oceans, that their descriptions were applicable only to reefs of the fringing class; but my astonishment ended satisfactorily, when I discovered that, by a strange chance, all the islands which these eminent naturalists had visited, though several in number, namely, the Mauritius, Timor, New Guinea, the Mariana, and Sandwich Archipelagoes, could be shown by their own statements to have been elevated within a recent geological era.

[7] “Annales des Sciences Nat.” tom. vi, p. 279, etc.

In the eastern half of the Pacific, the *Sandwich Islands* are all fringed, and almost every naturalist who has visited them, has remarked on the abundance of elevated corals and shells, apparently identical with living species. The Rev. W. Ellis informs me, that he has noticed round several parts of Hawaii, beds of coral-detritus, about twenty feet above the level of the sea, and where the coast is low they extend far inland. Upraised coral-rock forms a considerable part of the borders of Oahu; and at Elizabeth Island[8] it composes three strata, each about ten feet thick. Nihau, which forms the northern, as Hawaii does the southern end of the group (350 miles in length), likewise seems to consist of coral and volcanic rocks. Mr. Couthouy[9] has lately described with interesting details, several upraised beaches, ancient reefs with their surfaces perfectly preserved, and beds of recent shells and corals, at the islands of Maui, Morokai, Oahu, and Tauai (or Kauai) in this group. Mr. Pierce, an intelligent resident at Oahu, is convinced, from changes which have taken place within his memory, during the last sixteen years, “that the elevation is at present going forward at a very perceptible rate.” The natives at Kauai state that the land is there gaining rapidly on the sea, and Mr. Couthouy has no doubt, from the nature of the strata, that this has been effected by an elevation of the land.

[8] “Zoology of Captain Beechey’s Voyage,” p. 176. See also MM. Quoy and Gaimard in “Annales de Scien. Nat.” tom. vi.

[9] “Remarks on Coral Formations,” p. 51.

In the southern part of the Low Archipelago, Elizabeth Island is described by Captain Beechey,[10] as being quite flat, and about eighty feet in height; it is entirely composed of dead corals, forming a honeycombed, but compact rock. In cases like this, of an island having exactly the appearance, which the elevation of any one of the smaller surrounding atolls with a shallow lagoon would present, one is led to conclude (with little better reason, however, than the improbability of such small and low fabrics lasting, for an immense period, exposed to the many destroying agents of nature), that the elevation has taken place at an epoch not geologically remote. When merely the surface of an island of ordinary formation is strewed with marine bodies, and that continuously, or nearly so, from the beach to a certain height, and not above that height, it is exceedingly improbable that such organic remains, although they may not have been specially examined, should belong to any ancient period. It is necessary to bear these remarks in mind, in considering the evidence of the elevatory movements in the Pacific and Indian Oceans, as it does not often rest on specific determinations, and therefore should be received with caution. Six of the *Cook and Austral Islands* (S.W. of the Society group), are fringed; of these, five were described to me by the Rev. J. Williams, as formed of coral-rock, associated with some basalt in Mangaia), and the sixth as lofty and basaltic. Mangaia is nearly three hundred feet high, with a level summit; and according to Mr. S. Wilson[11] it is an upraised reef; “and there are in the central hollow, formerly the bed of the lagoon, many scattered patches of coral-rock, some of them raised to a height of forty feet.” These knolls of coral-rock were evidently once separate reefs in the lagoon of an atoll. Mr. Martens, at Sydney, informed me that this island is surrounded by a terrace-like plain at about the height of a hundred feet, which probably marks a pause in its elevation. From these facts we may infer, perhaps, that the Cook and Austral Islands have been upheaved at a period probably not very remote.

[10] Beechey’s “Voyage in the Pacific,” p. 46, 4to ed.

[11] Couthouy’s “Remarks,” p. 34.

Savage Island (S.E. of the Friendly group), is about forty feet in height. Forster[12] describes the plants as already growing out of the dead, but still upright and spreading trees of coral; and the younger Forster[13] believes that an ancient lagoon is now represented by a central plain; here we cannot doubt that the elevatory forces have recently acted. The same conclusion may be extended, though with somewhat less certainty, to the islands of the *friendly group*, which have been well described in the second and third voyages of Cook. The surface of Tongatabou is low and level, but with some parts a hundred feet high; the whole consists of coral-rock, "which yet shows the cavities and irregularities worn into it by the action of the tides."[14] On Eoua the same appearances were noticed at an elevation of between two hundred and three hundred feet. Vavao, also, at the opposite or northern end of the group, consists, according to the Rev. J. Williams, of coral-rock. Tongatabou, with its northern extensive reefs, resembles either an upraised atoll with one half originally imperfect, or one unequally elevated; and Anamouka, an atoll equally elevated. This latter island contains[15] in its centre a salt-water lake, about a mile-and-a-half in diameter, without any communication with the sea, and around it the land rises gradually like a bank; the highest part is only between twenty and thirty feet; but on this part, as well as on the rest of the land (which, as Cook observes, rises above the height of true lagoon-islands), coral-rock, like that on the beach, was found. In the *Navigator Archipelago*, Mr. Couthouy[16] found on Manua many and very large fragments of coral at the height of eighty feet, "on a steep hill-side, rising half a mile inland from a low sandy plain abounding in marine remains." The fragments were embedded in a mixture of decomposed lava and sand. It is not stated whether they were accompanied by shells, or whether the corals resembled recent species; as these remains were embedded they possibly may belong to a remote epoch; but I presume this was not the opinion of Mr. Couthouy. Earthquakes are very frequent in this archipelago.

[12] "Observations made during Voyage round the World," p. 147.

[13] "Voyage," vol. ii, p. 163.

[14] Cook's "Third Voyage" (4to ed.), vol. i, p. 314.

[15] *Ibid.*, vol. i, p. 235.

[16] "Remarks on Coral-Formations," p. 50.

Still proceeding westward we come to the *New Hebrides*; on these islands, Mr. G. Bennett (author of "Wanderings in New South Wales"), informs me he found much coral at a great altitude, which he considered of recent origin. Respecting *Santa Cruz*, and the *Solomon Archipelago*, I have no information; but at New Ireland, which forms the northern point of the latter chain, both Labillardiere and Lesson have described large beds of an apparently very modern madreporitic rock, with the form of the corals little altered. The latter author[17] states that this formation composes a newer line of coast, modelled round an ancient one. There only remains to be described in the Pacific, that curved line of fringed islands, of which the *Marianas* form the main part. Of these Guam, Rota, Tiniam, Saypan, and some islets farther north, are described by Quoy and Gaimard,[18] and Chamisso,[19] as chiefly composed of madreporitic limestone, which attains a considerable elevation, and is in several cases worn into successively rising cliffs: the two former naturalists seem to have compared the corals and shells with the existing ones, and state that they are of recent species. *Fais*, which lies in the prolonged line of the Marianas, is the only island in this part of the sea which is fringed; it is ninety feet high, and consists entirely of madreporitic rock.[20]

[17] "Voyage de la *Coquille*," Part. Zoolog.

[18] Freycinet's "Voyage autour du Monde." See also the "Hydrographical Memoir," p. 215.

[19] Kotzebue's "First Voyage."

[20] Lutké's "Voyage," vol. ii, p. 304.

In the *East Indian Archipelago*, many authors have recorded proofs of recent elevation. M. Lesson[21] states, that near Port Dory, on the north coast of New Guinea, the shores are flanked, to the height of 150 feet, by madreporitic strata of modern date. He mentions similar formations at Waigiou, Amboina, Bourou, Ceram, Sonda, and Timor: at this latter place, MM. Quoy and Gaimard[22] have likewise described the primitive rocks, as coated to a considerable height with coral. Some small islets eastward of Timor are said in Kolff's "Voyage,"[23] to resemble small coral islets upraised some feet above the sea. Dr. Malcolmson informs me that Dr. Hardie found in JAVA an extensive formation, containing an abundance of shells, of which the greater part appear to be of existing species. Dr. Jack[24] has described some upraised shells and corals, apparently recent, on Pulo Nias off *Sumatra*; and Marsden relates in his history of this great island, that the names of many promontories, show that they were originally islands. On part of the west coast of *Borneo* and at the *Sooloo Islands*, the form of the land, the nature of the soil, and the water-washed rocks, present appearances[25] (although it is doubtful whether such vague evidence is worthy of mention), of having recently been covered by the sea; and the inhabitants of the Sooloo Islands believe that this has been the case. Mr. Cuming, who has lately investigated, with so much success, the natural history of the *Philippines*, found near Cabagan, in Luzon, about fifty feet above the level of the R. Cagayan, and seventy miles from its mouth, a large bed of fossil shells: these, he informs me, are of the same species with those now existing on the shores of the neighbouring islands. From the accounts given us by Captain Basil Hall and Captain Beechey[26] of the lines of inland reefs, and walls of coral-rock worn into caves, above the present reach of the waves, at the *Loo Choo* Islands, there can be little doubt that they have been upraised at no very remote period.

[21] Partie Zoolog., "Voyage de la *Coquille*."

[22] "Ann. des Scien. Nat." tom. vi, p. 281.

[23] Translated by Windsor Earl, chapters vi, vii.

[24] "Geolog. Transact." 2nd series, vol. i, p. 403. On the Peninsula of Malacca, in front of Pinang, 5° 30′ N., Dr. Ward collected some shells, which Dr. Malcolmson informs me, although not compared with existing species, had a recent appearance. Dr. Ward describes in this neighbourhood ("Trans. Asiat. Soc." vol. xviii, part ii, p. 166) a single water-worn rock, with a conglomerate of sea-shells at its base, situated six miles inland, which, according to the traditions of the natives, was once surrounded by the sea. Captain Low has also described (*Ibid.*, part i, p. 131) mounds of shells lying two miles inland on this line of coast.

[25] "Notices of the East Indian Arch." Singapore, 1828, p. 6, and Append., p. 43.

[26] Captain B. Hall, "Voyage to Loo Choo," Append., pp. xxi and xxv. Captain Beechey's "Voyage," p. 496.

Dr. Davy[27] describes the northern province of *Ceylon* as being very low, and consisting of a limestone with shells and corals of very recent origin; he adds, that it does not admit of a doubt that the sea has retired from this district even within the memory of man. There is also some reason for believing that the western shores of India, north of Ceylon, have been upraised within the recent period.[28] *Mauritius* has certainly been upraised within the recent period, as I have stated in the chapter on fringing-reefs. The northern extremity of *Madagascar* is described by Captain Owen[29] as formed of madreporitic rock, as likewise are the shores and outlying islands along an immense space of *Eastern Africa*, from a little north of the equator for nine hundred miles southward. Nothing can be more vague than the expression "madreporitic rock;" but at the same time it is, I think, scarcely possible to look at the chart of the linear islets, which rise to a greater height than can be accounted for by the growth of coral, in front of the coast, from the equator to 2° S., without feeling convinced that a line of fringing-reefs has been elevated at a period so recent, that no great changes have since taken place on the surface of this part of the globe. Some, also, of the higher islands of madreporitic rock on this coast, for instance Pemba, have very singular forms, which seem to show the combined effect of the growth of coral round submerged banks, and their subsequent upheaval. Dr. Allan informs me that he never observed any elevated organic remains on the *Seychelles*, which come under our fringed class.

[27] "Travels in Ceylon," p. 13. This madreporitic formation is mentioned by M. Cordier in his report to the Institute (May 4th, 1839), on the voyage of the *Chevrette*, as one of immense extent, and belonging to the latest tertiary period.

[28] Dr. Benza, in his "Journey through the N. Circars" (the *Madras Lit. and Scient. Journ.* vol. v.) has described a formation with recent fresh-water and marine shells, occurring at the distance of three or four miles from the present shore. Dr. Benza, in conversation with me, attributed their position to a rise of the land. Dr. Malcolmson, however (and there cannot be a higher authority on the geology of India) informs me that he suspects that these beds may have been formed by the mere action of the waves and currents accumulating sediment. From analogy I should much incline to Dr. Benza's opinion.

[29] Owen's "Africa," vol. ii, p. 37, for Madagascar; and for S.

Africa, vol. i, pp. 412 and 426. Lieutenant Boteler's narrative contains fuller particulars regarding the coral-rock, vol. i, p. 174, and vol. ii, pp. 41 and 54. See also Ruschenberger's "Voyage round the World," vol. i, p. 60.

The nature of the formations round the shores of the *Red Sea*, as described by several authors, shows that the whole of this large area has been elevated within a very recent tertiary epoch. A part of this space in the appended map, is coloured blue, indicating the presence of barrier-reefs: on which circumstance I shall presently make some remarks. Rüppell[30] states that the tertiary formation, of which he has examined the organic remains, forms a fringe along the shores with a uniform height of from thirty and forty feet from the mouth of the Gulf of Suez to about latitude 26°; but that south of 26°, the beds attain only the height of from twelve to fifteen feet. This, however, can hardly be quite accurate; although possibly there may be a decrease in the elevation of the shores in the middle parts of the Red Sea, for Dr. Malcolmson (as he informs me) collected from the cliffs of Camaran Island (lat. 15° 30′ S.) shells and corals, apparently recent, at a height between thirty and forty feet; and Mr. Salt ("Travels in Abyssinia") describes a similar formation a little southward on the opposite shore at Amphila. Moreover, near the mouth of the Gulf of Suez, although on the coast opposite to that on which Dr. Rüppell says that the modern beds attain a height of only thirty to forty feet, Mr. Burton[31] found a deposit replete with existing species of shells, at the height of 200 feet. In an admirable series of drawings by Captain Moresby, I could see how continuously the cliff-bounded low plains of this formation extended with a nearly equable height, both on the eastern and western shores. The southern coast of Arabia seems to have been subjected to the same elevatory movement, for Dr. Malcolmson found at Sahar low cliffs containing shells and corals, apparently of recent species.

[30] Rüppell, "Reise in Abyssinien," Band i., s. 141.

[31] Lyell's "Principles of Geology," 5th ed., vol. iv, p. 25.

The *Persian Gulf* abounds with coral-reefs; but as it is difficult to distinguish them from sand-banks in this shallow sea, I have coloured only some near the mouth; towards the head of the gulf Mr. Ainsworth[32] says that the land is worn into terraces, and that the beds contain organic remains of existing forms. The *West Indian Archipelago* of "fringed" islands, alone remains to be mentioned; evidence of an elevation within a late tertiary epoch of nearly the whole of this great area, may be found in the works of almost all the naturalists who have visited it. I will give some of the principal references in a note.[33]

[32] Ainsworth's "Assyria and Babylon," p. 217.

[33] On Florida and the north shores of the Gulf of Mexico, Rogers' "Report to Brit. Assoc." vol. iii, p. 14.—On the shores of Mexico, Humboldt, "Polit. Essay on New Spain," vol. i, p. 62. (I have also some corroborative facts with respect to the shores of Mexico.)—Honduras and the Antilles, Lyell's "Principles," 5th ed., vol. iv, p. 22.—Santa Cruz and Barbadoes, Prof. Hovey, "Silliman's Journal", vol. xxxv, p. 74.—St. Domingo, Courrojolles, "Journ de Phys." tom. liv., p. 106.—Bahamas, "United Service Journal", No. lxxi, pp. 218 and 224. Jamaica, De la Beche, "Geol. Man." p. 142.—Cuba, Taylor in "Lond. and Edin. Mag." vol. xi, p. 17. Dr. Daubeny also, at a meeting of the Geolog. Soc., orally described some very modern beds lying on the N.W. parts of Cuba. I might have added many other less important references.

It is very remarkable on reviewing these details, to observe in how many instances fringing-reefs round the shores, have coincided with the existence on the land of upraised organic remains, which seem, from evidence more or less satisfactory, to belong to a late tertiary period. It may, however, be objected, that similar proofs of elevation, perhaps, occur on the coasts coloured blue in our map: but this certainly is not the case with the few following and doubtful exceptions.

The entire area of the Red Sea appears to have been upraised within a modern period; nevertheless I have been compelled (though on unsatisfactory evidence, as given in the Appendix) to class the reefs in the middle part, as barrier-reefs; should, however, the statements prove accurate to the less height of the tertiary bed in this middle part, compared with the northern and southern districts, we might well suspect that it had subsided subsequently to the general elevation by which the whole area has been upraised. Several authors[34] have stated that they have observed shells and corals high up on the mountains of the Society Islands,—a group encircled by barrier-reefs, and, therefore, supposed to have subsided: at Tahiti Mr. Stutchbury found on the apex of one of the highest mountains, between 5,000 and 7,000 feet above the level of the sea, "a distinct and regular stratum of semi-fossil coral." At Tahiti, however, other naturalists, as well as myself, have searched in vain at a low level near the coast, for upraised shells or masses of coral-reef, where if present they could hardly have been overlooked. From this fact, I concluded that probably the organic remains strewed high up on the surface of the land, had originally been embedded in the volcanic strata, and had subsequently been washed out by the rain. I have since heard from the Rev. W. Ellis, that the remains which he met with, were (as he believes) interstratified with an argillaceous tuff; this likewise was the case with the shells observed by the Rev. D. Tyerman at Huaheine. These remains have not been specifically examined; they may, therefore, and especially the stratum observed by Mr. Stutchbury at an immense height, be contemporaneous with the first formation of the Society Islands, and be of any degree of antiquity; or they may have been deposited at some subsequent, but probably not very recent, period of elevation; for if the period had been recent, the entire surface of the coast land of these islands, where the reefs are so extensive, would have been coated with upraised coral, which certainly is not the case. Two of the Harvey, or Cook Islands, namely, Aitutaki and Manouai, are encircled by reefs, which extend so far from the land, that I have coloured them blue, although with much hesitation, as the space within the reef is shallow, and the outline of the land is not abrupt. These two islands consist of coral-rock; but I have no evidence of their recent elevation, besides, the improbability of Mangaia, a fringed island in the same group (but distant 170 miles), having retained its nearly perfect atoll-like structure, during any immense lapse of time after its upheaval. The Red Sea, therefore, is the only area in which we have clear proofs of the recent elevation of a district, which, by our theory (although the barrier-reefs are there not well characterised), has lately subsided. But we have no reason to be surprised at oscillation, of level of this kind having occasionally taken place. There can be scarcely any doubt that Savage, Aurora,[35] and Mangaia Islands, and several of the islands in the Friendly group, existed originally as atolls, and these have undoubtedly since been upraised to some height above the level of the sea; so that by our theory, there has here, also, been an oscillation of level,—elevation having succeeded subsidence, instead of, as in the middle part of the Red Sea and at the Harvey Islands, subsidence having probably succeeded recent elevation.

[34] Ellis, in his "Polynesian Researches," was the first to call attention to these remains (vol. i, p. 38), and the tradition of the natives concerning them. See also Williams, "Nar. of Missionary Enterprise," p. 21; also Tyerman and G. Bennett, "Journal of Voyage," vol. i, p. 213; also Mr. Couthouy's "Remarks," p. 51; but this principal fact, namely, that there is a mass of upraised coral on the narrow peninsula of Tiarubu, is from hearsay evidence; also Mr. Stutchbury, *West of England Journal*, No. i, p. 54. There is a passage in Von Zach, "Corres. Astronom." vol. x, p. 266, inferring an uprising at Tahiti, from a footpath now used, which was formerly impassable; but I particularly inquired from several native chiefs, whether they knew of any change of this kind, and they were unanimous in giving me an answer in the negative.

[35] Aurora Island is described by Mr. Couthouy ("Remarks," p. 58); it lies 120 miles north-east of Tahiti; it is not coloured in the appended map, because it does not appear to be fringed by living reefs. Mr. Couthouy describes its summit as "presenting a broad table-land which declines a few feet towards the centre, where we may suppose the lagoon to have been placed." It is about two hundred feet in height, and consists of reef-rock and conglomerate, with existing species of coral embedded in it. The island has been elevated at two successive periods; the cliffs being marked halfway up with a horizontal water-worn line of deep excavations. Aurora Island seems closely to resemble in structure Elizabeth Island, at the southern end of the Low Archipelago.

It is an interesting fact, that Fais, which, from its composition, form, height, and situation at the western end of the Caroline Archipelago, one is strongly induced to believe existed before its upheaval as an atoll, lies exactly in the prolongation of the curved line of the Mariana group, which we know to be a line of recent elevation. I may add, that Elizabeth Island, in the southern part of the Low Archipelago, which seems to have had the same kind of origin as Fais, lies near Pitcairn Island, the only one in this part of the ocean which is high, and at the same time not surrounded by an encircling barrier-reef.

On the absence of active volcanoes in the areas of subsidence, and on their frequent presence in the areas of elevation.—Before making some concluding remarks on the relations of the spaces coloured blue and red, it will be convenient to consider the position on our map of the volcanoes historically known to have been in action. It is impossible not to be struck, first with the absence of volcanoes in the great areas of subsidence tinted pale and dark blue,—namely, in the central parts of the Indian Ocean, in the China Sea, in the sea between the barriers of Australia and New Caledonia, in the Caroline, Marshall, Gilbert, and Low Archipelagoes; and, secondly, with the coincidence of the principal volcanic chains with the parts coloured red, which indicates the presence of fringing-reefs; and, as we have just seen, the presence in most cases of upraised organic remains of a modern date. I may here remark that the reefs were all coloured before the volcanoes were added to the map, or indeed before I knew of the existence of several of them.

The volcano in Torres Strait, at the northern point of Australia, is that which lies nearest to a large subsiding area, although situated 125 miles within the outer margin of the actual barrier-reef. The Great Comoro Island, which probably contains a volcano, is only twenty miles distant from the barrier-reef of Mohila; Ambil volcano, in the Philippines, is distant only a little more than sixty miles from the atoll-formed Appoo reef: and there are two other volcanoes in the map within ninety miles of circles coloured blue. These few cases, which thus offer partial exceptions to the rule, of volcanoes being placed remote from the areas of subsidence, lie either near single and isolated atolls, or near small groups of encircled islands; and these by our theory can have, in few instances, subsided to the same amount in depth or area, as groups of atolls. There is not one active volcano within several hundred miles of an archipelago, or even a small group of atolls. It is, therefore, a striking fact that in the Friendly Archipelago, which owes its origin to the elevation of a group of atolls, two volcanoes, and, perhaps, others are known to be in action: on the other hand, on several of the encircled islands in the Pacific, supposed by our theory to have subsided, there are old craters and streams of lava, which show the effects of past and ancient eruptions. In these cases, it would appear as if the volcanoes had come into action, and had become extinguished on the same spots, according as the elevating or subsiding movements prevailed.

There are some other coasts on the map, where volcanoes in a state of action concur with proofs of recent elevation, besides those coloured red from being fringed by coral-reefs. Thus I hope to show in a future volume, that nearly the whole line of the west coast of South America, which forms the greatest volcanic chain in the world, from near the equator for a space of between 2,000 and 3,000 miles southward, has undergone an upward movement during a late geological period. The islands on the north-western shores of the Pacific, which form the second greatest volcanic chain, are very imperfectly known; but Luzon, in the Philippines, and the Loo Choo Islands, have been recently elevated; and at Kamtschatka[36] there are extensive tertiary beds of modern date. Evidence of the same nature, but not very satisfactory, may be detected in Northern New Zealand where there are two volcanoes. The co-existence in other parts of the world of active volcanoes, with upraised beds of a modern tertiary origin, will occur to every geologist.[37] Nevertheless, until it could be shown that volcanoes were inactive, or did not exist in subsiding areas, the conclusion that their distribution depended on the nature of the subterranean movements in progress, would have been hazardous. But now, viewing the appended map, it may, I think, be considered as almost established, that volcanoes are often (not necessarily always) present in those areas where the subterranean motive power has lately forced, or is now forcing outwards, the crust of the earth, but that they are invariably absent in those, where the surface has lately subsided or is still subsiding.[38]

[36] At Sedanka, in latitude 58° N. (Von Buch's "Descrip. des Isles Canaries," p. 455). In a forthcoming part, I shall give the evidence referred to with respect to the elevation of New Zealand.

[37] During the subterranean disturbances which took place in Chile, in 1835, I have shown ("Geolog. Trans." 2nd Ser., vol. v, p. 606) that at the same moment that a large district was upraised, volcanic matter burst forth at widely separated points, through both new and old vents.

[38] We may infer from this rule, that in any old deposit, which contains interstratified beds of erupted matter, there was at the period, and in the area of its formation, a *tendency* to an upward movement in the earth's surface, and certainly no movement of

subsidence.

On the relations of the areas of subsidence and elevation.—The immense surfaces on the map, which, both by our theory and by the plain evidence of upraised marine remains, have undergone a change of level either downwards or upwards during a late period, is a most remarkable fact. The existence of continents shows that the areas have been immense which at some period have been upraised; in South America we may feel sure, and on the north-western shores of the Indian Ocean we may suspect, that this rising is either now actually in progress, or has taken place quite recently. By our theory, we may conclude that the areas are likewise immense which have lately subsided, or, judging from the earthquakes occasionally felt and from other appearances, are now subsiding. The smallness of the scale of our map should not be overlooked: each of the squares on it contains (not allowing for the curvature of the earth) 810,000 square miles. Look at the space of ocean from near the southern end of the Low Archipelago to the northern end of the Marshall Archipelago, a length of 4,500 miles, in which, as far as is known, every island, except Aurora which lies just without the Low Archipelago, is atoll-formed. The eastern and western boundaries of our map are continents, and they are rising areas: the central spaces of the great Indian and Pacific Oceans, are mostly subsiding; between them, north of Australia, lies the most broken land on the globe, and there the rising parts are surrounded and penetrated by areas of subsidence,[39] so that the prevailing movements now in progress, seem to accord with the actual states of surface of the great divisions of the world.

[39] I suspect that the Arru and Timor-laut Islands present an included small area of subsidence, like that of the China Sea, but I have not ventured to colour them from my imperfect information, as given in the Appendix.

The blue spaces on the map are nearly all elongated; but it does not necessarily follow from this (a caution, for which I am indebted to Mr. Lyell), that the areas of subsidence were likewise elongated; for the subsidence of a long, narrow space of the bed of the ocean, including in it a transverse chain of mountains, surmounted by atolls, would only be marked on the map by a transverse blue band. But where a chain of atolls and barrier-reefs lies in an elongated area, between spaces coloured red, which therefore have remained stationary or have been upraised, this must have resulted either from the area of subsidence having originally been elongated (owing to some tendency in the earth’s crust thus to subside), or from the subsiding area having originally been of an irregular figure, or as broad as long, and having since been narrowed by the elevation of neighbouring districts. Thus the areas, which subsided during the formation of the great north and south lines of atolls in the Indian Ocean,—of the east and west line of the Caroline atolls,—and of the north-west and south-east line of the barrier-reefs of New Caledonia and Louisiade, must have originally been elongated, or if not so, they must have since been made elongated by elevations, which we know to belong to a recent period.

I infer from Mr. Hopkins’ researches,[40] that for the formation of a long chain of mountains, with few lateral spurs, an area elongated in the same direction with the chain, must have been subjected to an elevatory movement. Mountain-chains, however, when already formed, although running in very different directions, it seems[41] may be raised together by a widely-acting force: so, perhaps, mountain-chains may subside together. Hence, we cannot tell, whether the Caroline and Marshall Archipelagoes, two groups of atolls running in different directions and meeting each other, have been formed by the subsidence of two areas, or of one large area, including two distinct lines of mountains. We have, however, in the southern prolongation of the Mariana Islands, probable evidence of a line of recent elevation having intersected one of recent subsidence. A view of the map will show that, generally, there is a tendency to alternation in the parallel areas undergoing opposite kinds of movement; as if the sinking of one area balanced the rising of another.

[40] “Researches in Physical Geology,” Transact. Cambridge Phil. Soc., vol. vi, part i.

[41] For instance in S. America from lat. 34°, for very many degrees southward there are upraised beds containing recent species of shells, on both the Atlantic and Pacific side of the continent, and from the gradual ascent of the land, although with very unequal slopes, on both sides towards the Cordillera, I think it can hardly be doubted that the entire width has been upraised in mass within the recent period. In this case the two W.N.W. and

E.S.E. mountain-lines, namely the Sierra Ventana and the S. Tapalguen, and the great north and south line of the Cordillera have been together raised. In the West Indies the N. and S. line of the Eastern Antilles, and the E. and W. line of Jamaica, appear both to have been upraised within the latest geological period.

The existence in many parts of the world of high table-land, proves that large surfaces have been upraised in mass to considerable heights above the level of the ocean; although the highest points in almost every country consist of upturned strata, or erupted matter: and from the immense spaces scattered with atolls, which indicate that land originally existed there, although not one pinnacle now remains above the level of the sea, we may conclude that wide areas have subsided to an amount, sufficient to bury not only any formerly existing table-land, but even the heights formed by fractured strata, and erupted matter. The effects produced on the land by the later elevatory movements, namely, successively rising cliffs, lines of erosion, and beds of literal shells and pebbles, all requiring time for their production, prove that these movements have been very slow; we can, however, infer this with safety, only with respect to the few last hundred feet of rise. But with reference to the whole vast amount of subsidence, necessary to have produced the many atolls widely scattered over immense spaces, it has already been shown (and it is, perhaps, the most interesting conclusion in this volume), that the movements must either have been uniform and exceedingly slow, or have been effected by small steps, separated from each other by long intervals of time, during which the reef-constructing polypifers were able to bring up their solid frameworks to the surface. We have little means of judging whether many considerable oscillations of level have generally occurred during the elevation of large tracts; but we know, from clear geological evidence, that this has frequently taken place; and we have seen on our map, that some of the same islands have both subsided and been upraised. I conclude, however, that most of the large blue spaces, have subsided without many and great elevatory oscillations, because only a few upraised atolls have been observed: the supposition that such elevations have taken place, but that the upraised parts have been worn down by the surf, and thus have escaped observation, is overruled by the very considerable depth of the lagoons of all the larger atolls; for this could not have been the case, if they had suffered repeated elevations and abrasion. From the comparative observations made in these latter pages, we may finally conclude, that the subterranean changes which have caused some large areas to rise, and others to subside, have acted in a very similar manner.

Recapitulation.—In the three first chapters, the principal kinds of coral-reefs were described in detail, and they were found to differ little, as far as relates to the actual surface of the reef. An atoll differs from an encircling barrier-reef only in the absence of land within its central expanse; and a barrier-reef differs from a fringing-reef, in being placed at a much greater distance from the land with reference to the probable inclination of its submarine foundation, and in the presence of a deep-water lagoon-like space or moat within the reef. In the fourth chapter the growing powers of the reef-constructing polypifers were discussed; and it was shown, that they cannot flourish beneath a very limited depth. In accordance with this limit, there is no difficulty respecting the foundations on which fringing-reefs are based; whereas, with barrier-reefs and atolls, there is a great apparent difficulty on this head; in barrier-reefs from the improbability of the rock of the coast or of banks of sediment extending, in every instance, so far seaward within the required depth;—and in atolls, from the immensity of the spaces over which they are interspersed, and the apparent necessity for believing that they are all supported on mountain-summits, which although rising very near to the surface-level of the sea, in no one instance emerge above it. To escape this latter most improbable admission, which implies the existence of submarine chains of mountains of almost the same height, extending over areas of many thousand square miles, there is but one alternative; namely, the prolonged subsidence of the foundations, on which the atolls were primarily based, together with the upward growth of the reef-constructing corals. On this view every difficulty vanishes; fringing reefs are thus converted into barrier-reefs; and barrier-reefs, when encircling islands, are thus converted into atolls, the instant the last pinnacle of land sinks beneath the surface of the ocean.

Thus the ordinary forms and certain peculiarities in the structure of atolls and barrier-reefs can be explained;—namely, the wall-like structure on their inner sides, the basin or ring-like shape both of the marginal and central reefs in the Maldiva atolls—the union of some atolls as if by a ribbon—the apparent disseverment of others—and the occurrence, in atolls as well as in barrier-reefs, of portions of reef, and of the whole of some reefs, in a dead and submerged state, but retaining the outline of living reefs. Thus can be explained the existence of breaches through barrier-reefs in front of valleys, though separated from them by a wide space of deep water; thus, also, the ordinary outline of groups of atolls and the relative forms of the separate atolls one to another; thus can be explained the proximity of the two kinds of reefs formed during subsidence, and their separation from the spaces where fringing-reefs abound. On searching for other evidence of the movements supposed by our theory, we find marks of change in atolls and in barrier-reefs, and of subterranean disturbances under them; but from the nature of things, it is scarcely possible to detect any direct proofs of subsidence, although some appearances are strongly in favour of it. On the fringed coasts, however, the presence of upraised marine bodies of a recent epoch, plainly show, that these coasts, instead of having remained stationary, which is all that can be directly inferred from our theory, have generally been elevated.

Finally, when the two great types of structure, namely barrier-reefs and atolls on the one hand, and fringing-reefs on the other, were laid down in colours on our map, a magnificent and harmonious picture of the movements, which the crust of the earth has within a late period undergone, is presented to us. We there see vast areas rising, with volcanic matter every now and then bursting forth through the vents or fissures with which they are traversed. We see other wide spaces slowly sinking without any volcanic outburst, and we may feel sure, that this sinking must have been immense in amount as well as in area, thus to have buried over the broad face of the ocean every one of those mountains, above which atolls now stand like monuments, marking the place of their former existence. Reflecting how powerful an agent with respect to denudation, and consequently to the nature and thickness of the deposits in accumulation, the sea must ever be, when acting for prolonged periods on the land, during either its slow emergence or subsidence; reflecting, also, on the final effects of these movements in the interchange of land and ocean-water on the climate of the earth, and on the distribution of organic beings, I may be permitted to hope, that the conclusions derived from the study of coral-formations, originally attempted merely to explain their peculiar forms, may be thought worthy of the attention of geologists.

APPENDIX.

CONTAINING A DETAILED DESCRIPTION OF THE REEFS AND ISLANDS IN PLATE III.

In the beginning of the last chapter I stated the principles on which the map is coloured. There only remains to be said, that it is an exact copy of one by M. C. Gressier, published by the Dépôt Général de la Marine, in 1835. The names have been altered into English, and the longitude has been reduced to that of Greenwich. The colours were first laid down on accurate charts, on a large scale. The data, on which the volcanoes historically known to have been in action, have been marked with vermillion, were given in a note to the last chapter. I will commence my description on the eastern side of the map, and will describe each group of islands consecutively, proceeding westward across the Pacific and Indian Oceans, but ending with the West Indies.

The WESTERN SHORES OF AMERICA appear to be entirely without coral-reefs; south of the equator the survey of the *Beagle*, and north of it, the published charts show that this is the case. Even in the Bay of *Panama*, where corals flourish, there are no true coral-reefs, as I have been informed by Mr. Lloyd. There are no coral-reefs in the *Galapagos* Archipelago, as I know from personal inspection; and I believe there are none on the *Cocos, Revilla-gigedo*, and other neighbouring islands. *Clipperton* rock, 10° N., 109° W., has lately been surveyed by Captain Belcher; in form it is like the crater of a volcano. From a drawing appended to the MS. plan in the Admiralty, it evidently is not an atoll. The eastern parts of the Pacific present an enormous area, without any islands, except *E*, and *Sala*, and *Gomez* Islands, which do not appear to be surrounded by reefs.

The LOW ARCHIPELAGO.—This group consists of about eighty atolls: it will be quite superfluous to refer to descriptions of each. In D'Urville and Lottin's chart, one island (*Wolchonsky*) is written with a capital letter, signifying, as explained in a former chapter, that it is a high island; but this must be a mistake, as the original chart by Bellinghausen shows that it is a true atoll. Captain Beechey says of the thirty-two groups which he examined (of the greater number of which I have seen beautiful MS. charts in the Admiralty), that twenty-nine now contain lagoons, and he believes the other three originally did. Bellinghausen (see an account of his Russian voyage, in the "Biblioth. des Voyages," 1834, p. 443) says, that the seventeen islands which he discovered resembled each other in structure, and he has given charts on a large scale of all of them. Kotzebue has given plans of several; Cook and Bligh mention others; a few were seen during the voyage of the *Beagle*; and notices of other atolls are scattered through several publications. The *Actæon* group in this archipelago has lately been discovered (*Geograph. Journ.*, vol. vii, p. 454); it consists of three small and low islets, one of which has a lagoon. Another lagoon-island has been discovered (*Naut. Mag.*, 1839, p. 770), in 22° 4′ S., and 136° 20′ W. Towards the S.E. part of the group, there are some islands of different formation: *Elizabeth* Island is described by Beechey (p. 46, 4to ed.) as fringed by reefs, at the distance of between two and three hundred yards; coloured red. *Pitcairn* Island, in the immediate neighbourhood, according to the same authority, has no reefs of any kind, although numerous pieces of coral are thrown up on the beach; the sea close to its shore is very deep (see "Zool. of Beechey's Voyage," p. 164); it is left uncoloured. *Gambier* Islands (see Plate I Fig. 8), are encircled by a barrier-reef; the greatest depth within is thirty-eight fathoms; coloured pale blue. *Aurora* Island, which lies N.E. of Tahiti close to the large space coloured dark blue in the map, has been already described in a note (), on the authority of Mr. Couthouy; it is an upraised atoll, but as it does not appear to be fringed by living reefs, it is left uncoloured.

The SOCIETY Arch. is separated by a narrow space from the Low Archipelago; and in their parallel direction they manifest some relation to each other. I have already described the general character of the reefs of these fine encircled islands. In the "Atlas of the *Coquille's* Voyage" there is a good general chart of the group, and separate plans of some of the islands. *Tahiti*, the largest island in the group, is almost surrounded, as seen in Cook's chart, by a reef from half a mile to a mile and a half from the shore, with from ten to thirty fathoms within it. Some considerable submerged reefs lying parallel to the shore, with a broad and deep space within, have lately been discovered (*Naut. Mag.*, 1836, p. 264) on the N.E. coast of the island, where none are laid down by Cook.

At *Eimeo* the reef "which like a ring surrounds it, is in some places one or two miles distant from the shore, in others united to the beach" (Ellis, "Polynesian Researches," vol. i, p. 18, 12mo edition). Cook found deep water (twenty fathoms) in some of the harbours within the reef. Mr. Couthouy, however, states ("Remarks," p. 45) that both at Tahiti and Eimeo, the space between the barrier-reef and the shore, has been almost filled up,—"a nearly continuous fringing-reef surrounding the island, and varying from a few yards to rather more than a mile in width, the lagoons merely forming canals between this and the sea-reef," that is the barrier-reef. *Tapamanoa* is surrounded by a reef at a considerable distance from the shore; from the island being small it is breached, as I am informed by the Rev. W. Ellis, only by a narrow and crooked boat channel. This is the lowest island in the group, its height probably not exceeding 500 feet. A little way north of Tahiti, the low coral-islets of *Teturoa* are situated; from the description of them given me by the Rev. J. Williams (the author of the "Narrative of Missionary Enterprise"), I should have thought they had formed a small atoll, and likewise from the description given by the Rev. D. Tyerman and G. Bennett ("Journal of Voyage and Travels," vol. i, p. 183), who say that ten low coral-islets "are comprehended within one general reef, and separated from each other by interjacent lagoons;" but as Mr. Stutchbury (*West of England Journal*, vol. i, p. 54) describes it as consisting of a mere narrow ridge, I have left it uncoloured. *Maitea*, eastward of the group, is classed by Forster as a high encircled island; but from the account given by the Rev. D. Tyerman and G. Bennett (vol. i, p. 57) it appears to be an exceedingly abrupt cone, rising from the sea without any reef; I have left it uncoloured. It would be superfluous to describe the northern islands in this group, as they may be well seen in the chart accompanying the 4to edition of Cook's "Voyages," and in the "Atlas of the *Coquille's* Voyage." *Maurua* is the only one of the northern islands, in which the water within the reef is not deep, being only four and a half fathoms; but the great width of the reef, stretching three miles and a half southward of the land (which is represented in the drawing in the "Atlas of the *Coquille's* Voyage" as descending abruptly to the water) shows, on the principle explained in the beginning of the last chapter, that it belongs to the barrier class. I may here mention, from information communicated to me by the Rev. W. Ellis, that on the N.E. side of *Huaheine* there is a bank of sand, about a quarter of a mile wide, extending parallel to the shore, and separated from it by an extensive and deep lagoon; this bank of sand rests on coral-rock, and undoubtedly was originally a living reef. North of Bolabola lies the atoll of *Toubai* (Motou-iti of the "*Coquille's* Atlas") which is coloured dark blue; the other islands, surrounded by barrier-reefs, are pale blue; three of them are represented in Figs 3, 4, and 5, in Plate I. There are three low coral-groups lying a little E. of the Society Archipelago, and almost forming part of it, namely *Bellinghausen*, which is said by Kotzebue ("Second Voyage," vol. ii, p. 255), to be a lagoon-island; *Mopeha*, which, from Cook's description ("Second Voyage," book iii, chap. i), no doubt is an atoll; and the *Scilly* Islands, which are said by Wallis ("Voyage," chap. ix) to form a *group* of *low* islets and shoals, and, therefore, probably, they compose an atoll: the two former have been coloured blue, but not the latter.

MENDANA OR MARQUESAS Group.—These islands are entirely without reefs, as may be seen in Krusenstern's Atlas, making a remarkable contrast with the adjacent group of the Society Islands. Mr. F. D. Bennett has given some account of this group, in the seventh volume of the *Geograph. Journ.* He informs me that all the islands have the same general character, and that the water is very deep close to their shores. He visited three of them, namely, *Dominicana, Christiana,* and *Roapoa*; their beaches are strewed with rounded masses of coral, and although no regular reefs exist, yet the shore is in many places lined by coral-rock, so that a boat grounds on this formation. Hence these islands ought probably to come within the class of fringed islands and be coloured red; but as I am determined to err on the cautious side, I have left them uncoloured.

COOK or HARVEY and AUSTRAL ISLAND.—*Palmerston* Island is minutely described as an atoll by Captain Cook during his voyage in 1774; coloured blue. *Aitutaki* was partially surveyed by the *Beagle* (see map accompanying "Voyages of *Adventure* and *Beagle*"); the land is hilly, sloping gently to the beach; the highest point is 360 feet; on the southern side the reef projects five miles from the land: off this point the *Beagle* found no bottom with 270 fathoms: the reef is surmounted by many low coral-islets. Although within the reef the water is exceedingly shallow, not being more than a few feet deep, as I am informed by the Rev. J. Williams, nevertheless, from the great extension of this reef into a profoundly deep ocean, this island probably belongs, on the principle lately adverted to, to the barrier class, and I have coloured it pale blue; although with much hesitation.—*Manouai* or *Harvey* Island. The highest point is about fifty feet: the Rev. J. Williams informs me that the reef here, although it lies far from the shore, is less distant than at Aitutaki, but the water within the reef is rather deeper: I have also coloured this pale blue with many doubts.—Round *Mitiaro* Island, as I am informed by Mr. Williams, the reef is attached to the shore; coloured red.—*Mauki* or Maouti; the reef round this island (under the name of Parry Island, in the "Voyage of H.M.S. *Blonde*," p. 209) is described as a coral-flat, only fifty yards wide, and two feet under water. This statement has been corroborated by Mr. Williams, who calls the reef attached; coloured red. —*Aitu*, or Wateeo; a moderately elevated hilly island, like the others of this group. The reef is described in Cook's "Voyage," as attached to the shore, and about one hundred yards wide; coloured red.—*Fenoua-iti*; Cook describes this island as very low, not more than six or seven feet high (vol. i, book ii, chap. iii, 1777); in the chart published in the "*Coquille's* Atlas," a reef is engraved close to the shore: this island is not mentioned in the list given by Mr. Williams (page 16) in the "Narrative of Missionary Enterprise;" nature doubtful. As it is so near Atiu, it has been unavoidably coloured red.—*Rarotonga*; Mr. Williams informs me that it is a lofty basaltic island with an attached reef; coloured red.—There are three islands, *Rourouti, Roxburgh*, and *Hull*, of which I have not been able to obtain any account, and have left them uncoloured. Hull Island, in the French chart, is written with small letters as being low.—*Mangaia*; height about three hundred feet; "the surrounding reef joins the shore" (Williams, "Narrative," p. 18); coloured red.—*Rimetara*; Mr. Williams informs me that the reef is rather close to the shore; but, from information given me by Mr. Ellis, the reef does not appear to be quite so closely attached to it as in the foregoing cases: the island is about three hundred feet high (*Naut. Mag.*, 1839, p. 738); coloured red.—*Rurutu*; Mr. Williams and Mr. Ellis inform me that this island has an attached reef; coloured red. It is described by Cook under the name of Oheteroa: he says it is not surrounded, like the neighbouring islands by a reef; he must have meant a distant reef.—*Toubouai*; in Cook's chart ("Second Voyage," vol. ii, p. 2) the reef is laid down in part one mile, and in part two miles from the shore. Mr. Ellis ("Polynes. Res." vol. iii, p. 381) says the low land round the base of the island is very extensive; and this gentleman informs me that the water within the reef appears deep; coloured blue.—*Raivaivai*, or Vivitao; Mr. Williams informs me that the reef is here distant: Mr. Ellis, however, says that this is certainly not the case on one side of the island; and he believes that the water within the reef is not deep; hence I have left it uncoloured.—*Lancaster* Reef, described in *Naut. Mag.*, 1833 (p. 693), as an extensive crescent-formed coral-reef. I have not coloured it.—*Rapa*, or Oparree; from the accounts given of it by Ellis and Vancouver, there does not appear to be any reef. —*I. de Bass* is an adjoining island, of which I cannot find any account. —*Kemin* Island; Krusenstern seems hardly to know its position, and gives no further particulars.

ISLANDS BETWEEN *the Low and Gilbert Archipelagoes.*

Caroline Island (10° S., 150 deg W.) is described by Mr. F. D. Bennett (*Geograph. Journ.*, vol. vii, p. 225) as containing a fine lagoon; coloured blue.—*Flint* Island (11° S., 151° W.); Krusenstern believes that it is the same with Peregrino, which is described by Quiros (Burney's "Chron. Hist.," vol. ii, p. 283) as "a cluster of small islands connected by a reef, and forming a lagoon in the middle;" coloured blue.—*Wostock* is an island a little more than half a mile in diameter, and apparently quite flat and low, and was discovered by Bellinghausen; it is situated a little west of Caroline Island, but it is not placed on the French charts; I have not coloured it, although I entertain little doubt from the chart of Bellinghausen, that it originally contained a small lagoon.—*Penrhyn* Island (9° S., 158° W.); a plan of it in the "Atlas of the First Voyage" of Kotzebue, shows that it is an atoll; blue.—*Slarbuck* Island (5° S., 156° W.) is described in Byron's "Voyage in the *Blonde*" (p. 206) as formed of a flat coral-rock, with no trees; the height not given; not coloured. —*Malden* Island (4° S., 154° W.); in the same voyage (p. 205) this island is said to be of coral formation, and no part above forty feet high; I have not ventured to colour it, although, from being of coral-formation, it is probably fringed; in which case it should be red.—*Jarvis*, or *Bunker* Island (0° 20′ S., 160° W.) is described by Mr. F. D. Bennett (*Geograph. Journ.*, vol. vii, p. 227) as a narrow, low strip of coral-formation; not coloured.—*Brook*, is a small low island between the two latter; the position, and perhaps even the existence of it is doubtful; not coloured.

—*Pescado* and *Humphrey* Islands; I can find out nothing about these islands, except that the latter appears to be small and low; not coloured. —*Rearson*, or Grand Duke Alexander's (10° S., 161° W.); an atoll, of which a plan is given by Bellinghausen; blue.—*Souvoroff* Islands (13° S., 163° W.); Admiral Krusenstern, in the most obliging manner, obtained for me an account of these islands from Admiral Lazareff, who discovered them. They consist of five very low islands of coral-formation, two of which are connected by a reef, with deep water close to it. They do not surround a lagoon, but are so placed that a line drawn through them includes an oval space, part of which is shallow; these islets, therefore, probably once (as is the case with some of the islands in the Caroline Archipelago) formed a single atoll; but I have not coloured them.—*Danger* Island (10° S., 166° W.); described as low by Commodore Byron, and more lately surveyed by Bellinghausen; it is a small atoll with three islets on it; blue.—*Clarence* Island (9° S., 172° W.); discovered in the *Pandora* (G. Hamilton's "Voyage," p. 75): it is said, "in running along the land, we saw several canoes crossing the *lagoons*;" as this island is in the close vicinity of other low islands, and as it is said, that the natives make reservoirs of water in old cocoa-nut trees (which shows the nature of the land), I have no doubt it is an atoll, and have coloured it blue. *York* Island (8° S., 172° W.) is described by Commodore Byron (chap. x of his "Voyage") as an atoll; blue.—*Sydney* Island (4° S., 172° W.) is about three miles in diameter, with its interior occupied by a lagoon (Captain Tromelin, "Annal. Marit." 1829, p. 297); blue.—*Phoenix* Island (4° S., 171° W.) is nearly circular, low, sandy, not more than two miles in diameter, and very steep outside (Tromelin, "Annal. Marit." 1829, p. 297); it may be inferred that this island originally contained a lagoon, but I have not coloured it.—*New Nantucket* (0° 15′ N., 174° W.). From the French chart it must be a low island; I can find nothing more about it or about *Mary* Island; both uncoloured.—*Gardner* Island (5° S., 174° W.) from its position is certainly the same as *Kemin* Island described (Krusenstern, p. 435, Appen. to Mem., published 1827) as having a lagoon in its centre; blue.

ISLANDS SOUTH *of the Sandwich Archipelago.*

Christmas Island (2° N., 157° W.). Captain Cook, in his "Third Voyage" (vol. ii, chap. x), has given a detailed account of this atoll. The breadth of the islets on the reef is unusually great, and the sea near it does not deepen so suddenly as is generally the case. It has more lately been visited by Mr. F. D. Bennett (*Geograph. Journ.*, vol. vii, p. 226); and he assures me that it is low and of coral-formation: I particularly mention this, because it is engraved with a capital letter, signifying a high island, in D'Urville and Lottin's chart. Mr. Couthouy, also, has given some account of it ("Remarks," p. 46) from the Hawaiian "Spectator"; he believes it has lately undergone a small elevation, but his evidence does not appear to me satisfactory; the deepest part of the lagoon is said to be only ten feet; nevertheless, I have coloured it blue.—*Fanning* Island (4° N., 158° W.) according to Captain Tromelin ("Ann. Maritim.," 1829, p. 283), is an atoll: his account as observed by Krusenstern, differs from that given in Fanning's "Voyage" (p. 224), which, however, is far from clear; coloured blue.—*Washington* Island (4° N., 159° W.) is engraved as a low island in D'Urville's chart, but is described by Fanning (p. 226) as having a much greater elevation than Fanning Island, and hence I presume it is not an atoll; not coloured.—*Palmyra* Island (6° N., 162° W.) is an atoll divided into two parts (Krusenstern's "Mem. Suppl.," p. 50, also Fanning's "Voyage," p. 233); blue.—*Smyth's* or Johnston's Islands (17° N., 170° W.). Captain Smyth, R.N., has had the kindness to inform me that they consist of two very low, small islands, with a dangerous reef off the east end of them. Captain Smyth does not recollect whether these islets, together with the reef, surrounded a lagoon; uncoloured.

SANDWICH ARCHIPELAGO.—*Hawaii*; in the chart in Freycinet's "Atlas," small portions of the coast are fringed by reefs; and in the accompanying "Hydrog. Memoir," reefs are mentioned in several places, and the coral is said to injure the cables. On one side of the islet of Kohaihai there is a bank of sand and coral with five feet water on it, running parallel to the shore, and leaving a channel of about fifteen feet deep within. I have coloured this island red, but it is very much less perfectly fringed than others of the group.—*Maui*; in Freycinet's chart of the anchorage of Raheina, two or three miles of coast are seen to be fringed; and in the "Hydrog. Memoir," "banks of coral along shore" are spoken of. Mr. F. D. Bennett informs me that the reefs, on an average, extend about a quarter of a mile from the beach; the land is not very steep, and outside the reefs the sea does not become deep very suddenly; coloured red.—*Morotoi*, I presume, is fringed: Freycinet speaks of the breakers extending along the shore at a little distance from it. From the chart, I believe it is fringed; coloured red.—*Oahu*; Freycinet, in his "Hydrog. Memoir," mentions some of the reefs. Mr. F. D. Bennett informs me that the shore is skirted for forty or fifty miles in length. There is even a harbour for ships formed by the reefs, but it is at the mouth of a valley; red.—*Atooi*, in La Peyrouse's charts, is represented as fringed by a reef, in the same manner as Oahu and Morotoi; and this, as I have been informed by Mr. Ellis, on part at least of the shore, is of coral-formation: the reef does not leave a deep channel within; red.—*Oneehow*; Mr. Ellis believes that this island is also fringed by a coral-reef: considering its close proximity to the other islands, I have ventured to colour it red. I have in vain consulted the works of Cook, Vancouver, La Peyrouse, and Lisiansky, for any satisfactory account of the small islands and reefs, which lie scattered in a N.W. line prolonged from the Sandwich group, and hence have left them uncoloured, with one exception; for I am indebted to Mr. F. D. Bennett for informing me of an atoll-formed reef, in latitude 28° 22′, longitude 178° 30′ W., on which the *Gledstanes* was wrecked in 1837. It is apparently of large size, and extends in a N.W. and S.E. line: very few islets have been formed on it. The lagoon seems to be shallow; at least, the deepest part which was surveyed was only three fathoms. Mr. Couthouy ("Remarks," p. 38) describes this island under the name of *Ocean* island. Considerable doubts should be entertained regarding the nature of a reef of this kind, with a very shallow lagoon, and standing far from any other atoll, on account of the possibility of a crater or flat bank of rock lying at the proper depth beneath the surface of the water, thus affording a foundation for a ring-formed coral-reef. I have, however, thought myself compelled, from its large size and symmetrical outline, to colour it blue.

SAMOA or NAVIGATOR GROUP.—Kotzebue, in his "Second Voyage," contrasts the structure of these islands with many others in the Pacific, in not being furnished with harbours for ships, formed by distant coral-reefs. The Rev. J. Williams, however, informs me, that coral-reefs do occur in irregular patches on the shores of these islands; but that they do not form a continuous band, as round Mangaia, and other such perfect cases of fringed islands. From the charts accompanying La Peyrouse's "Voyage," it appears that the north shore of *Savaii, Maouna, Orosenga*, and *Manua*, are fringed by reefs. La Peyrouse, speaking of Maouna (p. 126), says that the coral-reef surrounding its shores, almost touches the beach; and is breached in front of the little coves and streams, forming passages for canoes, and probably even for boats. Further on (p. 159), he extends the same observation to all the islands which he visited. Mr. Williams in his "Narrative," speaks of a reef going round a small island attached to *Oyolava*, and returning again to it: all these islands have been coloured red.—A chart of *Rose* Island, at the extreme west end of the group, is given by Freycinet, from which I should have thought that it had been an atoll; but according to Mr. Couthouy ("Remarks," p. 43), it consists of a reef, only a league in circuit, surmounted by a very few low islets; the lagoon is very shallow, and is strewed with numerous large boulders of volcanic rock. This island, therefore, probably consists of a bank of rock, a few feet submerged, with the outer margin of its upper surface fringed with reefs; hence it cannot be properly classed with atolls, in which the foundations are always supposed to lie at a depth, greater than that at which the reef-constructing polypifers can live; not coloured.

Beveridge Reef, 20° S., 167° W., is described in the *Naut. Mag.* (May 1833, p. 442) as ten miles long in a N. and S. line, and eight wide; "in the inside of the reef there appears deep water;" there is a passage near the S.W. corner: this therefore seems to be a submerged atoll, and is coloured blue.

Savage Island, 19° S., 170° W., has been described by Cook and Forster. The younger Forster (vol. ii, p. 163) says it is about forty feet high: he suspects that it contains a low plain, which formerly was the lagoon. The Rev. J. Williams informs me that the reef fringing its shores, resembles that round Mangaia; coloured red.

FRIENDLY ARCHIPELAGO.—*Pylstaart* Island. Judging from the chart in Freycinet's "Atlas," I should have supposed that it had been regularly fringed; but as nothing is said in the "Hydrog. Memoir" (or in the "Voyage" of Tasman, the discoverer) about coral-reefs, I have left it uncoloured.—*Tongatabou*: In the "Atlas of the Voyage of the *Astrolabe*," the whole south side of the island is represented as narrowly fringed by the same reef which forms an extensive platform on the northern side. The origin of this latter reef, which might have been mistaken for a barrier-reef, has already been attempted to be explained, when giving the proofs of the recent elevation of this island.—In Cook's charts the little outlying island also of *Eoaigee*, is represented as fringed; coloured red.—*Eoua.* I cannot make out from Captain Cook's charts and descriptions, that this island has any reef, although the bottom of the neighbouring sea seems to be corally, and the island itself is formed of coral-rock.

Forster, however, distinctly ("Observations," p. 14) classes it with high islands having reefs, but it certainly is not encircled by a barrier-reef and the younger Forster ("Voyage," vol. i, p. 426) says, that "a bed of coral-rocks surrounded the coast towards the landing-place." I have therefore classed it with the fringed islands and coloured it red. The several islands lying N.W. of Tongatabou, namely *Anamouka, Komango, Kotou, Lefouga, Foa*, etc., are seen in Captain Cook's chart to be fringed by reefs, in several of them are connected together. From the various statements in the first volume of Cook's "Third Voyage," and especially in the fourth and sixth chapters, it appears that these reefs are of coral-formation, and certainly do not belong to the barrier class; coloured red. —*Toufoa and Kao*, forming the western part of the group, according to Forster have no reefs; the former is an active volcano.—*Vavao.* There is a chart of this singularly formed island, by Espinoza: according to Mr. Williams it consists of coral-rock: the Chevalier Dillon informs me that it is not fringed; not coloured. Nor are the islands of *Latte* and *Amargura*, for I have not seen plans on a large scale of them, and do not know whether they are fringed.

Niouha, 16° S., 174° W., or *Keppel* Island of Wallis, or *Cocos* Island. From a view and chart of this island given in Wallis's "Voyage" (4to ed.) it is evidently encircled by a reef; coloured blue: it is however remarkable that *Boscawen* Island, immediately adjoining, has no reef of any kind; uncoloured.

Wallis Island, 13° S., 176° W., a chart and view of this island in Wallis's "Voyage" (4to ed.) shows that it is encircled. A view of it in the *Naut. Mag.*, July 1833, p. 376, shows the same fact; blue.

Alloufatou, or *Horn* Island, *Onouafu*, or *Proby* Island, and *Hunter* Islands, lie between the Navigator and Fidji groups. I can find no distinct accounts of them.

FIDJI or VITI GROUP.—The best chart of the numerous islands of this group, will be found in the "Atlas of the *Astrolabe's* Voyage." From this, and from the description given in the "Hydrog. Memoir," accompanying it, it appears that many of these islands are bold and mountainous, rising to the height of between 3,000 and 4,000 feet. Most of the islands are surrounded by reefs, lying far from the land, and outside of which the ocean appears very deep. The *Astrolabe* sounded with ninety fathoms in several places about a mile from the reefs, and found no bottom. Although the depth within the reef is not laid down, it is evident from several expressions, that Captain D'Urville believes that ships could anchor within, if passages existed through the outer barriers. The Chevallier Dillon informs me that this is the case: hence I have coloured this group blue. In the S.E. part lies *Batoa*, or *Turtle* Island of Cook ("Second Voyage," vol. ii, p. 23, and chart, 4to ed.) surrounded by a coral-reef, "which in some places extends two miles from the shore;" within the reef the water appears to be deep, and outside it is unfathomable; coloured pale blue. At the distance of a few miles, Captain Cook (*Ibid.*, p. 24) found a circular coral-reef, four or five leagues in circuit, with deep water within; "in short, the bank wants only a few little islets to make it exactly like one of the half-drowned isles so often mentioned,"—namely, atolls. South of Batoa, lies the high island of *Ono*, which appears in Bellinghausen's "Atlas" to be encircled; as do some other small islands to the south; coloured pale blue; near Ono, there is an annular reef, quite similar to the one just described in the words of Captain Cook; coloured dark blue.

Rotoumah, 13° S., 179° E.—From the chart in Duperrey's "Atlas," I thought this island was encircled, and had coloured it blue, but the Chevallier Dillon assures me that the reef is only a shore or fringing one; red.

Independence Island, 10° S., 179° E., is described by Mr. G. Bennett, (*United Service Journ.*, 1831, part ii, p. 197) as a low island of coral-formation, it is small, and does not appear to contain a lagoon, although an opening through the reef is referred to. A lagoon probably once existed, and has since been filled up; left uncoloured.

ELLICE GROUP.—*Oscar, Peyster*, and *Ellice* Islands are figured in Arrowsmith's "Chart of the Pacific" (corrected to 1832) as atolls, and are said to be very low; blue.—*Nederlandisch* Island. I am greatly indebted to the kindness of Admiral Krusenstern, for sending me the original documents concerning this island. From the plans given by Captains Eeg and Khremtshenko, and from the detailed account given by the former, it appears that it is a narrow coral-island, about two miles long, containing a small lagoon. The sea is very deep close to the shore, which is fronted by sharp coral-rocks. Captain Eeg compares the lagoon with that of other coral-islands; and he distinctly says, the land is "very low." I have therefore coloured it blue. Admiral Krusenstern ("Memoir on the Pacific," Append., 1835) states that its shores are eighty feet high; this probably arose from the height of the cocoa-nut trees, with which it is covered, being mistaken for land.—*Gran Cocal* is said in Krusenstern's "Memoir," to be low, and to be surrounded by a reef; it is small, and therefore probably once contained a lagoon; uncoloured.—*St. Augustin.* From a chart and view of it, given in the "Atlas of the *Coquille's* Voyage," it appears to be a small atoll, with its lagoon partly filled up; coloured blue.

GILBERT GROUP.—The chart of this group, given in the "Atlas of the *Coquille's* Voyage," at once shows that it is composed of ten well characterised atolls. In D'Urville and Lottin's chart, *Sydenham* is written with a capital letter, signifying that it is high; but this certainly is not the case, for it is a perfectly characterised atoll, and a sketch, showing how low it is, is given in the "*Coquille's* Atlas." Some narrow strip-like reefs project from the southern side of *Drummond* atoll, and render it irregular. The southern island of the group is called *Chase* (in some charts, *Rotches*); of this I can find no account, but Mr. F. D. Bennett discovered (*Geograph. Journ.*, vol. vii, p. 229), a low extensive island in nearly the same latitude, about three degrees westward of the longitude assigned to Rotches, but very probably it is the same island. Mr. Bennett informs me that the man at the masthead reported an appearance of lagoon-water in the centre; and, therefore, considering its position, I have coloured it blue.—*Pitt* Island, at the extreme northern point of the group, is left uncoloured, as its exact position and nature is not known. —*Byron* Island, which lies a little to the eastward, does not appear to have been visited since Commodore Byron's voyage, and it was then seen only from a distance of eighteen miles; it is said to be low; uncoloured.

Ocean, Pleasant, and *Atlantic* Islands all lie considerably to the west of the Gilbert group: I have been unable to find any distinct account of them. Ocean Island is written with small letters in the French chart, but in Krusenstern's "Memoir" it is said to be high.

MARSHALL GROUP.—We are well acquainted with this group from the excellent charts of the separate islands, made during the two voyages of Kotzebue: a reduced one of the whole group may be easily seen in Krusenstern's "Atlas," and in Kotzebue's "Second Voyage." The group consists (with the exception of two *little* islands which probably have had their lagoon filled up) of a double row of twenty-three large and well-characterised atolls, from the examination of which Chamisso has given us his well-known account of coral-formations. I include *Gaspar Rico*, or *Cornwallis* Island in this group, which is described by Chamisso (Kotzebue's "First Voyage," vol. iii, p. 179) "as a low sickle-formed group, with mould only on the windward side." Gaspard Island is considered by some geographers as a distinct island lying N.E. of the group, but it is not entered in the chart by Krusenstern; left uncoloured. In the S.W. part of this group lies *Baring* Island, of which little is known (see Krusenstern's "Appendix," 1835, p. 149). I have left it uncoloured; but *Boston* Island I have coloured blue, as it is described (*Ibid.*) as consisting of fourteen small islands, which, no doubt, enclose a lagoon, as represented in a chart in the "'Coquille's' Atlas."—Two islands, *Aur Kawen* and *Gaspar Rico*, are written in the French chart with capital letters; but this is an error, for from the account given by Chamisso in Kotzebue's "First Voyage," they are certainly low. The nature, position, and even existence, of the shoals and small islands north of the Marshall group, are doubtful.

NEW HEBRIDES.—Any chart, on even a small scale, of these islands, will show that their shores are almost without reefs, presenting a remarkable contrast with those of New Caledonia on the one hand, and the Fidji group on the other. Nevertheless, I have been assured by Mr. G. Bennett, that coral grows vigorously on their shores; as indeed, will be further shown in some of the following notices. As, therefore, these islands are not encircled, and as coral grows vigorously on their shores, we might almost conclude, without further evidence, that they were fringed, and hence I have applied the red colour with rather greater freedom than in other instances.—*Matthew's Rock*, an active volcano, some way south of the group (of which a plan is given in the "Atlas of the *Astrolabe's* Voyage") does not appear to have reefs of any kind about it. —*Annatom*, the southernmost of the Hebrides; from a rough woodcut given in the *United Service Journal* (1831, part iii, p. 190), accompanying a paper by Mr. Bennett, it appears that the shore is fringed; coloured red.—*Tanna.* Forster, in his "Observations" (p. 22), says Tanna has on its shores coral-rock and madrepores; and the younger Forster, in his account (vol. ii, p. 269) speaking of the harbour says, the whole S.E. side consists of coral-reefs, which are overflowed at high-water; part of the southern shore in Cook's chart is represented as fringed; coloured red. —*Immer* is described (*United Service Journal,* 1831, part iii, p. 192) by Mr. Bennett as being of moderate elevation, with cliffs appearing like sandstone: coral grows in patches on its shore, but I have not coloured it; and I mention these facts, because Immer might have been thought from Forster's classification ("Observations," p. 14), to have been a low island or even an atoll.—*Erromango* Island; Cook ("Second Voyage," vol. ii, p. 45, 4to ed.) speaks of rocks everywhere *lining* the coast, and the natives offered to haul his boat over the breakers to the sandy beach: Mr. Bennett, in a letter to the Editor of the *Singapore Chron.*, alludes to the *reefs* on its shores. It may, I think, be safely inferred from these passages that the shore is fringed in parts by coral-reefs; coloured red. —*Sandwich* Island. The east coast is said (Cook's "Second Voyage," vol. ii, p. 41) to be low, and to be guarded by a chain of breakers. In the accompanying chart it is seen to be fringed by a reef; coloured red. —*Mallicollo.* Forster speaks of the reef-bounded shore: the reef is about thirty yards wide, and so shallow that a boat cannot pass over it. Forster also ("Observations," p. 23) says, that the rocks of the sea-shore consist of madrepore. In the plan of Sandwich harbour, the headlands are represented as fringed; coloured red.—*Aurora* and *Pentecost* Islands, according to Bougainville, apparently have no reefs; nor has the large island of *S. Espiritu*, nor *Bligh* Island or *Banks'* Islands, which latter lie to the N.E. of the Hebrides. But in none of these cases, have I met with any detailed account of their shores, or seen plans on a large scale; and it will be evident, that a fringing-reef of only thirty or even a few hundred yards in width, is of so little importance to navigation, that it will seldom be noticed, excepting by chance; and hence I do not doubt that several of these islands, now left uncoloured, ought to be red.

SANTA CRUZ GROUP.—*Vanikoro* (Fig. 1, Plate I) offers a striking example of a barrier- reef: it was first described by the Chevalier Dillon, in his voyage, and was surveyed in the *Astrolabe*; coloured pale blue. —*Tikopia* and *Fataka* Islands appear, from the descriptions of Dillon and D'Urville, to have no reefs; *Anouda* is a low, flat island, surrounded by cliffs ("*Astrolabe* Hydrog." and Krusenstern, "Mem." vol. ii, p. 432); these are uncoloured. *Toupoua* (*Otooboa* of Dillon) is stated by Captain Tromelin ("Annales Marit." 1829, p. 289) to be almost entirely included in a reef, lying at the distance of two miles from the shore. There is a space of three miles without any reef, which, although indented with bays, offers no anchorage from the extreme depth of the water close to the shore: Captain Dillon also speaks of the reefs fronting this island; coloured blue.—*Santa-Cruz.* I have carefully examined the works of Carteret, D'Entrecasteaux, Wilson, and Tromelin, and I cannot discover any mention of reefs on its shores; left uncoloured.—*Tinakoro* is a constantly active volcano without reefs.—*Mendana Isles* (mentioned by Dillon under the name of *Mammee*, etc.); said by Krusenstern to be low, and intertwined with reefs. I do not believe they include a lagoon; I have left them uncoloured.—*Duff's* Islands compose a small group directed in a N.W. and S.E. band; they are described by Wilson (p. 296, "Miss. Voy." 4to ed.), as formed by bold-peaked land, with the islands surrounded by coral-reefs, extending about half a mile from the shore; at a distance of a mile from the reefs he found only seven fathoms. As I have no reason for supposing there is deep water within these reefs, I have coloured them red. *Kennedy* Island, N.E. of Duff's. I have been unable to find any account of it.

NEW CALEDONIA.—The great barrier-reefs on the shores of this island have already been described (Fig. 5, Plate II). They have been visited by Labillardiere, Cook, and the northern point by D'Urville; this latter part so closely resembles an atoll that I have coloured it dark blue. The *Loyalty* group is situated eastward of this island; from the chart and description given in the "Voyage of the *Astrolabe*," they do not appear to have any reefs; north of this group, there are some extensive low reefs (called *Astrolabe* and *Beaupré*,) which do not seem to be atoll-formed; these are left uncoloured.

AUSTRALIAN BARRIER-REEF.—The limits of this great reef, which has already been described, have been coloured from the charts of Flinders and King. In the northern parts, an atoll-formed reef, lying outside the barrier, has been described by Bligh, and is coloured dark blue. In the space between Australia and New Caledonia, called by Flinders the

Corallian Sea, there are numerous reefs. Of these, some are represented in Krusenstern's "Atlas" as having an atoll-like structure; namely, *Bampton* shoal, *Frederic, Vine* or Horse-shoe, and *Alert* reefs; these have been coloured dark blue.

LOUISIADE.—The dangerous reefs which front and surround the western, southern, and northern coasts of this so-called peninsula and archipelago, seem evidently to belong to the barrier class. The land is lofty, with a low fringe on the coast; the reefs are distant, and the sea outside them profoundly deep. Nearly all that is known of this group is derived from the labours of D'Entrecasteaux and Bougainville: the latter has represented one continuous reef ninety miles long, parallel to the shore, and in places as much as ten miles from it; coloured pale blue. A little distance northward we have the *Laughlan* Islands, the reefs round which are engraved in the "Atlas of the Voyage of the *Astrolabe*," in the same manner as in the encircled islands of the Caroline Archipelago, the reef is, in parts, a mile and a half from the shore, to which it does not appear to be attached; coloured blue. At some little distance from the extremity of the Louisiade lies the *Wells* reef, described in G. Hamilton's "Voyage in H.M.S. *Pandora*" (p. 100): it is said, "We found we had got embayed in a double reef, which will soon be an island." As this statement is only intelligible on the supposition of the reef being crescent or horse-shoe formed, like so many other submerged annular reefs, I have ventured to colour it blue.

SOLOMON ARCHIPELAGO.—The chart in Krusenstern's "Atlas" shows that these islands are not encircled, and as coral appears from the works of Surville, Bougainville, and Labillardiere, to grow on their shores, this circumstance, as in the case of the New Hebrides, is a presumption that they are fringed. I cannot find out anything from D'Entrecasteaux's "Voyage," regarding the southern islands of the group, so have left them uncoloured.—*Malayta* Island in a rough MS. chart in the Admiralty has its northern shore fringed.—*Ysabel* Island, the N.E. part of this island, in the same chart, is also fringed: Mendana, speaking (Burney, vol. i, p. 280) of an islet adjoining the northern coast, says it is surrounded by reefs; the shores, also of Port Praslin appear regularly fringed.—*Choiseul* Island. In Bougainville's "Chart of Choiseul Bay," parts of the shores are fringed by coral-reefs.—*Bougainville* Island. According to D'Entrecasteaux the western shore abounds with coral-reefs, and the smaller islands are said to be attached to the larger ones by reefs; all the before-mentioned islands have been coloured red.—*Bouka* Islands. Captain Duperrey has kindly informed me in a letter that he passed close round the northern side of this island (of which a plan is given in his "Atlas of the *Coquille's* Voyage"), and that it was "garnie d'une bande de récifs à fleur d'eau adherentes au rivage;" and he infers, from the abundance of coral on the islands north and south of Bouka, that the reef probably is of coral; coloured red.

Off the north coast of the Solomon Archipelago there are several small groups which are little known; they appear to be low, and of coral-formation; and some of them probably have an atoll-like structure; the Chevallier Dillon, however, informs me that this is not the case with the B. de *Candelaria.—Outong Java*, according to the Spanish navigator, Maurelle, is thus characterised; but this is the only one which I have ventured to colour blue.

NEW IRELAND.—The shores of the S.W. point of this island and some adjoining islets, are fringed by reefs, as may be seen in the "Atlases of the Voyages of the *Coquille* and *Astrolabe*." M. Lesson observes that the reefs are open in front of each streamlet. The *Duke of York's* Island is also fringed; but with regard to the other parts of *New Ireland, New Hanover*, and the small islands lying northward, I have been unable to obtain any information. I will only add that no part of New Ireland appears to be fronted by distant reefs. I have coloured red only the above specified portions.

NEW BRITAIN AND THE NORTHERN SHORE OF NEW GUINEA.—From the charts in the "Voyage of the *Astrolabe*," and from the "Hydrog. Memoir," it appears that these coasts are entirely without reefs, as are the *Schouten* Islands, lying close to the northern shore of New Guinea. The western and south-western parts of New Guinea, will be treated of when we come to the islands of the East Indian Archipelago.

ADMIRALTY GROUP.—From the accounts by Bougainville, Maurelle, D'Entrecasteaux, and the scattered notices collected by Horsburgh, it appears, that some of the many islands composing it, are high, with a bold outline; and others are very low, small and interlaced with reefs. All the high islands appear to be fronted by distant reefs rising abruptly from the sea, and within some of which there is reason to believe that the water is deep. I have therefore little doubt they are of the barrier class.—In the southern part of the group we have *Elizabeth* Island, which is surrounded by a reef at the distance of a mile; and two miles eastward of it (Krusenstern, "Append." 1835, p. 42) there is a little island containing a lagoon.—Near here, also lies *Circular-reef* (Horsburgh, "Direct.," vol. i, p. 691, 4th ed.), "three or four miles in diameter having deep water inside with an opening at the N.N.W. part, and on the outside steep to." I have from these data, coloured the group pale blue, and *Circular-reef* dark blue.—The *Anachorites, Echequier*, and *Hermites*, consist of innumerable low islands of coral-formation, which probably have atoll-like forms; but not being able to ascertain this, I have not coloured them, nor *Durour* Island, which is described by Carteret as low.

The CAROLINE ARCHIPELAGO is now well-known, chiefly from the hydrographical labours of Lutké; it contains about forty groups of atolls, and three encircled islands, two of which are engraved in Figs 2 and 7, Plate I. Commencing with the eastern part; the encircling reef round *Ualen* appears to be only about half a mile from the shore; but as the land is low and covered with mangroves ("Voyage autour du Monde," par F. Lutké, vol. i, p. 339), the real margin has not probably been ascertained. The extreme depth in one of the harbours within the reef is thirty-three fathoms (see charts in "Atlas of *Coquille's* Voyage"), and outside at half a mile distant from the reef, no bottom was obtained with two hundred and fifty fathoms. The reef is surmounted by many islets, and the lagoon-like channel within is mostly shallow, and appears to have been much encroached on by the low land surrounding the central mountains; these facts show that time has allowed much detritus to accumulate; coloured pale blue.—*Pouynipète*, or Seniavine. In the greater part of the circumference of this island, the reef is about one mile and three quarters distant; on the north side it is five miles off the included high islets. The reef is broken in several places; and just within it, the depth in one place is thirty fathoms, and in another, twenty-eight, beyond which, to all appearance, there was "un porte vaste et sur" (Lutké, vol. ii, p. 4); coloured pale blue.—*Hogoleu* or *Roug*. This wonderful group contains at least sixty-two islands, and its reef is one hundred and thirty-five miles in circuit. Of the islands, only a few, about six or eight (see "Hydrog. Descrip." p. 428, of the "Voyage of the *Astrolabe*," and the large accompanying chart taken chiefly from that given by Duperrey) are high, and the rest are all small, low, and formed on the reef. The depth of the great interior lake has not been ascertained; but Captain D'Urville appears to have entertained no doubt about the possibility of taking in a frigate. The reef lies no less than fourteen miles distant from the northern coasts of the interior high islands, seven from their western sides, and twenty from the southern; the sea is deep outside. This island is a likeness on a grand scale to the Gambier group in the Low Archipelago. Of the groups of low[1] islands forming the chief part of the Caroline Archipelago, all those of larger size, have the true atoll-structure (as may be seen in the "Atlas" by Captain Lutké), and some even of the very small ones, as *Macaskill* and *Duperrey*, of which plans are given in the "Atlas of the *Coquille's* Voyage." There are, however, some low small islands of coral-formation, namely *Ollap, Tamatam, Bigali, Satahoual*, which do not contain lagoons; but it is probable that lagoons originally existed, but have since filled up: Lutké (vol. ii, p. 304) seems to have thought that all the low islands, with only one exception, contained lagoons. From the sketches, and from the manner in which the margins of these islands are engraved in the "Atlas of the Voyage of the *Coquille*," it might have been thought that they were not low; but by a comparison with the remarks of Lutké (vol. ii, p. 107, regarding Bigali) and of Freycinet ("Hydrog. Memoir *L'Uranie* Voyage," p. 188, regarding Tamatam, Ollap, etc.), it will be seen that the artist must have represented the land incorrectly. The most southern island in the group, namely *Piguiram*, is not coloured, because I have found no account of it. *Nougouor*, or *Monte Verdison*, which was not visited by Lutké, is described and figured by Mr. Bennett (*United Service Journal*, January 1832) as an atoll. All the above-mentioned islands have been coloured blue.

[1] In D'Urville and Lottin's chart, Peserare is written with capital letters; but this evidently is an error, for it is one of the low islets on the reef of Namonouyto (see Lutké's charts)—a regular atoll.

WESTERN PART OF THE CAROLINE ARCHIPELAGO.—*Fais* Island is ninety feet high, and is surrounded, as I have been informed by Admiral Lutké, by a narrow reef of living coral, of which the broadest part, as represented in the charts, is only 150 yards; coloured red.—*Philip* Island., I believe, is low; but Hunter, in his "Historical Journal," gives no clear account of it; uncoloured.—*Elivi*; from the manner in which the islets on the reefs are engraved, in the "Atlas of the *Astrolabe's* Voyage," I should have thought they were above the ordinary height, but Admiral Lutké assures me this is not the case: they form a regular atoll; coloured blue.—*Gouap* (*Eap* of Chamisso), is a high island with a reef (see chart in "Voyage of the *Astrolabe*"), more than a mile distant in most parts from the shore, and two miles in one part. Captain D'Urville thinks that there would be anchorage ("Hydrog. Descript. *Astrolabe* Voyage," p. 436) for ships within the reef, if a passage could be found; coloured pale blue.—*Goulou*, from the chart in the "*Astrolabe's* Atlas," appears to be an atoll. D'Urville ("Hydrog. Descript." p. 437) speaks of the low islets on the reef; coloured dark blue.

PELEW ISLANDS.—Krusenstern speaks of some of the islands being mountainous; the reefs are distant from the shore, and there are spaces within them, and not opposite valleys, with from ten to fifteen fathoms. According to a MS. chart of the group by Lieutenant Elmer in the Admiralty, there is a large space within the reef with deepish water; although the high land does not hold a central position with respect to the reefs, as is generally the case, I have little doubt that the reefs of the Pelew Islands ought to be ranked with the barrier class, and I have coloured them pale blue. In Lieutenant Elmer's chart there is a horseshoe-formed shoal, laid down thirteen miles N.W. of Pelew, with fifteen fathoms within the reef, and some dry banks on it; coloured dark blue.—*Spanish, Martires, Sanserot, Pulo Anna* and *Mariere* Islands are not coloured, because I know nothing about them, excepting that according to Krusenstern, the second, third, and fourth mentioned, are low, placed on coral-reefs, and therefore, perhaps, contain lagoons; but Pulo Mariere is a little higher.

MARIANA ARCHIPELAGO, or LADRONES.—*Guahan.* Almost the whole of this island is fringed by reefs, which extend in most parts about a third of a mile from the land. Even where the reefs are most extensive, the water within them is shallow. In several parts there is a navigable channel for boats and canoes within the reefs. In Freycinet's "Hydrog. Mem." there is an account of these reefs, and in the "Atlas," a map on a large scale; coloured red.—*Rota*. "L'ile est presque entièrement entourée des récifs" (p. 212, Freycinet's "Hydrog. Mem."). These reefs project about a quarter of a mile from the shore; coloured red.—*Tinian. The eastern* coast is precipitous, and is without reefs; but the western side is fringed like the last island; coloured red.—*Saypan*. The N.E. coast, and likewise the western shores appear to be fringed; but there is a great, irregular, horn-like reef projecting far from this side; coloured red.—*Farallon de Medinilla*, appears so regularly and closely fringed in Freycinet's charts, that I have ventured to colour it red, although nothing is said about reefs in the "Hydrographical Memoir." The several islands which form the northern part of the group are volcanic (with the exception perhaps of Torres, which resembles in form the madreporitic island of Medinilla), and appear to be without reefs.—*Mangs*, however, is described (by Freycinet, p. 219, "Hydrog.") from some Spanish charts, as formed of small islands placed "au milieu des nombreux récifs;" and as these reefs in the general chart of the group do not project so much as a mile; and as there is no appearance from a double line, of the existence of deep water within, I have ventured, although with much hesitation, to colour them red. Respecting *Folger* and *Marshall* Islands which lie some way east of the Marianas, I can find out nothing, excepting that they are probably low. Krusenstern says this of Marshall Island; and Folger Island is written with small letters in D'Urville's chart; uncoloured.

BONIN OR ARZOBISPO GROUP.—*Peel* Island has been examined by Captain Beechey, to whose kindness I am much indebted for giving me information regarding it: "At Port Lloyd there is a great deal of coral; and the inner harbour is entirely formed by coral-reefs, which extend outside the port along the coast." Captain Beechey, in another part of his letter to me, alludes to the reefs fringing the island in all directions; but at the same time it must be observed that the surf washes the volcanic rocks of the coast in the greater part of its circumference. I do not know whether the other islands of the Archipelago are fringed; I have coloured Peel Island red.—*Grampus* Island to the eastward, does not appear (Meare's "Voyage," p. 95) to have any reefs, nor does *Rosario* Island (from Lutké's chart), which lies to the westward. Respecting the few other islands in this part of the sea, namely the *Sulphur* Islands, with an active volcano, and those lying between Bonin and Japan (which are situated near the extreme limit in latitude, at which reefs are formed), I have not been able to find any clear account.

WEST END OF NEW GUINEA.—*Port Dory.* From the charts in the "Voyage of the *Coquille*," it would appear that the coast in this part is fringed by coral-reefs; M. Lesson, however, remarks that the coral is sickly; coloured red.—*Waigiou.* A considerable portion of the northern shores of these islands is seen in the charts (on a large scale) in Freycinet's "Atlas" to be fringed by coral-reefs. Forrest (p. 21, "Voyage to New Guinea") alludes to the coral-reefs lining the heads of Piapis Bay; and Horsburgh (vol. ii, p. 599, 4th edit.), speaking of the islands in Dampier Strait, says "sharp coral-rocks line their shores;" coloured red.—In the sea north of these islands, we have *Guedes* (or *Freewill*, or *St. David's*), which from the chart given in the 4to edit. of Carteret's "Voyage," must be an atoll. Krusenstern says the islets are very low; coloured blue.—*Carteret's Shoals*, in 2° 53′ N., are described as circular, with stony points showing all round, with deeper water in the middle; coloured blue.—*Aiou*; the plan of this group, given in the "Atlas of the Voyage of the *Astrolabe*," shows that it is an atoll; and, from a chart in Forrest's "Voyage," it appears that there is twelve fathoms within the circular reef; coloured blue.—The S.W. coast of New Guinea appears to be low, muddy, and devoid of reefs. The *Arru, Timor-laut*, and *Tenimber* groups have lately been examined by Captain Kolff, the MS. translation of which, by Mr. W. Earl, I have been permitted to read, through the kindness of Captain Washington, R.N. These islands are mostly rather low, and are surrounded by distant reefs (the Ki Islands, however, are lofty, and, from Mr. Stanley's survey, appear without reefs); the sea in some parts is shallow, in others profoundly deep (as near Larrat). From the imperfection of the published charts, I have been unable to decide to which class these reefs belong. From the distance to which they extend from the land, where the sea is very deep, I am strongly inclined to believe they ought to come within the barrier class, and be coloured blue; but I have been forced to leave them uncoloured.—The last-mentioned groups are connected with the east end of Ceram by a chain of small islands, of which the small groups of *Ceram-laut, Goram* and *Keffing* are surrounded by very extensive reefs, projecting into deep water, which, as in the last case, I strongly suspect belong to the barrier class; but I have not coloured them. From the south side of Keffing, the reefs project five miles (Windsor Earl's "Sailing Direct. for the Arafura Sea," p. 9).

CERAM.—In various charts which I have examined, several parts of the coast are represented as fringed by reefs.—*Manipa* Island, between Ceram and Bourou, in an old MS. chart in the Admiralty, is fringed by a very irregular reef, partly dry at low water, which I do not doubt is of coral-formation; both islands coloured red.—*Bourou*; parts of this island appear fringed by coral-reefs, namely, the eastern coast, as seen in Freycinet's chart; and *Cajeli Bay*, which is said by Horsburgh (vol. ii, p. 630) to be lined by coral-reefs, that stretch out a little way, and have only a few feet water on them. In several charts, portions of the islands forming the AMBOINA GROUP are fringed by reefs; for instance, *Noessa, Harenca*, and *Ucaster*, in Freycinet's charts. The above-mentioned islands have been coloured red, although the evidence is not very satisfactory.—North of Bourou the parallel line of the *Xulla* Isles extends: I have not been able to find out anything about them, excepting that Horsburgh (vol. ii, p. 543) says that the northern shore is surrounded by a reef at the distance of two or three miles; uncoloured.—*Mysol Group*; the Kanary Islands are said by Forrest ("Voyage," p. 130) to be divided from each other by deep straits, and are lined with coral-rocks; coloured red.—*Guebe*, lying between Waigiou and Gilolo, is engraved as if fringed; and it is said by Freycinet, that all the soundings under five fathoms were on coral; coloured red.—*Gilolo*. In a chart published by Dalrymple, the numerous islands on the western, southern (*Batchian* and the *Strait of Patientia*), and eastern sides appear fringed by narrow reefs; these reefs, I suppose, are of coral, for it is said in "Malte Brun" (vol. xii, p. 156), "Sur les côtes (of Batchian) comme *dans les plupart* des iles de cet archipel, il y a de rocs de médrepores d'une beauté et d'une variété infimies." Forrest, also (p. 50), says Seland, near Batchian, is a little island with reefs of coral; coloured red.—*Morty* Island (north of Gilolo). Horsburgh (vol. ii, p. 506) says the northern coast is lined by reefs, projecting one or two miles, and having no soundings close to them; I have left it uncoloured, although, as in some former cases, it ought probably to be pale blue.—*Celebes.* The western and northern coasts appear in the charts to be bold and without reefs. Near the extreme northern point, however, an islet in the *Straits of Limbe*, and parts of the adjoining shore, appear to be fringed: the east side of the bay of *Manado*, has deep water, and is fringed by sand and coral ("*Astrol.* Voyage," Hydrog. Part, pp. 453-4); this extreme point, therefore, I have coloured red.—Of the islands leading from this point to Magindanao, I have not been able to find any account, except of *Serangani*, which appears surrounded by narrow reefs; and Forrest ("Voyage," p. 164) speaks of coral on its shores; I have, therefore, coloured this island red. To the eastward of this chain lie several islands; of which I cannot find any account, except of *Karkalang*, which is said by Horsburgh (vol. ii, p. 504) to be lined by a dangerous reef, projecting several miles from the northern shore; not coloured.

ISLANDS NEAR TIMOR.—The account of the following islands is taken from Captain D. Kolff's "Voyage," in 1825, translated by Mr. W. Earl, from the Dutch.—*Lette* has "reefs extending along shore at the distance of half a mile from the land."—*Moa* has reefs on the S.W. part.—*Lakor* has a reef lining its shore; these islands are coloured red.—Still more eastward, *Luan* has, differently from the last-mentioned islands, an extensive reef; it is steep outside, and within there is a depth of twelve feet; from these facts, it is impossible to decide to which class this island belongs.—*Kissa*, off the point of Timor, has its "shore fronted by a reef, steep too on the outer side, over which small proahs can go at the time of high water;" coloured red.—*Timor*; most of the points, and some considerable spaces of the northern shore, are seen in Freycinet's chart to be fringed by coral-reefs; and mention is made of them in the accompanying "Hydrog. Memoir;" coloured red.—*Savu*, S.E. of Timor, appears in Flinders' chart to be fringed; but I have not coloured it, as I do not know that the reefs are of coral.—*Sandalwood* Island has, according to Horsburgh (vol. ii, p. 607), a reef on its southern shore, four miles distant from the land; as the neighbouring sea is deep, and generally bold, this probably is a barrier-reef, but I have not ventured to colour it.

N.W. COAST OF AUSTRALIA.—It appears, in Captain King's Sailing Directions ("Narrative of Survey," vol. ii, pp. 325-369), that there are many extensive coral-reefs skirting, often at considerable distances, the N.W. shores, and encompassing the small adjoining islets. Deep water, in no instance, is represented in the charts between these reefs and the land; and, therefore, they probably belong to the fringing class. But as they extend far into the sea, which is generally shallow, even in places where the land seems to be somewhat precipitous; I have not coloured them. Houtman's Abrolhos (lat. 28° S. on west coast) have lately been surveyed by Captain Wickham (as described in *Naut. Mag.* 1841, p. 511): they lie on the edge of a steeply shelving bank, which extends about thirty miles seaward, along the whole line of coast. The two southern reefs, or islands, enclose a lagoon-like space of water, varying in depth from five to fifteen fathoms, and in one spot with twenty-three fathoms. The greater part of the island has been formed on their inland sides, by the accumulation of fragments of coral; the seaward face consisting of nearly bare ledges of rock. Some of the specimens, brought home by Captain Wickham, contained fragments of marine shells, but others did not; and these closely resembled a formation at King George's Sound, principally due to the action of the wind on calcareous dust, which I shall describe in a forthcoming part. From the extreme irregularity of these reefs with their lagoons, and from their position on a bank, the usual depth of which is only thirty fathoms, I have not ventured to class them with atolls, and hence have left them uncoloured.—*Rowley Shoals.* These lie some way from the N.W. coast of Australia: according to Captain King ("Narrative of Survey," vol. i, p. 60), they are of coral-formation. They rise abruptly from the sea, and Captain King had no bottom with 170 fathoms close to them. Three of them are crescent-shaped; they are mentioned by Mr. Lyell, on the authority of Captain King, with reference to the direction of their open sides. "A third oval reef of the same group is entirely submerged" ("Principles of Geology," book iii, chap. xviii); coloured blue.—*Scott's Reefs*, lying north of Rowley Shoals, are briefly described by Captain Wickham (*Naut. Mag.* 1841, p. 440): they appear to be of great size, of a circular form, and "with smooth water within, forming probably a lagoon of great extent." There is a break on the western side, where there probably is an entrance: the water is very deep off these reefs; coloured blue.

Proceeding westward along the great volcanic chain of the East Indian Archipelago, *Solor Strait* is represented in a chart published by Dalrymple from a Dutch MS., as fringed; as are parts of *Flores*, of *Adenara*, and of *Solor.* Horsburgh speaks of coral growing on these shores; and therefore I have no doubt that the reefs are of coral, and accordingly have coloured them red. We hear from Horsburgh (vol. ii, p. 602) that a coral-flat bounds the shores of *Sapy* Bay. From the same authority it appears (p. 610) that reefs fringe the island of *Timor-Young*, on the N. shore of Sumbawa; and, likewise (p. 600), that *Bally* town in *Lombock*, is fronted by a reef, stretching along the shore at a distance of a hundred fathoms, with channels through it for boats; these places, therefore, have been coloured red.—*Bally* Island. In a Dutch MS. chart on a large scale of Java, which was brought from that island by Dr. Horsfield, who had the kindness to show it me at the India House, its western, northern, and southern shores appear very regularly fringed by a reef (see also Horsburgh, vol. ii, p. 593); and as coral is found abundantly there, I have not the least doubt that the reef is of coral, and therefore have coloured it red.

JAVA.—My information regarding the reefs of this great island is derived from the chart just mentioned. The greater part of *Maduara* is represented in it as regularly fringed, and likewise portions of the coast of Java immediately south of it. Dr. Horsfield informs me that coral is very abundant near *Sourabaya.* The islets and parts of the N. coast of Java, west of *Point Buang*, or *Japara*, are fringed by reefs, said to be of coral. *Lubeck*, or *Bavian* Islands, lying at some distance from the shore of Java, are regularly fringed by coral-reefs. *Carimon Java* appears equally so, though it is not directly said that the reefs are of coral; there is a depth between thirty and forty fathoms round these islands. Parts of the shores of *Sunda Strait*, where the water is from forty to eighty fathoms deep, and the islets near *Batavia* appear in several charts to be fringed. In the Dutch chart the southern shore, in the narrowest part of the island, is in two places fringed by reefs of coral. West of *Segorrowodee* Bay, and the extreme S.E. and E. portions are likewise fringed by coral-reefs; all the above-mentioned places coloured red.

Macassar Strait; the east coast of Borneo appears, in most parts, free from reefs, and where they occur, as on the east coast of *Pamaroong*, the sea is very shallow; hence no part is coloured. In *Macassar* Strait itself, in about lat. 2° S., there are many small islands with coral-shoals projecting far from them. There are also (old charts by Dalrymple) numerous little flats of coral, not rising to the surface of the water, and shelving suddenly from five fathoms to no bottom with fifty fathoms; they do not appear to have a lagoon-like structure. There are similar coral-shoals a little farther south; and in lat. 4° 55′ there are two, which are engraved from modern surveys, in a manner which might represent an annular reef with deep water inside: Captain Moresby, however, who was formerly in this sea, doubts this fact, so that I have left them uncoloured: at the same time I may remark, that these two shoals make a nearer approach to the atoll-like structure than any other within the E. Indian Archipelago. Southward of these shoals there are other low islands and irregular coral-reefs; and in the space of sea, north of the great volcanic chain, from Timor to Java, we have also other islands, such as the *Postillions, Kalatoa, Tokan-Bessees*, etc., which are chiefly low, and are surrounded by very irregular and distant reefs. From the imperfect charts I have seen, I have not been able to decide whether they belong to the atoll or barrier-classes, or whether they merely fringe submarine banks, and gently sloping land. In the Bay of *Bonin*, between the two southern arms of Celebes, there are numerous coral-reefs; but none of them seem to have an atoll-like structure. I have, therefore, not coloured any of the islands in this part of the sea; I think it, however, exceedingly probable that some of them ought to be blue. I may add that there is a harbour on the S.E. coast of *Bouton* which, according to an old chart, is formed by a reef, parallel to the shore, with deep water within; and in the "Voyage of the *Coquille*," some neighbouring islands are represented with reefs a good way distant, but I do not know whether with deep water within. I have not thought the evidence sufficient to permit me to colour them.

SUMATRA.—Commencing with the west coast and outlying islands, *Engano Island* is represented in the published chart as surrounded by a narrow reef, and Napier, in his "Sailing Directions," speaks of the reef being of coral (also Horsburgh, vol. ii, p. 115); coloured red.—*Rat Island* (3° 51′ S.) is surrounded by reefs of coral, partly dry at low water, (Horsburgh, vol. ii, p. 96).—*Trieste Island* (4° 2′ S.). The shore is represented in a chart which I saw at the India House, as fringed in such a manner, that I feel sure the fringe consists of coral; but as the island is so low, that the sea sometimes flows quite over it (Dampier, "Voyage," vol. i, p. 474), I have not coloured it.—*Pulo Dooa* (lat. 3°). In an old chart it is said there are chasms in the reefs round the island, admitting boats to the watering-place, and that the southern islet consists of a mass of sand and coral.—*Pulo Pisang*; Horsburgh (vol. ii, p. 86) says that the rocky coral-bank, which stretches about forty yards from the shore, is steep to all round: in a chart, also, which I have seen, the island is represented as regularly fringed.—*Pulo Mintao* is lined with reefs on its west side (Horsburgh, vol. ii, p. 107).—*Pulo Baniak*; the same authority (vol. ii, p. 105), speaking of a part, says it is faced with coral-rocks. —*Minguin* (3° 36′ N.). A coral-reef fronts this place, and projects into the sea nearly a quarter of a mile ("Notices of the Indian Arch." published at Singapore, p. 105).—*Pulo Brassa* (5° 46′ N.). A reef surrounds it at a cable's length (Horsburgh, vol. ii, p. 60). I have coloured all the above-specified points red. I may here add, that both Horsburgh and Mr. Moor (in the "Notices" just alluded to) frequently speak of the numerous reefs and banks of coral on the west coast of Sumatra; but these nowhere have the structure of a barrier-reef, and Marsden ("History of Sumatra") states, that where the coast is flat, the fringing-reefs extend furthest from it. The northern and southern points, and the greater part of the east coast, are low, and faced with mud banks, and therefore without coral.

NICOBAR ISLANDS.—The chart represents the islands of this group as fringed by reefs. With regard to *Great Nicobar*, Captain Moresby informs me, that it is fringed by reefs of coral, extending between two and three hundred yards from the shore. The *Northern Nicobars* appear so regularly fringed in the published charts, that I have no doubt the reefs are of coral. This group, therefore, is coloured red.

ANDAMAN ISLANDS.—From an examination of the MS. chart, on a large scale, of this island, by Captain Arch. Blair, in the Admiralty, several portions of the coast appear fringed; and as Horsburgh speaks of coral-reefs being numerous in the vicinity of these islands, I should have coloured them red, had not some expressions in a paper in the "Asiatic Researches" (vol. iv, p. 402) led me to doubt the existence of reefs; uncoloured.

The coast of *Malacca, Tenasserim* and the coasts northward, appear in the greater part to be low and muddy: where reefs occur, as in parts of *Malacca Straits*, and near *Singapore*, they are of the fringing kind; but the water is so shoal, that I have not coloured them. In the sea, however, between Malacca and the west coast of Borneo, where there is a greater depth from forty to fifty fathoms, I have coloured red some of the groups, which are regularly fringed. The northern *Natunas* and the *Anambas* Islands are represented in the charts on a large scale, published in the "Atlas of the Voyage of the *Favourite*," as fringed by reefs of coral, with very shoal water within them.—*Tumbelan* and *Bunoa* Islands (1° N.) are represented in the English charts as surrounded by a very regular fringe. —*St. Barbes* (0° 15′ N.) is said by Horsburgh (vol. ii, p. 279) to be fronted by a reef, over which boats can land only at high water.—The shore of *Borneo* at *Tunjong Apee* is also fronted by a reef, extending not far from the land (Horsburgh, vol. ii, p. 468). These places I have coloured red; although with some hesitation, as the water is shallow. I might perhaps have added *Pulo Leat,* in Gaspar Strait, *Lucepara*, and *Carimata*; but as the sea is confined and shallow, and the reefs not very regular, I have left them uncoloured.

The water shoals gradually towards the whole west coast of *Borneo*: I cannot make out that it has any reefs of coral. The islands, however, off the northern extremity, and near the S.W. end of *Palawan*, are fringed by very distant coral-reefs; thus the reefs in the case of *Balabac* are no less than five miles from the land; but the sea, in the whole of this district, is so shallow, that the reefs might be expected to extend very far from the land. I have not, therefore, thought myself authorised to colour them. The N.E. point of Borneo, where the water is very shoal, is connected with Magindanao by a chain of islands called the *Sooloo Archipelago*, about which I have been able to obtain very little information; *Pangootaran*, although ten miles long, entirely consists of a bed of coral-rock ("Notices of E. Indian Arch." p. 58): I believe from Horsburgh that the island is low; not coloured.—*Tahow Bank*, in some old charts, appears like a submerged atoll; not coloured. Forrest ("Voyage," p. 21) states that one of the islands near Sooloo is surrounded by coral-rocks; but there is no distant reef. Near the S. end of *Basselan*, some of the islets in the chart accompanying Forrest's "Voyage," appear fringed with reefs; hence I have coloured, though unwillingly, parts of the Sooloo group red. The sea between Sooloo and Palawan, near the shoal coast of Borneo, is interspersed with irregular reefs and shoal patches; not coloured: but in the northern part of this sea, there are two low islets, *Cagayanes* and *Cavilli*, surrounded by extensive coral-reefs; the breakers round the latter (Horsburgh, vol. ii, p. 513) extend five or six miles from a sandbank, which forms the only dry part; these breakers are steep to outside; there appears to be an opening through them on one side, with four or five fathoms within: from this description, I strongly suspect that Cavilli ought to be considered an atoll; but, as I have not seen any chart of it, on even a moderately large scale, I have not coloured it. The islets off the northern end of *Palawan*, are in the same case as those off the southern end, namely they are fringed by reefs, some way distant from the shore, but the water is exceedingly shallow; uncoloured. The western shore of Palawan will be treated of under the head of China Sea.

PHILIPPINE ARCHIPELAGO.—A chart on a large scale of *Appoo Shoal*, which lies near the S.E. coast of Mindoro, has been executed by Captain D. Ross: it appears atoll-formed, but with rather an irregular outline; its diameter is about ten miles; there are two well-defined passages leading into the interior lagoon, which appears open; close outside the reef all round, there is no bottom with seventy fathoms; coloured blue. —*Mindoro*: the N.W. coast is represented in several charts, as fringed by a reef, and *Luban Island* is said, by Horsburgh (vol. ii, p. 436), to be "lined by a reef."—*Luzon*: Mr. Cuming, who has lately investigated with so much success the Natural History of the Philippines, informs me, that about three miles of the shore north of Point St. Jago, is fringed by a reef; as are (Horsburgh, vol. ii, p. 437) the Three Friars off Silanguin Bay. Between Point Capones and Playa Honda, the coast is "lined by a coral-reef, stretching out nearly a mile in some places," (Horsburgh); and Mr. Cuming visited some fringing-reefs on parts of this coast, namely, near Puebla, Iba, and Mansinglor. In the neighbourhood of Solon-solon Bay, the shore is lined (Horsburgh, ii, p. 439) by coral-reefs, stretching out a great way: there are also reefs about the islets off Solamague; and as I am informed by Mr. Cuming, near St. Catalina, and a little north of it. The same gentleman informs me there are reefs on the S.E. point of this island in front of Samar, extending from Malalabon to Bulusan. These appear to be the principal fringing-reefs on the coasts of Luzon; and they have all been coloured red. Mr. Cuming informs me that none of them have deep water within; although it appears from Horsburgh that some few extend to a considerable distance from the shore. Within the Philippine Archipelago, the shores of the islands do not appear to be commonly fringed, with the exception of the S. shore of *Masbate*, and nearly the whole of *Bohol*; which are both coloured red. On the S. shore of *Magindanao*, Bunwoot Island is surrounded (according to Forrest, "Voyage," p. 253), by a coral-reef, which in the chart appears one of the fringing class. With respect to the eastern coasts of the whole Archipelago, I have not been able to obtain any account.

BABUYAN ISLANDS.—Horsburgh says (vol. ii, p. 442), coral-reefs line the shores of the harbour in Fuga; and the charts show there are other reefs about these islands. Camiguin has its shore in parts lined by coral-rock (Horsburgh, p. 443); about a mile off shore there is between thirty and thirty-five fathoms. The plan of Port San Pio Quinto shows that its shores are fringed with coral; coloured red.—BASHEE ISLANDS: Horsburgh, speaking of the southern part of the group (vol. ii, p. 445) says the shores of both islands are fortified by a reef, and through some of the gaps in it, the natives can pass in their boats in fine weather; the bottom near the land is coral-rock. From the published charts, it is evident that several of these islands are most regularly fringed; coloured red. The northern islands are left uncoloured, as I have been unable to find any account of them.—FORMOSA. The shores, especially the western one, seem chiefly composed of mud and sand, and I cannot make out that they are anywhere lined by reefs; except in a harbour (Horsburgh, vol. ii, p. 449) at the extreme northern point: hence, of course, the whole of this island is left uncoloured. The small adjoining islands are in the same case.—PATCHOW, OR MADJIKO-SIMA GROUPS. *Patchuson* has been described by Captain Broughton ("Voy. to the N. Pacific," p. 191); he says, the boats, with some difficulty, found a passage through the coral-reefs, which extend along the coast, nearly half a mile off it. The boats were well sheltered within the reef; but it does not appear that the water is deep there. Outside the reef the depth is very irregular, varying from five to fifty fathoms; the form of the land is not very abrupt; coloured red.—*Taypin-san*; from the description given (p. 195) by the same author, it appears that a very irregular reef extends, to the distance of several miles, from the southern island; but whether it encircles a space of deep water is not evident; nor, indeed, whether these outlying reefs are connected with those more immediately adjoining the land; left uncoloured. I may here just add that the shore of *Kumi* (lying west of Patchow), has a narrow reef attached to it in the plan of it, in La Peyrouse's "Atlas;" but it does not appear in the account of the voyage that it is of coral; uncoloured.—LOO CHOO. The greater part of the coast of this moderately hilly island, is skirted by reefs, which do not extend far from the shore, and which do not leave a channel of deep water within them, as may be seen in the charts accompanying Captain B. Hall's voyage to Loo Choo (see also remarks in Appendix, pp. xxi. and xxv.). There are, however, some ports with deep water, formed by reefs in front of valleys, in the same manner as happens at Mauritius. Captain Beechey, in a letter to me, compares these reefs with those encircling the Society Islands; but there appears to me a marked difference between them, in the less distance at which the Loo Choo reefs lie from the land with relation to the probable submarine inclination, and in the absence of an interior deep water-moat or channel, parallel to the land. Hence, I have classed these reefs with fringing-reefs, and coloured them red.—PESCADORES (west of Formosa). Dampier (vol. i, p. 416), has compared the appearance of the land to the southern parts of England. The islands are interlaced with coral-reefs; but as the water is very shoal, and as spits of sand and gravel (Horsburgh, vol. ii, p. 450) extend far out from them, it is impossible to draw any inferences regarding the nature of the reefs.

CHINA SEA.—Proceeding from north to south, we first meet the *Pratas Shoal* (lat. 20° N.) which, according to Horsburgh (vol. ii, p. 335), is composed of coral, is of a circular form, and has a low islet on it. The reef is on a level with the water's edge, and when the sea runs high, there are breakers mostly all round, "but the water within seems pretty deep in some places; although steep-to in most parts outside, there appear to be several parts where a ship might find anchorage outside the breakers;" coloured blue.—The *Paracells* have been accurately surveyed by Captain D. Ross, and charts on a large scale published: but few low islets have been formed on these shoals, and this seems to be a general circumstance in the China Sea; the sea close outside the reefs is very deep; several of them have a lagoon-like structure; or separate islets (*Prattle, Robert, Drummond*, etc.) are so arranged round a moderately shallow space, as to appear as if they had once formed one large atoll. —*Bombay Shoal* (one of the Paracells) has the form of an annular reef, and is "apparently deep within;" it seems to have an entrance (Horsburgh, vol. ii, p. 332) on its west side; it is very steep outside. —*Discovery Shoal*, also is of an oval form, with a lagoon-like space within, and three openings leading into it, in which there is a depth from two to twenty fathoms. Outside, at the distance (Horsburgh, vol. ii, p. 333) of only twenty yards from the reef, soundings could not be obtained. The Paracells are coloured blue.—*Macclesfield Bank*: this is a coral-bank of great size, lying east of the Paracells; some parts of the bank are level, with a sandy bottom, but, generally, the depth is very irregular. It is intersected by deep cuts or channels. I am not able to perceive in the published charts (its limits, however, are not very accurately known) whether the central part is deeper, which I suspect is the case, as in the Great Chagos Bank, in the Indian Ocean; not coloured.—*Scarborough Shoal*: this coral-shoal is engraved with a double row of crosses, forming a circle, as if there was deep water within the reef: close outside there was no bottom, with a hundred fathoms; coloured blue.—The sea off the west coast of Palawan and the northern part of Borneo is strewed with shoals: *Swallow Shoal*, according to Horsburgh (vol. ii, p. 431) "is formed, *like most* of the shoals hereabouts, of a belt of coral-rocks, "with a basin of deep water within."—*Half-Moon Shoal* has a similar structure; Captain D. Ross describes it, as a narrow belt of coral-rock, with a basin of deep water in the centre," and deep sea close outside.—*Bombay Shoal* appears (Horsburgh, vol. ii, p. 432) "to be a basin of smooth water surrounded by breakers." These three shoals I have coloured blue.—The *Paraquas Shoals* are of a circular form, with deep gaps running through them; not coloured.—A bank gradually shoaling to the depth of thirty fathoms, extends to a distance of about twenty miles from the northern part of *Borneo*, and to thirty miles from the northern part of *Palawan.* Near the land this bank appears tolerably free from danger, but a little further out it is thickly studded with coral-shoals, which do not generally rise quite to the surface; some of them are very steep-to, and others have a fringe of shoal-water round them. I should have thought that these shoals had level surfaces, had it not been for the statement made by Horsburgh "that most of the shoals hereabouts are formed of a belt of coral." But, perhaps that expression was more particularly applied to the shoals further in the offing. If these reefs of coral have a lagoon-like structure, they should have been coloured blue, and they would have formed an imperfect barrier in front of Palawan and the northern part of Borneo. But, as the water is not very deep, these reefs may have grown up from inequalities on the bank: I have not coloured them.—The coast of *China, Tonquin*, and *Cochin-China*, forming the western boundary of the China Sea, appear to be without reefs: with regard to the two last-mentioned coasts, I speak after examining the charts on a large scale in the "Atlas of the Voyage of the *Favourite*."

INDIAN OCEAN.—*South Keeling* atoll has been specially described. Nine miles north of it lies North Keeling, a very small atoll, surveyed by the *Beagle*, the lagoon of which is dry at low water.—*Christmas Island*, lying to the east, is a high island, without, as I have been informed by a person who passed it, any reefs at all.—CEYLON: a space about eighty miles in length of the south-western and southern shores of these islands has been described by Mr. Twynam (*Naut. Mag.* 1836, pp. 365 and 518); parts of this space appear to be very regularly fringed by coral-reefs, which extend from a quarter to half a mile from the shore. These reefs are in places breached, and afford safe anchorage for the small trading craft. Outside, the sea gradually deepens; there is forty fathoms about six miles off shore: this part I have coloured red. In the published charts of Ceylon there appear to be fringing-reefs in several parts of the south-eastern shores, which I have also coloured red.—At Venloos Bay the shore is likewise fringed. North of Trincomalee there are also reefs of the same kind. The sea off the northern part of Ceylon is exceedingly shallow; and therefore I have not coloured the reefs which fringe portions of its shores, and the adjoining islets, as well as the Indian promontory of *Madura.*

CHAGOS, MALDIVA, AND LACCADIVE ARCHIPELAGOES.—These three great groups which have already been often noticed, are now well-known from the admirable surveys of Captain Moresby and Lieutenant Powell. The published charts, which are worthy of the most attentive examination, at once show that the *Chagos* and *Maldiva* groups are entirely formed of great atolls, or lagoon-formed reefs, surmounted by islets. In the *Laccadive* group, this structure is less evident; the islets are low, not exceeding the usual height of coral-formations (see Lieutenant Wood's account, *Geograph. Journ.*, vol. vi, p. 29), and most of the reefs are circular, as may be seen in the published charts; and within several of them, as I am informed by Captain Moresby, there is deepish water; these, therefore, have been coloured blue. Directly north, and almost forming part of this group, there is a long, narrow, slightly curved bank, rising out of the depths of the ocean, composed of sand, shells, and decayed coral, with from twenty-three to thirty fathoms on it. I have no doubt that it has had the same origin with the other Laccadive banks; but as it does not deepen towards the centre I have not coloured it. I might have referred to other authorities regarding these three archipelagoes; but after the publication of the charts by Captain Moresby, to whose personal kindness in giving me much information I am exceedingly indebted, it would have been superfluous.

Sahia de Malha bank consists of a series of narrow banks, with from eight to sixteen fathoms on them; they are arranged in a semicircular manner, round a space about forty fathoms deep, which slopes on the S.E. quarter to unfathomable depths; they are steep-to on both sides, but more especially on the ocean-side. Hence this bank closely resembles in structure, and I may add from Captain Moresby's information in composition, the Pitt's Bank in the Chagos group; and the Pitt's Bank, must, after what has been shown of the Great Chagos Bank, be considered as a sunken, half-destroyed atoll; hence coloured blue. —*Cargados Carajos Bank.* Its southern portion consists of a large, curved, coral-shoal, with some low islets on its eastern edge, and likewise some on the western side, between which there is a depth of about twelve fathoms. Northward, a great bank extends. I cannot (probably owing to the want of perfect charts) refer this reef and bank to any class;—therefore not coloured.—*Ile de Sable* is a little island, lying west of C. Carajos, only some toises in height ("Voyage of the *Favourite*," vol. i, p. 130); it is surrounded by reefs; but its structure is unintelligible to me. There are some small banks north of it, of which I can find no clear account.—*Mauritius.* The reefs round this island have been described in the chapter on fringing-reefs; coloured red.—*Rodriguez.* The coral-reefs here are exceedingly extensive; in one part they project even five miles from the shore. As far as I can make out, there is no deep-water moat within them; and the sea outside does not deepen very suddenly. The outline, however, of the land appears to be ("Life of Sir J. Makintosh," vol. ii, p. 165) hilly and rugged. I am unable to decide whether these reefs belong to the barrier class; as seems probable from their great extension, or to the fringing class; uncoloured.—*Bourbon.* The greater part of the shores of this island are without reefs; but Captain Carmichael (Hooker's "Bot. Misc.") states that a portion, fifteen miles in length, on the S.E. side, is imperfectly fringed with coral reefs: I have not thought this sufficient to colour the island.

SEYCHELLES.—The rocky islands of primary formation, composing this group, rise from a very extensive and tolerably level bank, having a depth between twenty and forty fathoms. In Captain Owen's chart, and in that in the "Atlas of the Voyage of the *Favourite*," it appears that the east side of *Mahe* and the adjoining islands of *St. Anne* and *Cerf*, are regularly fringed by coral-reefs. A portion of the S.E. part of *Curieuse Island*, the N., and part of the S.W. shore of *Praslin Island*, and the whole west side of *Digue Island*, appear fringed. From a MS. account of these islands by Captain F. Moresby, in the Admiralty, it appears that *Silhouette* is also fringed; he states that all these islands are formed of granite and quartz, that they rise abruptly from the sea, and that "coral-reefs have grown round them, and project for some distance." Dr. Allan, of Forres, who visited these islands, informs me that there is no deep water between the reefs and the shore. The above specified points have been coloured red. *Amirantes Islands*: The small islands of this neighbouring group, according to the MS. account of them by Captain F. Moresby, are situated on an extensive bank; they consist of the debris of corals and shells; are only about twenty feet in height, and are environed by reefs, some attached to the shore, and some rather distant from it.—I have taken great pains to procure plans and information regarding the several islands lying between S.E. and S.W. of the Amirantes, and the Seychelles; relying chiefly on Captain F. Moresby and Dr. Allan, it appears that the greater number, namely—*Platte, Alphonse, Coetivi, Galega, Providence, St. Pierre, Astova, Assomption*, and *Glorioso*, are low, formed of sand or coral-rock, and irregularly shaped; they are situated on very extensive banks, and are connected with great coral-reefs. Galega is said by Dr. Allan, to be rather higher than the other islands; and St. Pierre is described by Captain F. Moresby, as being cavernous throughout, and as not consisting of either limestone or granite. These islands, as well as the Amirantes, certainly are not atoll-formed, and they differ as a group from every other group with which I am acquainted; I have not coloured them; but probably the reefs belong to the fringing class. Their formation is attributed, both by Dr. Allan and Captain F. Moresby, to the action of the currents, here exceedingly violent, on banks, which no doubt have had an independent geological origin. They resemble in many respects some islands and banks in the West Indies, which owe their origin to a similar agency, in conjunction with an elevation of the entire area. In close vicinity to the several islands, there are three others of an apparently different nature: first, *Juan de Nova*, which appears from some plans and accounts to be an atoll; but from others does not appear to be so; not coloured. Secondly *Cosmoledo*; "this group consists of a ring of coral, ten leagues in circumference, and a quarter of a mile broad in some places, enclosing a magnificent lagoon, into which there did not appear a single opening" (Horsburgh, vol. i, p. 151); coloured blue. Thirdly, *Aldabra*; it consists of three islets, about twenty-five feet in height, with red cliffs (Horsburgh, vol. i, p. 176) surrounding a very shallow basin or lagoon. The sea is profoundly deep close to the shore. Viewing this island in a chart, it would be thought an atoll; but the foregoing description shows that there is something different in its nature; Dr. Allan also states that it is cavernous, and that the coral-rock has a vitrified appearance. Is it an upheaved atoll, or the crater of a volcano?—uncoloured.

COMORO GROUP.—*Mayotta*, according to Horsburgh (vol. i, p. 216, 4th ed.), is completely surrounded by a reef, which runs at the distance of three, four, and in some places even five miles from the land; in an old chart, published by Dalrymple, a depth in many places of thirty-six and thirty-eight fathoms is laid down within the reef. In the same chart, the space of open water within the reef in some parts is even more than three miles wide: the land is bold and peaked; this island, therefore, is encircled by a well-characterised barrier-reef, and is coloured pale blue.—*Johanna*; Horsburgh says (vol. i, p. 217) this island from the N.W. to the S.W. point, is bounded by a reef, at the distance of two miles from the shore; in some parts, however, the reef must be attached, since Lieutenant Boteler ("Narr." vol. i, p. 161) describes a passage through it, within which there is room only for a few boats. Its height, as I am informed by Dr. Allan, is about 3,500 feet; it is very precipitous, and is composed of granite, greenstone, and quartz; coloured blue.—*Mohilla*; on the S. side of this island there is anchorage, in from thirty to forty-five fathoms, between a reef and the shore (Horsburgh, vol. i, p. 214); in Captain Owen's chart of Madagascar, this island is represented as encircled; coloured blue.—*Great Comoro Island* is, as I am informed by Dr. Allan, about 8,000 feet high, and apparently volcanic; it is not regularly encircled; but reefs of various shapes and dimensions, jut out from every headland on the W., S., and S.E. coasts, inside of which reefs there are channels, often parallel with the shore, with deep water. On the north-western coasts the reefs appear attached to the shores. The land near the coast is in some places bold, but generally speaking it is flat; Horsburgh says (vol. i, p. 214) the water is profoundly deep close to the *shore*, from which expression I presume some parts are without reefs. From this description I apprehend the reef belongs to the barrier class; but I have not coloured it, as most of the charts which I have seen, represent the reefs round it as very much less extensive than round the other islands in the group.

MADAGASCAR.—My information is chiefly derived from the published charts by Captain Owen, and the accounts given by him and by Lieutenant Boteler. Commencing at the S.W. extremity of the island; towards the northern part of the *Star Bank* (in lat. 25° S.) the coast for ten miles is fringed by a reef; coloured red. The shore immediately S. of *St. Augustine's Bay* appears fringed; but *Tullear* Harbour, directly N. of it, is formed by a narrow reef ten miles long, extending parallel to the shore, with from four to ten fathoms within it. If this reef had been more extensive, it must have been classed as a barrier-reef; but as the line of coast falls inwards here, a submarine bank perhaps extends parallel to the shore, which has offered a foundation for the growth of the coral; I have left this part uncoloured. From lat. 22° 16′ to 21° 37′, the shore is fringed by coral-reefs (see Lieutenant Boteler's "Narrative," vol. ii, p. 106), less than a mile in width, and with shallow water within. There are outlying coral-shoals in several parts of the offing, with about ten fathoms between them and the shore, and the depth of the sea one mile and a half seaward, is about thirty fathoms. The part above specified is engraved on a large scale; and as in the charts on rather a smaller scale the same fringe of reef extends as far as lat. 33° 15′; I have coloured the whole of this part of the coast red. The islands of *Juan de Nova* (in lat. 17° S.) appear in the charts on a large scale to be fringed, but I have not been able to ascertain whether the reefs are of coral; uncoloured. The main part of the west coast appears to be low, with outlying sandbanks, which, Lieutenant Boteler (vol. ii, p. 106) says, "are faced on the edge of deep water by a line of sharp-pointed coral-rocks." Nevertheless I have not coloured this part, as I cannot make out by the charts that the coast itself is fringed. The headlands of *Narrenda* and *Passandava* Bays (14° 40′) and the islands in front of *Radama Harbour* are represented in the plans as regularly fringed, and have accordingly been coloured red. With respect to the *East coast of Madagascar*, Dr. Allan informs me in a letter, that the whole line of coast, from *Tamatave*, in 18° 12′, to *C. Amber*, at the extreme northern point of the island, is bordered by coral-reefs. The land is low, uneven, and gradually rising from the coast. From Captain Owen's charts, also, the existence of these reefs, which evidently belong to the fringing class, on some parts, namely N. of *British Sound*, and near *Ngoncy*, of the above line of coast might have been inferred. Lieutenant Boteler (vol. i, p. 155) speaks of "the reef surrounding the island of *St. Mary's* at a small distance from the shore." In a previous chapter I have described, from the information of Dr. Allan, the manner in which the reefs extend in N.E. lines from the headlands on this coast, thus sometimes forming rather deep channels within them, this seems caused by the action of the currents, and the reefs spring up from the submarine prolongations of the sandy headlands. The above specified portion of the coast is coloured red. The remaining S.E. portions do not appear in any published chart to possess reefs of any kind; and the Rev. W. Ellis, whose means of information regarding this side of Madagascar have been extensive, informs me he believes there are none.

EAST COAST OF AFRICA.—Proceeding from the northern part, the coast appears, for a considerable space, without reefs. My information, I may here observe, is derived from the survey by Captain Owen, together with his narrative; and that by Lieutenant Boteler. At *Mukdeesha* (10° 1′ N.) there is a coral-reef extending four or five miles along the shore (Owen's "Narr." vol. i, p. 357) which in the chart lies at the distance of a quarter of a mile from the shore, and has within it from six to ten feet water: this then is a fringing-reef, and is coloured red. From *Juba*, a little S. of the equator, to *Lamoo* (in 2° 20′ S.) "the coast and islands are formed of madrepore" (Owen's "Narrative," vol. i, p. 363). The chart of this part (entitled *Dundas Islands*), presents an extraordinary appearance; the coast of the mainland is quite straight and it is fronted at the average distance of two miles, by exceedingly narrow, straight islets, fringed with reefs. Within the chain of islets, there are extensive tidal flats and muddy bays, into which many rivers enter; the depths of these spaces varies from one to four fathoms—the latter depth not being common, and about twelve feet the average. Outside the chain of islets, the sea, at the distance of a mile, varies in depth from eight to fifteen fathoms. Lieutenant Boteler ("Narr.," vol. i, p. 369) describes the muddy bay of *Patta*, which seems to resemble other parts of this coast, as fronted by small, narrow, level islets formed of decomposing coral, the margin of which is seldom of greater height than twelve feet, overhanging the rocky surface from which the islets rise. Knowing that the islets are formed of coral, it is, I think, scarcely possible to view the coast, and not at once conclude that we here see a fringing-reef, which has been upraised a few feet: the unusual depth of from two to four fathoms within some of these islets, is probably due to muddy rivers having prevented the growth of coral near the shore. There is, however, one difficulty on this view, namely, that before the elevation took place, which converted the reef into a chain of islets, the water must apparently have been still deeper; on the other hand it may be supposed that the formation of a nearly perfect barrier in front, of so large an extent of coast, would cause the currents (especially in front of the rivers), to deepen their muddy beds. When describing in the chapter on fringing-reefs, those of Mauritius, I have given my reasons for believing that the shoal spaces within reefs of this kind, must, in many instances, have been deepened. However this may be, as several parts of this line of coast are undoubtedly fringed by living reefs, I have coloured it red.—*Maleenda* (3° 20′ S.). In the plan of the harbour, the south headland appears fringed; and in Owen’s chart on a larger scale, the reefs are seen to extend nearly thirty miles southward; coloured red.—*Mombas* (4° 5′ S.). The island which forms the harbour, “is surrounded by cliffs of madrepore, capable of being rendered almost impregnable” (Owen’s “Narr.,” vol. i, p. 412). The shore of the mainland N. and S. of the harbour, is most regularly fringed by a coral-reef at a distance from half a mile to one mile and a quarter from the land; within the reef the depth is from nine to fifteen feet; outside the reef the depth at rather less than half a mile is thirty fathoms. From the charts it appears that a space about thirty-six miles in length, is here fringed; coloured red.—*Pemba* (5° S.) is an island of coral-formation, level, and about two hundred feet in height (Owen’s “Narr.,” vol. i, p. 425); it is thirty-five miles long, and is separated from the mainland by a deep sea. The outer coast is represented in the chart as regularly fringed; coloured red. The mainland in front of Pemba is likewise fringed; but there also appear to be some outlying reefs with deep water between them and the shore. I do not understand their structure, either from the charts or the description, therefore have not coloured them.—*Zanzibar* resembles Pemba in most respects; its southern half on the western side and the neighbouring islets are fringed; coloured red. On the mainland, a little S. of Zanzibar, there are some banks parallel to the coast, which I should have thought had been formed of coral, had it not been said (Boteler’s “Narr.,” vol. ii, p. 39) that they were composed of sand; not coloured.—*Latham’s Bank* is a small island, fringed by coral-reefs; but being only ten feet high, it has not been coloured.—*Monfeea* is an island of the same character as Pemba; its outer shore is fringed, and its southern extremity is connected with Keelwa Point on the mainland by a chain of islands fringed by reefs; coloured red. The four last-mentioned islands resemble in many respects some of the islands in the Red Sea, which will presently be described.—*Keelwa.* In a plan of the shore, a space of twenty miles N. and S. of this place is fringed by reefs, apparently of coral: these reefs are prolonged still further southward in Owen’s general chart. The coast in the plans of the rivers *Lindy* and *Monghow* (9° 59′ and 10° 7′ S.) has the same structure; coloured red.—*Querimba Islands* (from 10° 40′ to 13° S.). A chart on a large scale is given of these islands; they are low, and of coral-formation (Boteler’s “Narr.,” vol. ii, p. 54); and generally have extensive reefs projecting from them which are dry at low water, and which on the outside rise abruptly from a deep sea: on their insides they are separated from the continent by a channel, or rather a succession of bays, with an average depth of ten fathoms. The small headlands on the continent also have coral-banks attached to them; and the Querimba islands and banks are placed on the lines of prolongation of these headlands, and are separated from them by very shallow channels. It is evident that whatever cause, whether the drifting of sediment or subterranean movements, produced the headlands, likewise produced, as might have been expected, submarine prolongations to them; and these towards their outer extremities, have since afforded a favourable basis for the growth of coral-reefs, and subsequently for the formation of islets. As these reefs clearly belong to the fringing class, the Querimba islands have been coloured red. —*Monabila* (13° 32′ S.). In the plan of this harbour, the headlands outside are fringed by reefs apparently of coral; coloured red. —*Mozambique* (150° S.) The outer part of the island on which the city is built, and the neighbouring islands, are fringed by coral-reefs; coloured red. From the description given in Owen’s “Narr.” (vol. i, p. 162), the shore from *Mozambique* to *Delagoa Bay* appears to be low and sandy; many of the shoals and islets off this line of coast are of coral-formation; but from their small size and lowness, it is not possible, from the charts, to know whether they are truly fringed. Hence this portion of coast is left uncoloured, as are likewise those parts more northward, of which no mention has been made in the foregoing pages from the want of information.

PERSIAN GULF.—From the charts lately published on a large scale by the East India Company, it appears that several parts, especially the southern shores of this gulf, are fringed by coral-reefs; but as the water is very shallow, and as there are numerous sandbanks, which are difficult to distinguish on the chart from reefs, I have not coloured the upper part red. Towards the mouth, however, where the water is rather deeper, the islands of *Ormuz* and *Larrack*, appear so regularly fringed, that I have coloured them red. There are certainly no atolls in the Persian Gulf. The shores of *Immaum*, and of the promontory forming the southern headland of the Persian Gulf, seem to be without reefs. The whole S.W. part (except one or two small patches) of *Arabia Felix*, and the shores of *Socotra* appear from the charts and memoir of Captain Haines (*Geograph. Journ.*, 1839, p. 125) to be without any reefs. I believe there are no extensive coral-reefs on any part of the coasts of *India*, except on the low promontory of *Madura* (as already mentioned) in front of Ceylon.

RED SEA.—My information is chiefly derived from the admirable charts published by the East India Company in 1836, from personal communication with Captain Moresby, one of the surveyors, and from the excellent memoir, “Über die Natur der Corallen-Bänken des Rothen Meeres,” by Ehrenberg. The plains immediately bordering the Red Sea seem chiefly to consist of a sedimentary formation of the newer tertiary period. The shore is, with the exception of a few parts, fringed by coral-reefs. The water is generally profoundly deep close to the shore; but this fact, which has attracted the attention of most voyagers, seems to have no necessary connection with the presence of reefs; for Captain Moresby particularly observed to me, that, in lat. 24° 10′ on the eastern side, there is a piece of coast, with very deep water close to it, without any reefs, but not differing in other respects from the usual nature of the coast-line. The most remarkable feature in the Red Sea is the chain of submerged banks, reefs, and islands, lying some way from the shore, chiefly on the eastern side; the space within being deep enough to admit a safe navigation in small vessels. The banks are generally of an oval form, and some miles in width; but some of them are very long in proportion to their width. Captain Moresby informs me that any one, who had not made actual plans of them, would be apt to think that they were much more elongated than they really are. Many of them rise to the surface, but the greater number lie from five to thirty fathoms beneath it, with irregular soundings on them. They consist of sand and living coral; coral on most of them, according to Captain Moresby, covering the greater part of their surface. They extend parallel to the shore, and they are not unfrequently connected in their middle parts by short transverse banks with the mainland. The sea is generally profoundly deep quite close to them, as it is near most parts of the coast of the mainland; but this is not universally the case, for between lat. 15° and 17° the water deepens quite gradually from the banks, both on the eastern and western shores, towards the middle of the sea. Islands in many parts arise from these banks; they are low, flat-topped, and consist of the same horizontally stratified formation with that forming the plain-like margin of the mainland. Some of the smaller and lower islands consist of mere sand. Captain Moresby informs me, that small masses of rock, the remnants of islands, are left on many banks where there is now no dry land. Ehrenberg also asserts that most of the islets, even the lowest, have a flat abraded basis, composed of the same tertiary formation: he believes that as soon as the surf wears down the protuberant parts of a bank, just beneath the level of the sea, the surface becomes protected from further abrasion by the growth of coral, and he thus accounts for the existence of so many banks standing on a level with the surface of this sea. It appears that most of the islands are certainly decreasing in size.

The form of the banks and islands is most singular in the part just referred to, namely, from lat. 15° to 17°, where the sea deepens quite gradually: the *Dhalac* group, on the western coast, is surrounded by an intricate archipelago of islets and shoals; the main island is very irregularly shaped, and it includes a bay seven miles long, by four across, in which no bottom was found with 252 feet: there is only one entrance into this bay, half a mile wide, and with an island in front of it. The submerged banks on the eastern coast, within the same latitudes, round *Farsan Island*, are, likewise, penetrated by many narrow creeks of deep water; one is twelve miles long, in the form of a hatchet, in which, close to its broad upper end, soundings were not struck with 360 feet, and its entrance is only half a mile wide: in another creek of the same nature, but even with a more irregular outline, there was no bottom with 480 feet. The island of Farsan, itself, has as singular a form as any of its surrounding banks. The bottom of the sea round the Dhalac and Farsan Islands consists chiefly of sand and agglutinated fragments, but, in the deep and narrow creeks, it consists of mud; the islands themselves consist of thin, horizontally stratified, modern tertiary beds, containing but little broken coral,[2] their shores are fringed by living coral-reefs.

[2] Rüppell, "Reise in Abyssinie," Band. i, S. 247.

From the account given by Rüppell[3] of the manner in which Dhalac has been rent by fissures, the opposite sides of which have been unequally elevated (in one instance to the amount of fifty feet), it seems probable that its irregular form, as well as probably that of Farsan, may have been partly caused by unequal elevations; but, considering the general form of the banks, and of the deep-water creeks, together with the composition of the land, I think their configuration is more probably due in great part to strong currents having drifted sediment over an uneven bottom: it is almost certain that their form cannot be attributed to the growth of coral. Whatever may have been the precise origin of the Dhalac and Farsan Archipelagoes, the greater number of the banks on the eastern side of the Red Sea seem to have originated through nearly similar means. I judge of this from their similarity in configuration (in proof of which I may instance a bank on the east coast in lat. 22°; and although it is true that the northern banks generally have a less complicated outline), and from their similarity in composition, as may be observed in their upraised portions. The depth within the banks northward of lat. 17°, is usually greater, and their outer sides shelve more abruptly (circumstances which seem to go together) than in the Dhalac and Farsan Archipelagoes; but this might easily have been caused by a difference in the action of the currents during their formation: moreover, the greater quantity of living coral, which, according to Captain Moresby, exists on the northern banks, would tend to give them steeper margins.

[3] *Ibid.*, S. 245.

From this account, brief and imperfect as it is, we can see that the great chain of banks on the eastern coast, and on the western side in the southern portion, differ greatly from true barrier-reefs wholly formed by the growth of coral. It is indeed the direct conclusion of Ehrenberg ("Über die," etc., pp. 45 and 51), that they are connected in their origin quite secondarily with the growth of coral; and he remarks that the islands off the coast of Norway, if worn down level with the sea, and merely coated with living coral, would present a nearly similar appearance. I cannot, however, avoid suspecting, from information given me by Dr. Malcolmson and Captain Moresby, that Ehrenberg has rather under-rated the influence of corals, in some places at least, on the formation of the tertiary deposits of the Red Sea.

The west coast of the Red Sea between lat. 19° and 22°.—There are, in this space, reefs, which, if I had known nothing of those in other parts of the Red Sea, I should unhesitatingly have considered as barrier-reefs; and, after deliberation, I have come to the same conclusion. One of these reefs, in 20° 15′, is twenty miles long, less than a mile in width (but expanding at the northern end into a disc), slightly sinuous, and extending parallel to the mainland at the distance of five miles from it, with very deep water within; in one spot soundings were not obtained with 205 fathoms. Some leagues further south, there is another linear reef, very narrow, ten miles long, with other small portions of reef, north and south, almost connected with it; and within this line of reefs (as well as outside) the water is profoundly deep. There are also some small linear and sickle-formed reefs, lying a little way out at sea. All these reefs are covered, as I am informed by Captain Moresby, by living corals. Here, then, we have all the characters of reefs of the barrier class; and in some outlying reefs we have an approach to the structure of atolls. The source of my doubts about the classification of these reefs, arises from having observed in the Dhalac and Farsan groups the narrowness and straightness of several spits of sand and rock: one of these spits in the Dhalac group is nearly fifteen miles long, only two broad, and it is bordered on each side with deep water; so that, if worn down by the surf, and coated with living corals, it would form a reef nearly similar to those within the space under consideration. There is, also, in this space (lat. 21°) a peninsula, bordered by cliffs, with its extremity worn down to the level of the sea, and its basis fringed with reefs: in the line of prolongation of this peninsula, there lies the island of *Macowa* (formed, according to Captain Moresby, of the usual tertiary deposit), and some smaller islands, large parts of which likewise appear to have been worn down, and are now coated with living corals. If the removal of the strata in these several cases had been more complete, the reefs thus formed would have nearly resembled those barrier-like ones now under discussion. Notwithstanding these facts, I cannot persuade myself that the many very small, isolated, and sickle-formed reefs and others, long, nearly straight, and very narrow, with the water unfathomably deep close round them, could possibly have been formed by corals merely coating banks of sediment, or the abraded surfaces of irregularly shaped islands. I feel compelled to believe that the foundations of these reefs have subsided, and that the corals, during their upward growth, have given to these reefs their present forms: I may remark that the subsidence of narrow and irregularly-shaped peninsulas and islands, such as those existing on the coasts of the Red Sea, would afford the requisite foundations for the reefs in question.

The west coast from lat. 22° to 24°.—This part of the coast (north of the space coloured blue on the map) is fronted by an irregularly shelving bank, from about ten to thirty fathoms deep; numerous little reefs, some of which have the most singular shapes, rise from this bank. It may be observed, respecting one of them, in lat. 23° 10′, that if the promontory in lat. 24° were worn down to the level of the sea, and coated with corals, a very similar and grotesquely formed reef would be produced. Many of the reefs on this part of the coast may thus have originated; but there are some sickle, and almost atoll-formed reefs lying in deep water off the promontory in lat. 24°, which lead me to suppose that all these reefs are more probably allied to the barrier or atoll classes. I have not, however, ventured to colour this portion of coast. *On the west coast from lat. 19° to 17°* (south of space coloured blue on the map), there are many low islets of very small dimensions, not much elongated, and rising out of great depths at a distance from the coast; these cannot be classed either with atolls, or barrier- or fringing-reefs. I may here remark that the outlying reefs on the west coast, between lat. 19° and 24°, are the only ones in the Red Sea, which approach in structure to the true atolls of the Indian and Pacific Oceans, but they present only imperfect miniature likenesses of them.

Eastern coast.—I have felt the greatest doubt about colouring any portion of this coast, north of the fringing-reefs round the Farsan Islands in 16° 10′. There are many small outlying coral-reefs along the whole line of coast; but as the greater number rise from banks not very deeply submerged (the formation of which has been shown to be only secondarily connected with the growth of coral), their origin may be due simply to the growth of knolls of corals, from an irregular foundation situated within a limited depth. But between lat. 18° and 20°, there are so many linear, elliptic, and extremely small reefs, rising abruptly out of profound depths, that the same reasons, which led me to colour blue a portion of the west coast, have induced me to do the same in this part. There exist some small outlying reefs rising from deep water, north of lat. 20° (the northern limit coloured blue), on the east coast; but as they are not very numerous and scarcely any of them linear, I have thought it right to leave them uncoloured.

In the *southern parts* of the Red Sea, considerable spaces of the mainland, and of some of the Dhalac islands, are skirted by reefs, which, as I am informed by Captain Moresby, are of living coral, and have all the characters of the fringing class. As in these latitudes, there are no outlying linear or sickle-formed reefs, rising out of unfathomable depths, I have coloured these parts of the coast red. On similar grounds, I have coloured red the *northern parts of the western coast* (north of lat. 24° 30′), and likewise the shores of the chief part of the *Gulf of Suez.* In the *Gulf of Acaba*, as I am informed by Captain Moresby there are no coral-reefs, and the water is profoundly deep.

WEST INDIES.—My information regarding the reefs of this area, is derived from various sources, and from an examination of numerous charts; especially of those lately executed during the survey under Captain Owen, R.N. I lay under particular obligation to Captain Bird Allen, R.N., one of the members of the late survey, for many personal communications on this subject. As in the case of the Red Sea, it is necessary to make some preliminary remarks on the submerged banks of the West Indies, which are in some degree connected with coral-reefs, and cause considerable doubts in their classification. That large accumulations of sediment are in progress on the West Indian shores, will be evident to any one who examines the charts of that sea, especially of the portion north of a line joining Yucutan and Florida. The area of deposition seems less intimately connected with the debouchement of the great rivers, than with the course of the sea-currents; as is evident from the vast extension of the banks from the promontories of Yucutan and Mosquito.

Besides the coast-banks, there are many of various dimensions which stand quite isolated; these closely resemble each other, they lie from two or three to twenty or thirty fathoms under water, and are composed of sand, sometimes firmly agglutinated, with little or no coral; their surfaces are smooth and nearly level, shelving only to the amount of a few fathoms, very gradually all round towards their edges, where they plunge abruptly into the unfathomable sea. This steep inclination of their sides, which is likewise characteristic of the coast-banks, is very remarkable: I may give as an instance, the Misteriosa Bank, on the edges of which the soundings change in 250 fathoms horizontal distance, from 11 to 210 fathoms; off the northern point of the bank of Old Providence, in 200 fathoms horizontal distance, the change is from 19 to 152 fathoms; off the Great Bahama Bank, in 160 fathoms horizontal distance, the inclination is in many places from 10 fathoms to no bottom with 190 fathoms. On coasts in all parts of the world, where sediment is accumulating, something of this kind may be observed; the banks shelve very gently far out to sea, and then terminate abruptly. The form and composition of the banks standing in the middle parts of the W. Indian Sea, clearly show that their origin must be chiefly attributed to the accumulation of sediment; and the only obvious explanation of their isolated position is the presence of a nucleus, round which the currents have collected fine drift matter. Any one who will compare the character of the bank surrounding the hilly island of Old Providence, with those banks in its neighbourhood which stand isolated, will scarcely doubt that they surround submerged mountains. We are led to the same conclusion by examining the bank called Thunder Knoll, which is separated from the Great Mosquito Bank by a channel only seven miles wide, and 145 fathoms deep. There cannot be any doubt that the Mosquito Bank has been formed by the accumulation of sediment round the promontory of the same name; and Thunder Knoll resembles the Mosquito Bank, in the state of its surface submerged twenty fathoms, in the inclinations of its sides, in composition, and in every other respect. I may observe, although the remark is here irrelevant, that geologists should be cautious in concluding that all the outlyers of any formation have once been connected together, for we here see that deposits, doubtless of exactly the same nature, may be deposited with large valley-like spaces between them.

Linear strips of coral-reefs and small knolls project from many of the isolated, as well as coast-banks; sometimes they occur quite irregularly placed, as on the Mosquito Bank, but more generally they form crescents on the windward side, situated some little distance within the outer edge of the banks:—thus on the Serranilla Bank they form an interrupted chain which ranges between two and three miles within the windward margin: generally they occur, as on Roncador, Courtown, and Anegada Banks, nearer the line of deep water. Their occurrence on the windward side is conformable to the general rule, of the efficient kinds of corals flourishing best where most exposed; but their position some way within the line of deep water I cannot explain, without it be, that a depth somewhat less than that close to the outer margin of the banks, is most favourable to their growth. Where the corals have formed a nearly continuous rim, close to the windward edge of a bank some fathoms submerged, the reef closely resembles an atoll; but if the bank surrounds an island (as in the case of Old Providence), the reef resembles an encircling barrier-reef. I should undoubtedly have classed some of these fringed banks as imperfect atolls, or barrier-reefs, if the sedimentary nature of their foundations had not been evident from the presence of other neighbouring banks, of similar forms and of similar composition, but without the crescent-like marginal reef: in the third chapter, I observed that probably some atoll-like reefs did exist, which had originated in the manner here supposed.

Proofs of elevation within recent tertiary periods abound, as referred to in the sixth chapter, over nearly the whole area of the West Indies. Hence it is easy to understand the origin of the low land on the coasts, where sediment is now accumulating; for instance on the northern part of Yucutan, and on the N.E. part of Mosquito, where the land is low, and where extensive banks appear to be in progressive formation. Hence, also, the origin of the Great Bahama Banks, which are bordered on their western and southern edges by very narrow, long, singularly shaped islands, formed of sand, shells, and coral-rock, and some of them about a hundred feet in height, is easily explained by the elevation of banks fringed on their windward (western and southern) sides by coral-reefs. On this view, however, we must suppose either that the chief part of the surfaces of the great Bahama sandbanks were all originally deeply submerged, and were brought up to their present level by the same elevatory action, which formed the linear islands; or that during the elevation of the banks, the superficial currents and swell of the waves continued wearing them down and keeping them at a nearly uniform level: the level is not quite uniform; for, in proceeding from the N.W. end of the Bahama group towards the S.E. end, the depth of the banks increases, and the area of land decreases, in a very gradual and remarkable manner. The latter view, namely, that these banks have been worn down by the currents and swell during their elevation, seems to me the most probable one. It is, also, I believe, applicable to many banks, situated in widely distant parts of the West Indian Sea, which are wholly submerged; for, on any other view, we must suppose, that the elevatory forces have acted with astonishing uniformity.

The shores of the Gulf of Mexico, for the space of many hundred miles, is formed by a chain of lagoons, from one to twenty miles in breadth ("Columbian Navigator," p. 178, etc.), containing either fresh or salt water, and separated from the sea by linear strips of sand. Great spaces of the shores of Southern Brazil,[4] and of the United States from Long Island (as observed by Professor Rogers) to Florida have the same character. Professor Rogers, in his "Report to the British Association" (vol. iii, p. 13), speculates on the origin of these low, sandy, linear islets; he states that the layers of which they are composed are too homogeneous, and contain too large a proportion of shells, to permit the common supposition of their formation being simply due to matter thrown up, where it now lies, by the surf: he considers these islands as upheaved bars or shoals, which were deposited in lines where opposed currents met. It is evident that these islands and spits of sand parallel to the coast, and separated from it by shallow lagoons, have no necessary connection with coral-formations. But in Southern Florida, from the accounts I have received from persons who have resided there, the upraised islands seem to be formed of strata, containing a good deal of coral, and they are extensively fringed by living reefs; the channels within these islands are in some places between two and three miles wide, and five or six fathoms deep, though generally[5] they are less in depth than width. After having seen how frequently banks of sediment in the West Indian Sea are fringed by reefs, we can readily conceive that bars of sediment might be greatly aided in their formation along a line of coast, by the growth of corals; and such bars would, in that case, have a deceptive resemblance with true barrier-reefs.

[4] In the *London and Edinburgh Philosophical Journal,* 1841, p. 257, I have described a singular bar of sandstone lying parallel to the coast off Pernambuco in Brazil, which probably is an analogous formation.

[5] In the ordinary sea-charts, no lagoons appear on the coast of Florida, north of 26°; but Major Whiting (*Silliman's Journal*, vol. xxxv, p. 54) says that many are formed by sand thrown up along the whole line of coast from St. Augustine's to Jupiter Inlet.

Having now endeavoured to remove some sources of doubt in classifying the reefs of the West Indies, I will give my authorities for colouring such portions of the coast as I have thought myself warranted in doing. Captain Bird Allen informs me, that most of the islands on the *Bahama Banks* are fringed, especially on their windward sides, with living reefs; and hence I have coloured those, which are thus represented in Captain Owen's late chart, red. The same officer informs me, that the islands along the southern part of *Florida* are similarly fringed; coloured red. CUBA: Proceeding along the northern coast, at the distance of forty miles from the extreme S.E. point, the shores are fringed by reefs, which extend westward for a space of 160 miles, with only a few breaks. Parts of these reefs are represented in the plans of the harbours on this coast by Captain Owen; and an excellent description is given of them by Mr. Taylor (Loudon's "Mag. of Nat. Hist.," vol. ix, p. 449); he states that they enclosed a space called the "*baxo*," from half to three-quarters of a mile in width, with a sandy bottom, and a little coral. In most parts people can wade, at low water, to the reef; but in some parts the depth is between two and three fathoms. Close outside the reef, the depth is between six and seven fathoms; these well-characterised fringing-reefs are coloured red. Westward of longitude 77° 30′, on the northern side of Cuba, a great bank commences, which extends along the coast for nearly four degrees of longitude. In the place of its commencement, in its structure, and in the "*cays*," or low islands on its edge, there is a marked correspondence (as observed by Humboldt, "Pers. Narr.," vol. vii, p. 88) between it and the Great Bahama and Sal Banks, which lie directly in front. Hence one is led to attribute the same origin to both these sets of banks; namely, the accumulation of sediment, conjoined with an elevatory movement, and the growth of coral on their outward edges; those parts which appear fringed by living reefs are coloured red. Westward of these banks, there is a portion of coast apparently without reefs, except in the harbours, the shores of which seem in the published plans to be fringed. The *Colorado Shoals* (see Captain Owen's charts), and the low land at the western end of Cuba, correspond as closely in relative position and structure to the banks at the extreme point of Florida, as the banks above described on the north side of Cuba, do to the Bahamas, the depth within the islets and reefs on the outer edge of the *Colorados*, is generally between two and three fathoms, increasing to twelve fathoms in the southern part, where the bank becomes nearly open, without islets or coral-reefs; the portions which are fringed are coloured red. The southern shore of Cuba is deeply concave, and the included space is filled up with mud and sandbanks, low islands and coral-reefs. Between the mountainous *Isle of Pines* and the southern shore of Cuba, the general depth is only between two and three fathoms; and in this part small islands, formed of fragmentary rock and broken madrepores (Humboldt, "Pers. Narr.," vol. vii, pp. 51, 86 to 90, 291, 309, 320), rise abruptly, and just reach the surface of the sea. From some expressions used in the "Columbian Navigator" (vol. i, pt ii, p. 94), it appears that considerable spaces along the outer coast of Southern Cuba are bounded by cliffs of coral-rock, formed probably by the upheaval of coral-reefs and sandbanks. The charts represent the southern part of the Isle of Pines as fringed by reefs, which the "Columb. Navig." says extend some way from the coast, but have only from nine to twelve feet water on them; these are coloured red.—I have not been able to procure any detailed description of the large groups of banks and "cays" further eastward on the southern side of Cuba; within them there is a large expanse, with a muddy bottom, from eight to twelve fathoms deep; although some parts of this line of coast are represented in the general charts of the West Indies, as fringed, I have not thought it prudent to colour them. The remaining portion of the south coast of Cuba appears to be without coral-reefs.

YUCUTAN.—The N.E. part of the promontory appears in Captain Owen's charts to be fringed; coloured red. The eastern coast, from 20° to 18° is fringed. South of lat. 18°, there commences the most remarkable reef in the West Indies: it is about one hundred and thirty miles in length, ranging in a N. and S. line, at an average distance of fifteen miles from the coast. The islets on it are all low, as I have been informed by Captain B. Allen; the water deepens suddenly on the outside of the reef, but not more abruptly than off many of the sedimentary banks: within its southern extremity (off *Honduras*) the depth is twenty-five fathoms; but in the more northern parts, the depth soon increases to ten fathoms, and within the northernmost part, for a space of twenty miles, the depth is only from one to two fathoms. In most of these respects we have the characteristics of a barrier-reef; nevertheless, from observing, first, that the channel within the reef is a continuation of a great irregular bay, which penetrates the mainland to the depth of fifty miles; and secondly, that considerable spaces of this barrier-like reef are described in the charts (for instance, in lat. 16° 45′ and 16° 12′) as formed of pure sand; and thirdly, from knowing that sediment is accumulating in many parts of the West Indies in banks parallel to the shore; I have not ventured to colour this reef as a barrier, without further evidence that it has really been formed by the growth of corals, and that it is not merely in parts a spit of sand, and in other parts a worn down promontory, partially coated and fringed by reefs; I lean, however, to the probability of its being a barrier-reef, produced by subsidence. To add to my doubts, immediately on the outside of this barrier-like reef, *Turneffe, Lighthouse*, and *Glover* reefs are situated, and these reefs have so completely the form of atolls, that if they had occurred in the Pacific, I should not have hesitated about colouring them blue. *Turneffe Reef* seems almost entirely filled up with low mud islets; and the depth within the other two reefs is only from one to three fathoms. From this circumstance and from their similarity in form, structure, and relative position, both to the bank called *Northern Triangles*, on which there is an islet between seventy and eighty feet, and to *Cozumel* Island, the level surface of which is likewise between seventy and eighty feet in height, I consider it more probable that the three foregoing banks are the worn down bases of upheaved shoals, fringed with corals, than that they are true atolls, wholly produced by the growth of coral during subsidence; left uncoloured.

In front of the eastern *Mosquito* coast, there are between lat. 12° and 16° some extensive banks (already mentioned, p. 148), with high islands rising from their centres; and there are other banks wholly submerged, both of which kinds of banks are bordered, near their windward margins, by crescent-shaped coral-reefs. But it can hardly be doubted, as was observed in the preliminary remarks, that these banks owe their origin, like the great bank extending from the Mosquito promontory, almost entirely to the accumulation of sediment, and not to the growth of corals; hence I have not coloured them.

Cayman Island: this island appears in the charts to be fringed; and Captain B. Allen informs me that the reefs extend about a mile from the shore, and have only from five to twelve feet water within them; coloured red.—*Jamaica:* judging from the charts, about fifteen miles of the S.E. extremity, and about twice that length on the S.W. extremity, and some portions on the S. side near Kingston and Port Royal, are regularly fringed, and therefore are coloured red. From the plans of some harbours on the N. side of Jamaica, parts of the coast appear to be fringed; but as these are not represented in the charts of the whole island, I have not coloured them.—*St. Domingo:* I have not been able to obtain sufficient information, either from plans of the harbours, or from general charts, to enable me to colour any part of the coast, except sixty miles from Port de Plata westward, which seems very regularly fringed; many other parts, however, of the coast are probably fringed, especially towards the eastern end of the island.—*Puerto Rico:* considerable portions of the southern, western, and eastern coasts, and some parts of the northern coast, appear in the charts to be fringed; coloured red.—Some miles in length of the southern side of the Island of *St. Thomas* is fringed; most of the *Virgin Gorda* Islands, as I am informed by Mr. Schomburgk, are fringed; the shores of *Anegada*, as well as the bank on which it stands, are likewise fringed; these islands have been coloured red. The greater part of the southern side of *Santa Cruz* appears in the Danish survey to be fringed (see also Prof. Hovey's account of this island, in *Silliman's Journal*, vol. xxxv, p. 74); the reefs extend along the shore for a considerable space, and project rather more than a mile; the depth within the reef is three fathoms; coloured red.—The *Antilles*, as remarked by Von Buch ("Descrip. Iles Canaries," p. 494), may be divided into two linear groups, the western row being volcanic, and the eastern of modern calcareous origin; my information is very defective on the whole group. Of the eastern islands, *Barbuda* and the western coasts of *Antigua* and *Mariagalante* appear to be fringed: this is also the case with *Barbadoes*, as I have been informed by a resident; these islands are coloured red. On the shores of the Western Antilles, of volcanic origin, very few coral-reefs appear to exist. The island of *Martinique*, of which there are beautifully executed French charts, on a very large scale, alone presents any appearance worthy of special notice. The south-western, southern, and eastern coasts, together forming about half the circumference of the island, are skirted by very irregular banks, projecting generally rather less than a mile from the shore, and lying from two to five fathoms submerged. In front of almost every valley, they are breached by narrow, crooked, steep-sided passages. The French engineers ascertained by boring, that these submerged banks consisted of madreporitic rocks, which were covered in many parts by thin layers of mud or sand. From this fact, and especially from the structure of the narrow breaches, I think there can be little doubt that these banks once formed living reefs, which fringed the shores of the island, and like other reefs probably reached the surface. From some of these submerged banks reefs of living coral rise abruptly, either in small detached patches, or in lines parallel to, but some way within the outer edges of the banks on which they are based. Besides the above banks which skirt the shores of the island, there is on the eastern side a range of linear banks, similarly constituted, twenty miles in length, extending parallel to the coast line, and separated from it by a space between two and four miles in width, and from five to fifteen fathoms in depth. From this range of detached banks, some linear reefs of living coral likewise rise abruptly; and if they had been of greater length (for they do not front more than a sixth part of the circumference of the island), they would necessarily from their position have been coloured as barrier-reefs; as the case stands they are left uncoloured. I suspect that after a small amount of subsidence, the corals were killed by sand and mud being deposited on them, and the reefs being thus prevented from growing upwards, the banks of madreporitic rock were left in their present submerged condition.

THE BERMUDA ISLANDS have been carefully described by Lieutenant Nelson, in an excellent Memoir in the "Geological Transactions" (vol. v, part i, p. 103). In the form of the bank or reef, on one side of which the islands stand, there is a close general resemblance to an atoll; but in the following respects there is a considerable difference,—first, in the margin of the reef not forming (as I have been informed by Mr. Chaffers, R.N.) a flat, solid surface, laid bare at low water, and regularly bounding the internal space of shallow water or lagoon; secondly, in the border of gradually shoaling water, nearly a mile and a half in width, which surrounds the entire outside of the reef (as is laid down in Captain Hurd’s chart); and thirdly, in the size, height, and extraordinary form of the islands, which present little resemblance to the long, narrow, simple islets, seldom exceeding half a mile in breadth, which surmount the annular reefs of almost all the atolls in the Indian and Pacific Oceans. Moreover, there are evident proofs (Nelson, *Ibid.*, p. 118), that islands similar to the existing ones, formerly extended over other parts of the reef. It would, I believe, be difficult to find a true atoll with land exceeding thirty feet in height; whereas, Mr. Nelson estimates the highest point of the Bermuda Islands to be 260 feet; if, however, Mr. Nelson’s view, that the whole of the land consists of sand drifted by the winds, and agglutinated together, were proved correct, this difference would be immaterial; but, from his own account (p. 118), there occur in one place, five or six layers of red earth, interstratified with the ordinary calcareous rock, and including stones too heavy for the wind to have moved, without having at the same time utterly dispersed every grain of the accompanying drifted matter. Mr. Nelson attributes the origin of these several layers, with their embedded stones, to as many violent catastrophes; but further investigation in such cases has generally succeeded in explaining phenomena of this kind by ordinary and simpler means. Finally, I may remark, that these islands have a considerable resemblance in shape to Barbuda in the West Indies, and to Pemba on the eastern coast of Africa, which latter island is about two hundred feet in height, and consists of coral-rock. I believe that the Bermuda Islands, from being fringed by living reefs, ought to have been coloured red; but I have left them uncoloured, on account of their general resemblance in external form to a lagoon-island or atoll.

GEOLOGICAL OBSERVATIONS ON VOLCANIC ISLANDS.

CRITICAL INTRODUCTION.

The preparation of the series of works published under the general title "Geology of the Voyage of the *Beagle*" occupied a great part of Darwin's time during the ten years that followed his return to England. The second volume of the series, entitled "Geological Observations on Volcanic Islands, with Brief Notices on the Geology of Australia and the Cape of Good Hope," made its appearance in 1844. The materials for this volume were collected in part during the outward voyage, when the *Beagle* called at St. Jago in the Cape de Verde Islands, and St. Paul's Rocks, and at Fernando Noronha, but mainly during the homeward cruise; then it was that the Galapagos Islands were surveyed, the Low Archipelago passed through, and Tahiti visited; after making calls at the Bay of Islands, in New Zealand, and also at Sydney, Hobart Town and King George's Sound in Australia, the *Beagle* sailed across the Indian Ocean to the little group of the Keeling or Cocos Islands, which Darwin has rendered famous by his observations, and thence to Mauritius; calling at the Cape of Good Hope on her way, the ship then proceeded successively to St. Helena and Ascension, and revisited the Cape de Verde Islands before finally reaching England.

Although Darwin was thus able to gratify his curiosity by visits to a great number of very interesting volcanic districts, the voyage opened for him with a bitter disappointment. He had been reading Humboldt's "Personal Narrative" during his last year's residence in Cambridge, and had copied out from it long passages about Teneriffe. He was actually making inquiries as to the best means of visiting that island, when the offer was made to him to accompany Captain Fitzroy in the *Beagle.* His friend Henslow too, on parting with him, had given him the advice to procure and read the recently published first volume of the "Principles of Geology," though he warned him against accepting the views advocated by its author. During the time the *Beagle* was beating backwards and forwards when the voyage commenced, Darwin, although hardly ever able to leave his berth, was employing all the opportunities which the terrible sea-sickness left him, in studying Humboldt and Lyell. We may therefore form an idea of his feelings when, on the ship reaching Santa Cruz, and the Peak of Teneriffe making its appearance among the clouds, they were suddenly informed that an outbreak of cholera would prevent any landing!

Ample compensation for this disappointment was found, however, when the ship reached Porta Praya in St. Jago, the largest of the Cape de Verde Islands. Here he spent three most delightful weeks, and really commenced his work as a geologist and naturalist. Writing to his father he says, "Geologising in a volcanic country is most delightful; besides the interest attached to itself, it leads you into most beautiful and retired spots. Nobody but a person fond of Natural History can imagine the pleasure of strolling under cocoa-nuts in a thicket of bananas and coffee-plants, and an endless number of wild flowers. And this island, that has given me so much instruction and delight, is reckoned the most uninteresting place that we perhaps shall touch at during our voyage. It certainly is generally very barren, but the valleys are more exquisitely beautiful, from the very contrast. It is utterly useless to say anything about the scenery; it would be as profitable to explain to a blind man colours, as to a person who has not been out of Europe, the total dissimilarity of a tropical view. Whenever I enjoy anything, I always look forward to writing it down, either in my log-book (which increases in bulk), or in a letter; so you must excuse raptures, and those raptures badly expressed. I find my collections are increasing wonderfully, and from Rio I think I shall be obliged to send a cargo home."

The indelible impression made on Darwin's mind by this first visit to a volcanic island, is borne witness to by a remarkable passage in the "Autobiography" written by him in 1876. "The geology of St. Jago is very striking, yet simple; a stream of lava formerly flowed over the bed of the sea, formed of triturated recent shells and corals, which it has baked into a hard white rock. Since then the whole island has been upheaved. But the line of white rock revealed to me a new and important fact, namely that there had been afterwards subsidence round the craters which had since been in action, and had poured forth lava. It then first dawned on me that I might perhaps write a book on the geology of the various countries visited, and this made me thrill with delight. That was a memorable hour to me, and how distinctly I can call to mind the low cliff of lava beneath which I rested, with the sun glaring hot, a few strange desert plants growing near and with living corals in the tidal pools at my feet."

Only five years before, when listening to poor Professor Jameson's lectures on the effete Wernerianism, which at that time did duty for geological teaching, Darwin had found them "incredibly dull," and he declared that "the sole effect they produced on me was a determination never so long as I lived to read a book on Geology, or in any way to study the science."

What a contrast we find in the expressions which he makes use of in referring to Geological Science, in his letters written home from the *Beagle*! After alluding to the delight of collecting and studying marine animals, he exclaims, "But Geology carries the day!" Writing to Henslow he says, "I am quite charmed with Geology, but, like the wise animal between two bundles of hay, I do not know which to like best; the old crystalline group of rocks, or the softer and more fossiliferous beds." And just as the long voyage is about to come to a close he again writes, "I find in Geology a never-failing interest; as it has been remarked, it creates the same grand ideas respecting this world which Astronomy does for the Universe." In this passage Darwin doubtless refers to a remark of Sir John Herschel's in his admirable "Preliminary Discourse on the Study of Natural Philosophy,"—a book which exercised a most remarkable and beneficial influence on the mind of the young naturalist.

If there cannot be any doubt as to the strong predilection in Darwin's mind for geological studies, both during and after the memorable voyage, there is equally little difficulty in perceiving the school of geological thought which, in spite of the warnings of Sedgwick and Henslow, had obtained complete ascendancy over his mind. He writes in 1876: "The very first place which I examined, namely St. Jago in the Cape de Verde Islands, showed me clearly the wonderful superiority of Lyell's manner of treating Geology, compared with that of any other author, whose works I had with me, or ever afterwards read." And again, "The science of Geology is enormously indebted to Lyell—more so, as I believe, than to any other man who ever lived . . . I am proud to remember that the first place, namely, St. Jago, in the Cape de Verde Archipelago, in which I geologised, convinced me of the infinite superiority of Lyell's views over those advocated in any other work known to me."

The passages I have cited will serve to show the spirit in which Darwin entered upon his geological studies, and the perusal of the following pages will furnish abundant proofs of the enthusiasm, acumen, and caution with which his researches were pursued.

Large collections of rocks and minerals were made by Darwin during his researches, and sent home to Cambridge, to be kept under the care of his faithful friend Henslow. After visiting his relations and friends, Darwin's first care on his return to England was to unpack and examine these collections. He accordingly, at the end of 1836, took lodgings for three months in Fitzwilliam Street, Cambridge, so as to be near Henslow; and in studying and determining his geological specimens received much valuable aid from the eminent crystallographer and mineralogist, Professor William Hallows Miller.

The actual writing of the volume upon volcanic islands was not commenced till 1843, when Darwin had settled in the spot which became his home for the rest of his life—the famous house at Down, in Kent. Writing to his friend Mr. Fox, on March 28th, 1843, he says, "I am very slowly progressing with a volume, or rather pamphlet, on the volcanic islands which we visited: I manage only a couple of hours per day, and that not very regularly. It is uphill work writing books, which cost money in publishing, and which are not read even by geologists."

The work occupied Darwin during the whole of the year 1843, and was issued in the spring of the following year, the actual time engaged in preparing it being recorded in his diary as "from the summer of 1842 to January 1844;" but the author does not appear to have been by any means satisfied with the result when the book was finished. He wrote to Lyell, "You have pleased me much by saying that you intend looking through my 'Volcanic Islands;' it cost me eighteen months!!! and I have heard of very few who have read it. Now I shall feel, whatever little (and little it is) there is confirmatory of old work, or new, will work its effect and not be lost." To Sir Joseph Hooker he wrote, "I have just finished a little volume on the volcanic islands which we visited. I do not know how far you care for dry simple geology, but I hope you will let me send you a copy.”

Every geologist knows how full of interest and suggestiveness is this book of Darwin’s on volcanic islands. Probably the scant satisfaction which its author seemed to find in it may be traced to the effect of a contrast which he felt between the memory of glowing delights he had experienced when, hammer in hand, he roamed over new and interesting scenes, and the slow, laborious, and less congenial task of re-writing and arranging his notes in book-form.

In 1874, in writing an account of the ancient volcanoes of the Hebrides, I had frequent occasion to quote Mr. Darwin’s observations on the Atlantic volcanoes, in illustration of the phenomena exhibited by the relics of still older volcanoes in our own islands. Darwin, in writing to his old friend Sir Charles Lyell upon the subject, says, “I was not a little pleased to see my volcanic book quoted, for I thought it was completely dead and forgotten.”

Two years later the original publishers of this book and of that on South America proposed to re-issue them. Darwin at first hesitated, for he seemed to think there could be little of abiding interest in them; he consulted me upon the subject in one of the conversations which I used to have with him at that time, and I strongly urged upon him the reprint of the works. I was much gratified when he gave way upon the point, and consented to their appearing just as originally issued. In his preface he says, “Owing to the great progress which Geology has made in recent times, my views on some few points may be somewhat antiquated, but I have thought it best to leave them as they originally appeared.”

It may be interesting to indicate, as briefly as possible, the chief geological problem upon which the publication of Darwin’s “Volcanic Islands” threw new and important light. The merit of the work consisted in supplying interesting observations, which in some cases have proved of crucial value in exploding prevalent fallacies; in calling attention to phenomena and considerations that had been quite overlooked by geologists, but have since exercised an important influence in moulding geological speculation; and lastly in showing the importance which attaches to small and seemingly insignificant causes, some of which afford a key to the explanation of very curious geological problems.

Visiting as he did the districts in which Von Buch and others had found what they thought to be evidence of the truth of “Elevation-craters,” Darwin was able to show that the facts were capable of a totally different interpretation. The views originally put forward by the old German geologist and traveller, and almost universally accepted by his countrymen, had met with much support from Elie de Beaumont and Dufrenoy, the leaders of geological thought in France. They were, however, stoutly opposed by Scrope and Lyell in this country, and by Constant Prevost and Virlet on the other side of the channel. Darwin, in the work before us, shows how little ground there is for the assumption that the great ring-craters of the Atlantic islands have originated in gigantic blisters of the earth’s surface which, opening at the top, have given origin to the craters. Admitting the influence of the injection of lava into the structure of the volcanic cones, in increasing their bulk and elevation, he shows that, in the main, the volcanoes are built up by repeated ejections causing an accumulation of materials around the vent.

While, however, agreeing on the whole with Scrope and Lyell, as to the explosive origin of ordinary volcanic craters, Darwin clearly saw that, in some cases, great craters might be formed or enlarged, by the subsidence of the floors after eruptions. The importance of this agency, to which too little attention has been directed by geologists, has recently been shown by Professor Dana, in his admirable work on Kilauea and the other great volcanoes of the Hawaiian Archipelago.

The effects of subsidence at a volcanic centre in producing a downward dip of the strata around it, was first pointed out by Darwin, as the result of his earliest work in the Cape de Verde Islands. Striking illustrations of the same principle have since been pointed out by M. Robert and others in Iceland, by Mr. Heaphy in New Zealand, and by myself in the Western Isles of Scotland.

Darwin again and again called attention to the evidence that volcanic vents exhibit relations to one another which can only be explained by assuming the existence of lines of fissure in the earth’s crust, along which the lavas have made their way to the surface. But he, at the same time, clearly saw that there was no evidence of the occurrence of great deluges of lava along such fissures; he showed how the most remarkable plateaux, composed of successive lava sheets, might be built up by repeated and moderate ejections from numerous isolated vents; and he expressly insists upon the rapidity with which the cinder-cones around the orifices of ejection and the evidences of successive outflows of lava would be obliterated by denudation.

One of the most striking parts of the book is that in which he deals with the effects of denudation in producing "basal wrecks" or worn down stumps of volcanoes. He was enabled to examine a series of cases in which could be traced every gradation, from perfect volcanic cones down to the solidified plugs which had consolidated in the vents from which ejections had taken place. Darwin's observations on these points have been of the greatest value and assistance to all who have essayed to study the effects of volcanic action during earlier periods of the earth's history. Like Lyell, he was firmly persuaded of the continuity of geological history, and ever delighted in finding indications, in the present order of nature, that the phenomena of the past could be accounted for by means of causes which are still in operation. Lyell's last work in the field was carried on about his home in Forfarshire, and only a few months before his death he wrote to Darwin: "All the work which I have done has confirmed me in the belief that the only difference between Palæozoic and recent volcanic rocks is no more than we must allow for, by the enormous time to which the products of the oldest volcanoes have been subjected to chemical changes."

Darwin was greatly impressed, as the result of his studies of volcanic phenomena, followed by an examination of the great granite-masses of the Andes, with the relations between the so-called Plutonic rocks and those of undoubtedly volcanic origin. It was indeed a fortunate circumstance, that after studying some excellent examples of recent volcanic rocks, he proceeded to examine in South America many fine illustrations of the older igneous rock-masses, and especially of the most highly crystalline types of the same, and then on his way home had opportunities of reviving the impression made upon him by the fresh and unaltered volcanic rocks. Some of the general considerations suggested by these observations were discussed in a paper read by him before the Geological Society, on March 7th, 1838, under the title "On the Connection of Certain Volcanic Phenomena, and On the Formation of Mountain-chains, and the Effect of Continental Elevations." The exact bearing of these two classes of facts upon one another are more fully discussed in his book on South American geology.

The proofs of recent elevation around many of the volcanic islands led Darwin to conclude that volcanic areas were, as a rule, regions in which upward movements were taking place, and he was naturally led to contrast them with the areas in which, as he showed, the occurrence of atolls, encircling reefs, and barrier-reefs afford indication of subsidence. In this way he was able to map out the oceanic areas in different zones, along which opposite kinds of movement were taking place. His conclusions on this subject were full of novelty and suggestiveness.

Very clearly did Darwin recognise the importance of the fact that most of the oceanic islands appear to be of volcanic origin, though he was careful to point out the remarkable exceptions which somewhat invalidate the generalisation. In his "Origin of Species" he has elaborated the idea and suggested the theory of the permanence of ocean-basins, a suggestion which has been adopted and pushed farther by subsequent authors, than we think its originator would have approved. His caution and fairness of mind on this and similar speculative questions was well-known to all who were in the habit of discussing them with him.

Some years before the voyage of the *Beagle,* Mr. Poulett Scrope had pointed out the remarkable analogies that exist between certain igneous rocks of banded structure, as seen in the Ponza Islands, and the foliated crystalline schists. It does not appear that Darwin was acquainted with this remarkable memoir, but quite independently he called attention to the same phenomena when he came to study some very similar rocks which occur in the island of Ascension. Coming fresh from the study of the great masses of crystalline schist in the South American continent, he was struck by the circumstance that in the undoubtedly igneous rocks of Ascension we find a similar separation of the constituent minerals along parallel "folia." These observations led Darwin to the same conclusion as that arrived at some time before by Scrope—namely that when crystallisation takes place in rock masses under the influence of great deforming stresses, a separation and parallel arrangement of the constituent minerals will result. This is a process which is now fully recognised as having been a potent factor in the production of the metamorphic rock, and has been called by more recent writers "dynamo-metamorphism."

In this, and in many similar discussions, in which exact mineralogical knowledge was required, it is remarkable how successful Darwin was in making out the true facts with regard to the rocks he studied by the simple aid of a penknife and pocket-lens, supplemented by a few chemical tests and the constant use of the blowpipe. Since his day, the method of study of rocks by thin sections under the microscope has been devised, and has become a most efficient aid in all petrographical inquiries. During the voyage of H.M.S. *Challenger,* many of the islands studied by Darwin have been revisited and their rocks collected. The results of their study by one of the greatest masters of the science of micropetrography—Professor Renard of Brussels—have been recently published in one of the volumes of "Reports on the *Challenger* Expedition." While much that is new and valuable has been contributed to geological science by these more recent investigations, and many changes have been made in nomenclature and other points of detail, it is interesting to find that all the chief facts described by Darwin and his friend Professor Miller have stood the test of time and further study, and remain as a monument of the acumen and accuracy in minute observation of these pioneers in geological research.

JOHN W. JUDD.

Chapter I

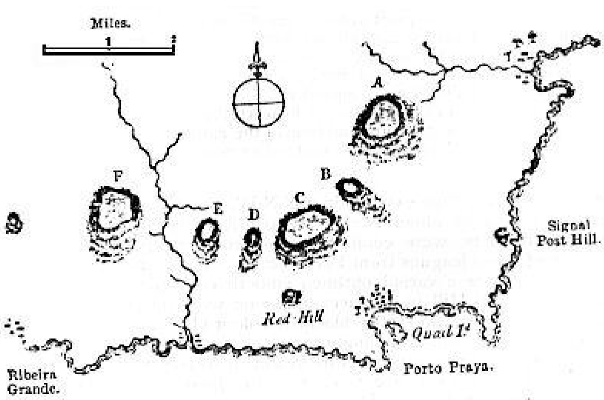
ST. JAGO, IN THE CAPE DE VERDE ARCHIPELAGO.

Rocks of the lowest series.—A calcareous sedimentary deposit, with recent shells, altered by the contact of superincumbent lava, its horizontality and extent.—Subsequent volcanic eruptions, associated with calcareous matter in an earthy and fibrous form, and often enclosed within the separate cells of the scoriæ.—Ancient and obliterated orifices of eruption of small size. Difficulty of tracing over a bare plain recent streams of lava.—Inland hills of more ancient volcanic rock.—Decomposed olivine in large masses. Feldspathic rocks beneath the upper crystalline basaltic strata. Uniform structure and form of the more ancient volcanic hills.—Form of the valleys near the coast. Conglomerate now forming on the sea beach.

The island of St. Jago extends in a N.N.W. and S.S.E. direction, thirty miles in length by about twelve in breadth. My observations, made during two visits, were confined to the southern portion within the distance of a few leagues from Porto Praya. The country, viewed from the sea, presents a varied outline: smooth conical hills of a reddish colour (like Red Hill in Fig. 1[1]) and others less regular, flat-topped, and of a blackish colour (like A, B, C,) rise from successive, step-formed plains of lava. At a distance, a chain of mountains, many thousand feet in height, traverses the interior of the island. There is no active volcano in St. Jago, and only one in the group, namely at Fogo. The island since being inhabited has not suffered from destructive earthquakes.

[1] The outline of the coast, the position of the villages, streamlets, and of most of the hills in this woodcut, are copied from the chart made on board H.M.S. *Leven.* The square-topped hills (A, B, C, etc.) are put in merely by eye, to illustrate my description.

The lowest rocks exposed on the coast near Porto Praya, are highly crystalline and compact; they appear to be of ancient, submarine, volcanic origin; they are unconformably covered by a thin, irregular, calcareous deposit, abounding with shells of a late tertiary period; and this again is capped by a wide sheet of basaltic lava, which has flowed in successive streams from the interior of the island, between the square-topped hills marked A, B, C, etc. Still more recent streams of lava have been erupted from the scattered cones, such as Red and Signal Post Hills. The upper strata of the square-topped hills are intimately related in mineralogical composition, and in other respects, with the lowest series of the coast-rocks, with which they seem to be continuous.



Part of St. Jago, one of the Cape de Verde islands.

Mineralogical description of the rocks of the lowest series.—These rocks possess an extremely varying character; they consist of black, brown, and grey, compact, basaltic bases, with numerous crystals of augite, hornblende, olivine, mica, and sometimes glassy feldspar. A common variety is almost entirely composed of crystals of augite with olivine. Mica, it is known, seldom occurs where augite abounds; nor probably does the present case offer a real exception, for the mica (at least in my best characterised specimen, in which one nodule of this mineral is nearly half an inch in length) is as perfectly rounded as a pebble in a conglomerate, and evidently has not been crystallised in the base, in which it is now enclosed, but has proceeded from the fusion of some pre-existing rock. These compact lavas alternate with tuffs, amygdaloids, and wacke, and in some places with coarse conglomerate. Some of the argillaceous wackes are of a dark green colour, others, pale yellowish-green, and others nearly white; I was surprised to find that some of the latter varieties, even where whitest, fused into a jet black enamel, whilst some of the green varieties afforded only a pale gray bead. Numerous dikes, consisting chiefly of highly compact augitic rocks, and of gray amygdaloidal varieties, intersect the strata, which have in several places been dislocated with considerable violence, and thrown into highly inclined positions. One line of disturbance crosses the northern end of Quail Island (an islet in the Bay of Porto Praya), and can be followed to the mainland. These disturbances took place before the deposition of the recent sedimentary bed; and the surface, also, had previously been denuded to a great extent, as is shown by many truncated dikes.

Description of the calcareous deposit overlying the foregoing volcanic rocks.—This stratum is very conspicuous from its white colour, and from the extreme regularity with which it ranges in a horizontal line for some miles along the coast. Its average height above the sea, measured from the upper line of junction with the superincumbent basaltic lava, is about sixty feet; and its thickness, although varying much from the inequalities of the underlying formation, may be estimated at about twenty feet. It consists of quite white calcareous matter, partly composed of organic *débris*, and partly of a substance which may be aptly compared in appearance with mortar. Fragments of rock and pebbles are scattered throughout this bed, often forming, especially in the lower part, a conglomerate. Many of the fragments of rock are whitewashed with a thin coating of calcareous matter. At Quail Island, the calcareous deposit is replaced in its lowest part by a soft, brown, earthy tuff, full of Turritellæ; this is covered by a bed of pebbles, passing into sandstone, and mixed with fragments of echini, claws of crabs, and shells; the oyster-shells still adhering to the rock on which they grew. Numerous white balls appearing like pisolitic concretions, from the size of a walnut to that of an apple, are embedded in this deposit; they usually have a small pebble in their centres. Although so like concretions, a close examination convinced me that they were Nulliporæ, retaining their proper forms, but with their surfaces slightly abraded: these bodies (plants as they are now generally considered to be) exhibit under a microscope of ordinary power, no traces of organisation in their internal structure. Mr. George R. Sowerby has been so good as to examine the shells which I collected: there are fourteen species in a sufficiently perfect condition for their characters to be made out with some degree of certainty, and four which can be referred only to their genera. Of the fourteen shells, of which a list is given in the Appendix, eleven are recent species; one, though undescribed, is perhaps identical with a species which I found living in the harbour of Porto Praya; the two remaining species are unknown, and have been described by Mr. Sowerby. Until the shells of this Archipelago and of the neighbouring coasts are better known, it would be rash to assert that even these two latter shells are extinct. The number of species which certainly belong to existing kinds, although few in number, are sufficient to show that the deposit belongs to a late tertiary period. From its mineralogical character, from the number and size of the embedded fragments, and from the abundance of Patellæ, and other littoral shells, it is evident that the whole was accumulated in a shallow sea, near an ancient coast-line.

Effects produced by the flowing of the superincumbent basaltic lava over the calcareous deposit.—These effects are very curious. The calcareous matter is altered to the depth of about a foot beneath the line of junction; and a most perfect gradation can be traced, from loosely aggregated, small, particles of shells, corallines, and Nulliporæ, into a rock, in which not a trace of mechanical origin can be discovered, even with a microscope. Where the metamorphic change has been greatest, two varieties occur. The first is a hard, compact, white, fine-grained rock, striped with a few parallel lines of black volcanic particles, and resembling a sandstone, but which, upon close examination, is seen to be crystallised throughout, with the cleavages so perfect that they can be readily measured by the reflecting goniometer. In specimens, where the change has been less complete, when moistened and examined under a strong lens, the most interesting gradation can be traced, some of the rounded particles retaining their proper forms, and others insensibly melting into the granulo-crystalline paste. The weathered surface of this stone, as is so frequently the case with ordinary limestones, assumes a brick-red colour.

The second metamorphosed variety is likewise a hard rock, but without any crystalline structure. It consists of a white, opaque, compact, calcareous stone, thickly mottled with rounded, though regular, spots of a soft, earthy, ochraceous substance. This earthy matter is of a pale yellowish-brown colour, and appears to be a mixture of carbonate of lime with iron; it effervesces with acids, is infusible, but blackens under the blowpipe, and becomes magnetic. The rounded form of the minute patches of earthy substance, and the steps in the progress of their perfect formation, which can be followed in a suit of specimens, clearly show that they are due either to some power of aggregation in the earthy particles amongst themselves, or more probably to a strong attraction between the atoms of the carbonate of line, and consequently to the segregation of the earthy extraneous matter. I was much interested by this fact, because I have often seen quartz rocks (for instance, in the Falkland Islands, and in the lower Silurian strata of the Stiper-stones in Shropshire), mottled in a precisely analogous manner, with little spots of a white, earthy substance (earthy feldspar?); and these rocks, there was good reason to suppose, had undergone the action of heat,—a view which thus receives confirmation. This spotted structure may possibly afford some indication in distinguishing those formations of quartz, which owe their present structure to igneous action, from those produced by the agency of water alone; a source of doubt, which I should think from my own experience, that most geologists, when examining arenaceo-quartzose districts must have experienced.

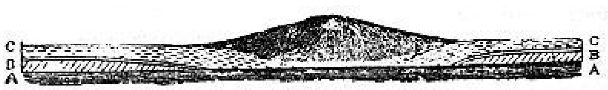
The lowest and most scoriaceous part of the lava, in rolling over the sedimentary deposit at the bottom of the sea, has caught up large quantities of calcareous matter, which now forms a snow-white, highly crystalline basis to a breccia, including small pieces of black, glossy scoriæ. A little above this, where the lime is less abundant, and the lava more compact, numerous little balls, composed of spicula of calcareous spar, radiating from common centres, occupy the interstices. In one part of Quail Island, the lime has thus been crystallised by the heat of the superincumbent lava, where it is only thirteen feet in thickness; nor had the lava been originally thicker, and since reduced by degradation, as could be told from the degree of cellularity of its surface. I have already observed that the sea must have been shallow in which the calcareous deposit was accumulated. In this case, therefore, the carbonic acid gas has been retained under a pressure, insignificant compared with that (a column of water, 1,708 feet in height) originally supposed by Sir James Hall to be requisite for this end: but since his experiments, it has been discovered that pressure has less to do with the retention of carbonic acid gas, than the nature of the circumjacent atmosphere; and hence, as is stated to be the case by Mr. Faraday,[2] masses of limestone are sometimes fused and crystallised even in common limekilns. Carbonate of lime can be heated to almost any degree, according to Faraday, in an atmosphere of carbonic acid gas, without being decomposed; and Gay-Lussac found that fragments of limestone, placed in a tube and heated to a degree, not sufficient by itself to cause their decomposition, yet immediately evolved their carbonic acid, when a stream of common air or steam was passed over them: Gay-Lussac attributes this to the mechanical displacement of the nascent carbonic acid gas. The calcareous matter beneath the lava, and especially that forming the crystalline spicula between the interstices of the scoriæ, although heated in an atmosphere probably composed chiefly of steam, could not have been subjected to the effects of a passing stream; and hence it is, perhaps, that they have retained their carbonic acid, under a small amount of pressure.

[2] I am much indebted to Mr. E. W. Brayley in having given me the following references to papers on this subject: Faraday in the *Edinburgh New Philosophical Journal*, vol. xv, p. 398; Gay-Lussac in *Annales de Chem. et Phys.,* tome lxiii, p. 219, translated in the *London and Edinburgh Philosophical Magazine,* vol. x, p. 496.

The fragments of scoriæ, embedded in the crystalline calcareous basis, are of a jet black colour, with a glossy fracture like pitchstone. Their surfaces, however, are coated with a layer of a reddish-orange, translucent substance, which can easily be scratched with a knife; hence they appear as if overlaid by a thin layer of rosin. Some of the smaller fragments are partially changed throughout into this substance: a change which appears quite different from ordinary decomposition. At the Galapagos Archipelago (as will be described in a future chapter), great beds are formed of volcanic ashes and particles of scoriæ, which have undergone a closely similar change.

The extent and horizontality of the calcareous stratum.—The upper line of surface of the calcareous stratum, which is so conspicuous from being quite white and so nearly horizontal, ranges for miles along the coast, at the height of about sixty feet above the sea. The sheet of basalt, by which it is capped, is on an average eighty feet in thickness. Westward of Porto Praya beyond Red Hill, the white stratum with the superincumbent basalt is covered up by more recent streams. Northward of Signal Post Hill, I could follow it with my eye, trending away for several miles along the sea cliffs. The distance thus observed is about seven miles; but I cannot doubt from its regularity that it extends much farther. In some ravines at right angles to the coast, it is seen gently dipping towards the sea, probably with the same inclination as when deposited round the ancient shores of the island. I found only one inland section, namely, at the base of the hill marked A, where, at the height of some hundred feet, this bed was exposed; it here rested on the usual compact augitic rock associated with wacke, and was covered by the widespread sheet of modern basaltic lava. Some exceptions occur to the horizontality of the white stratum: at Quail Island, its upper surface is only forty feet above the level of the sea; here also the capping of lava is only between twelve and fifteen feet in thickness; on the other hand, at the north-east side of Porto Praya harbour, the calcareous stratum, as well as the rock on which it rests, attain a height above the average level: the inequality of level in these two cases is not, as I believe, owing to unequal elevation, but to original irregularities at the bottom of the sea. Of this fact, at Quail Island, there was clear evidence in the calcareous deposit being in one part of much greater than the average thickness, and in another part being entirely absent; in this latter case, the modern basaltic lavas rested directly on those of more ancient origin.

Fig. 2



SIGNAL POST HILL
A—Ancient volcanic rocks. B—Calcareous stratum. C—Upper balastic lava.

Under Signal Post Hill, the white stratum dips into the sea in a remarkable manner. This hill is conical, 450 feet in height, and retains some traces of having had a crateriform structure; it is composed chiefly of matter erupted posteriorly to the elevation of the great basaltic plain, but partly of lava of apparently submarine origin and of considerable antiquity. The surrounding plain, as well as the eastern flank of this hill, has been worn into steep precipices, overhanging the sea. In these precipices, the white calcareous stratum may be seen, at the height of about seventy feet above the beach, running for some miles both northward and southward of the hill, in a line appearing to be perfectly horizontal; but for a space of a quarter of a mile directly under the hill, it dips into the sea and disappears. On the south side the dip is gradual, on the north side it is more abrupt, as is shown in Fig. 2. As neither the calcareous stratum, nor the superincumbent basaltic lava (as far as the latter can be distinguished from the more modern ejections), appears to thicken as it dips, I infer that these strata were not originally accumulated in a trough, the centre of which afterwards became a point of eruption; but that they have subsequently been disturbed and bent. We may suppose either that Signal Post Hill subsided after its elevation with the surrounding country, or that it never was uplifted to the same height with it. This latter seems to me the most probable alternative, for during the slow and equable elevation of this portion of the island, the subterranean motive power, from expending part of its force in repeatedly erupting volcanic matter from beneath this point, would, it is likely, have less force to uplift it. Something of the same kind seems to have occurred near Red Hill, for when tracing upwards the naked streams of lava from near Porto Praya towards the interior of the island, I was strongly induced to suspect, that since the lava had flowed, the slope of the land had been slightly modified, either by a small subsidence near Red Hill, or by that portion of the plain having been uplifted to a less height during the elevation of the whole area.

The basaltic lava, superincumbent on the calcareous deposit.—This lava is of a pale grey colour, fusing into a black enamel; its fracture is rather earthy and concretionary; it contains olivine in small grains. The central parts of the mass are compact, or at most crenulated with a few minute cavities, and are often columnar. At Quail Island this structure was assumed in a striking manner; the lava in one part being divided into horizontal laminæ, which became in another part split by vertical fissures into five-sided plates; and these again, being piled on each other, insensibly became soldered together, forming fine symmetrical columns. The lower surface of the lava is vesicular, but sometimes only to the thickness of a few inches; the upper surface, which is likewise vesicular, is divided into balls, frequently as much as three feet in diameter, made up of concentric layers. The mass is composed of more than one stream; its total thickness being, on an average, about eighty feet: the lower portion has certainly flowed beneath the sea, and probably likewise the upper portion. The chief part of this lava has flowed from the central districts, between the hills marked A, B, C, etc., in the woodcut-map. The surface of the country, near the coast, is level and barren; towards the interior, the land rises by successive terraces, of which four, when viewed from a distance, could be distinctly counted.

Volcanic eruptions subsequent to the elevation of the coastland; the ejected matter associated with earthy lime.—These recent lavas have proceeded from those scattered, conical, reddish-coloured hills, which rise abruptly from the plain-country near the coast. I ascended some of them, but will describe only one, namely, *Red Hill*, which may serve as a type of its class, and is remarkable in some especial respects. Its height is about six hundred feet; it is composed of bright red, highly scoriaceous rock of a basaltic nature; on one side of its summit there is a hollow, probably the last remnant of a crater. Several of the other hills of this class, judging from their external forms, are surmounted by much more perfect craters. When sailing along the coast, it was evident that a considerable body of lava had flowed from Red Hill, over a line of cliff about one hundred and twenty feet in height, into the sea: this line of cliff is continuous with that forming the coast, and bounding the plain on both sides of this hill; these streams, therefore, were erupted, after the formation of the coast-cliffs, from Red Hill, when it must have stood, as it now does, above the level of the sea. This conclusion accords with the highly scoriaceous condition of all the rock on it, appearing to be of subaerial formation: and this is important, as there are some beds of calcareous matter near its summit, which might, at a hasty glance, have been mistaken for a submarine deposit. These beds consist of white, earthy, carbonate of lime, extremely friable so as to be crushed with the least pressure; the most compact specimens not resisting the strength of the fingers. Some of the masses are as white as quicklime, and appear absolutely pure; but on examining them with a lens, minute particles of scoriæ can always be seen, and I could find none which, when dissolved in acids, did not leave a residue of this nature. It is, moreover, difficult to find a particle of the lime which does not change colour under the blowpipe, most of them even becoming glazed. The scoriaceous fragments and the calcareous matter are associated in the most irregular manner, sometimes in obscure beds, but more generally as a confused breccia, the lime in some parts and the scoriæ in others being most abundant. Sir H. De la Beche has been so kind as to have some of the purest specimens analysed, with a view to discover, considering their volcanic origin, whether they contained much magnesia; but only a small portion was found, such as is present in most limestones.

Fragments of the scoriæ embedded in the calcareous mass, when broken, exhibit many of their cells lined and partly filled with a white, delicate, excessively fragile, moss-like, or rather conferva-like, reticulation of carbonate of lime. These fibres, examined under a lens of one-tenth of an inch focal distance, appear cylindrical; they are rather above one-thousandth of an inch in diameter; they are either simply branched, or more commonly united into an irregular mass of network, with the meshes of very unequal sizes and of unequal numbers of sides. Some of the fibres are thickly covered with extremely minute spicula, occasionally aggregated into little tuffs; and hence they have a hairy appearance. These spicula are of the same diameter throughout their length; they are easily detached, so that the object-glass of the microscope soon becomes scattered over with them. Within the cells of many fragments of the scoria, the lime exhibits this fibrous structure, but generally in a less perfect degree. These cells do not appear to be connected with one another. There can be no doubt, as will presently be shown, that the lime was erupted, mingled with the lava in its fluid state, and therefore I have thought it worth while to describe minutely this curious fibrous structure, of which I know nothing analogous. From the earthy condition of the fibres, this structure does not appear to be related to crystallisation.

Other fragments of the scoriaceous rock from this hill, when broken, are often seen marked with short and irregular white streaks, which are owing to a row of separate cells being partly, or quite, filled with white calcareous powder. This structure immediately reminded me of the appearance in badly kneaded dough, of balls and drawn-out streaks of flour, which have remained unmixed with the paste; and I cannot doubt that small masses of the lime, in the same manner remaining unmixed with the fluid lava, have been drawn out when the whole was in motion. I carefully examined, by trituration and solution in acids, pieces of the scoriæ, taken from within half-an-inch of those cells which were filled with the calcareous powder, and they did not contain an atom of free lime. It is obvious that the lava and lime have on a large scale been very imperfectly mingled; and where small portions of the lime have been entangled within a piece of the viscid lava, the cause of their now occupying, in the form of a powder or of a fibrous reticulation, the vesicular cavities, is, I think, evidently due to the confined gases having most readily expanded at the points where the incoherent lime rendered the lava less adhesive.

A mile eastward of the town of Praya, there is a steep-sided gorge, about one hundred and fifty yards in width, cutting through the basaltic plain and underlying beds, but since filled up by a stream of more modern lava. This lava is dark grey, and in most parts compact and rudely columnar; but at a little distance from the coast, it includes in an irregular manner a brecciated mass of red scoriæ mingled with a considerable quantity of white, friable, and in some parts, nearly pure earthy lime, like that on the summit of Red Hill. This lava, with its entangled lime, has certainly flowed in the form of a regular stream; and, judging from the shape of the gorge, towards which the drainage of the country (feeble though it now be) still is directed, and from the appearance of the bed of loose water-worn blocks with their interstices unfilled, like those in the bed of a torrent, on which the lava rests, we may conclude that the stream was of subaerial origin. I was unable to trace it to its source, but, from its direction, it seemed to have come from Signal Post Hill, distant one mile and a quarter, which, like Red Hill, has been a point of eruption subsequent to the elevation of the great basaltic plain. It accords with this view, that I found on Signal Post Hill, a mass of earthy, calcareous matter of the same nature, mingled with scoriæ. I may here observe that part of the calcareous matter forming the horizontal sedimentary bed, especially the finer matter with which the embedded fragments of rock are whitewashed, has probably been derived from similar volcanic eruptions, as well as from triturated organic remains: the underlying, ancient, crystalline rocks, also, are associated with much carbonate of lime, filling amygdaloidal cavities, and forming irregular masses, the nature of which latter I was unable to understand.

Considering the abundance of earthy lime near the summit of Red Hill, a volcanic cone six hundred feet in height, of subaerial growth,—considering the intimate manner in which minute particles and large masses of scoriæ are embedded in the masses of nearly pure lime, and on the other hand, the manner in which small kernels and streaks of the calcareous powder are included in solid pieces of the scoriæ,—considering, also, the similar occurrence of lime and scoriæ within a stream of lava, also supposed, with good reason, to have been of modern subaerial origin, and to have flowed from a hill, where earthy lime also occurs: I think, considering these facts, there can be no doubt that the lime has been erupted, mingled with the molten lava. I am not aware that any similar case has been described: it appears to me an interesting one, inasmuch as most geologists must have speculated on the probable effects of a volcanic focus, bursting through deep-seated beds of different mineralogical composition. The great abundance of free silex in the trachytes of some countries (as described by Beudant in Hungary, and by P. Scrope in the Panza Islands), perhaps solves the inquiry with respect to deep-seated beds of quartz; and we probably here see it answered, where the volcanic action has invaded subjacent masses of limestone. One is naturally led to conjecture in what state the now earthy carbonate of lime existed, when ejected with the intensely heated lava: from the extreme cellularity of the scoriæ on Red Hill, the pressure cannot have been great, and as most volcanic eruptions are accompanied by the emission of large quantities of steam and other gases, we here have the most favourable conditions, according to the views at present entertained by chemists, for the expulsion of the carbonic acid.[3] Has the slow re-absorption of this gas, it may be asked, given to the lime in the cells of the lava, that peculiar fibrous structure, like that of an efflorescing salt? Finally, I may remark on the great contrast in appearance between this earthy lime, which must have been heated in a free atmosphere of steam and other gases, while the white, crystalline, calcareous spar, produced by a single thin sheet of lava (as at Quail Island) rolling over similar earthy lime and the *débris* of organic remains, at the bottom of a shallow sea.

> [3] Whilst deep beneath the surface, the carbonate of lime was, I presume, in a fluid state. Hutton, it is known, thought that all amygdaloids were produced by drops of molten limestone floating in the trap, like oil in water: this no doubt is erroneous, but if the matter forming the summit of Red Hill had been cooled under the pressure of a moderately deep sea, or within the walls of a dike, we should, in all probability, have had a trap rock associated with large masses of compact, crystalline, calcareous spar, which, according to the views entertained by many geologists, would have been wrongly attributed to subsequent infiltration.

Signal Post Hill.—This hill has already been several times mentioned, especially with reference to the remarkable manner in which the white calcareous stratum, in other parts so horizontal (Fig. 2), dips under it into the sea. It has a broad summit, with obscure traces of a crateriform structure, and is composed of basaltic rocks,[4] some compact, others highly cellular with inclined beds of loose scoriæ, of which some are associated with earthy lime. Like Red Hill, it has been the source of eruptions, subsequently to the elevation of the surrounding basaltic plain; but unlike that hill, it has undergone considerable denudation, and has been the seat of volcanic action at a remote period, when beneath the sea. I judge of this latter circumstance from finding on its inland flank the last remnants of three small points of eruption. These points are composed of glossy scoriæ, cemented by crystalline calcareous spar, exactly like the great submarine calcareous deposit, where the heated lava has rolled over it: their demolished state can, I think, be explained only by the denuding action of the waves of the sea. I was guided to the first orifice by observing a sheet of lava, about two hundred yards square, with steepish sides, superimposed on the basaltic plain with no adjoining hillock, whence it could have been erupted; and the only trace of a crater which I was able to discover, consisted of some inclined beds of scoriæ at one of its corners. At the distance of fifty yards from a second level-topped patch of lava, but of much smaller size, I found an irregular circular group of masses of cemented, scoriaceous breccia, about six feet in height, which doubtless had once formed the point of eruption. The third orifice is now marked only by an irregular circle of cemented scoriæ, about four yards in diameter, and rising in its highest point scarcely three feet above the level of the plain, the surface of which, close all round, exhibits its usual appearance: here we have a horizontal basal section of a volcanic spiracle, which, together with all its ejected matter, has been almost totally obliterated.

> [4] Of these, one common variety is remarkable for being full of small fragments of a dark jasper-red earthy mineral, which, when examined carefully, shows an indistinct cleavage; the little fragments are elongated in form, are soft, are magnetic before and after being heated, and fuse with difficulty into a dull enamel. This mineral is evidently closely related to the oxides of iron, but I cannot ascertain what it exactly is. The rock containing this mineral is crenulated with small angular cavities, which are lined and filled with yellowish crystals of carbonate of lime.

The stream of lava, which fills the narrow gorge[5] eastward of the town of Praya, judging from its course, seems, as before remarked, to have come from Signal Post Hill, and to have flowed over the plain, after its elevation: the same observation applies to a stream (possibly part of the same one) capping the sea cliffs, a little eastward of the gorge. When I endeavoured to follow these streams over the stony level plain, which is almost destitute of soil and vegetation, I was much surprised to find, that although composed of hard basaltic matter, and not having been exposed to marine denudation, all distant traces of them soon became utterly lost. But I have since observed at the Galapagos Archipelago, that it is often impossible to follow even great deluges of quite recent lava across older streams, except by the size of the bushes growing on them, or by the comparative states of glossiness of their surfaces,—characters which a short lapse of time would be sufficient quite to obscure. I may remark, that in a level country, with a dry climate, and with the wind blowing always in one direction (as at the Cape de Verde Archipelago), the effects of atmospheric degradation are probably much greater than would at first be expected; for soil in this case accumulates only in a few protected hollows, and being blown in one direction, it is always travelling towards the sea in the form of the finest dust, leaving the surface of the rocks bare, and exposed to the full effects of renewed meteoric action.

[5] The sides of this gorge, where the upper basaltic stratum is intersected, are almost perpendicular. The lava, which has since filled it up, is attached to these sides, almost as firmly as a dike is to its walls. In most cases, where a stream of lava has flowed down a valley, it is bounded on each side by loose scoriaceous masses.

Inland hills of more ancient volcanic rocks.—These hills are laid down by eye, and marked as A, B, C, etc., in Map 1. They are related in mineralogical composition, and are probably directly continuous with the lowest rocks exposed on the coast. These hills, viewed from a distance, appear as if they had once formed part of an irregular tableland, and from their corresponding structure and composition this probably has been the case. They have flat, slightly inclined summits, and are, on an average, about six hundred feet in height; they present their steepest slope towards the interior of the island, from which point they radiate outwards, and are separated from each other by broad and deep valleys, through which the great streams of lava, forming the coast-plains, have descended. Their inner and steeper escarpments are ranged in an irregular curve, which rudely follows the line of the shore, two or three miles inland from it. I ascended a few of these hills, and from others, which I was able to examine with a telescope, I obtained specimens, through the kindness of Mr. Kent, the assistant-surgeon of the *Beagle*; although by these means I am acquainted with only a part of the range, five or six miles in length, yet I scarcely hesitate, from their uniform structure, to affirm that they are parts of one great formation, stretching round much of the circumference of the island.

The upper and lower strata of these hills differ greatly in composition. The upper are basaltic, generally compact, but sometimes scoriaceous and amygdaloidal, with associated masses of wacke: where the basalt is compact, it is either fine-grained or very coarsely crystallised; in the latter case it passes into an augitic rock, containing much olivine; the olivine is either colourless, or of the usual yellow and dull reddish shades. On some of the hills, beds of calcareous matter, both in an earthy and in a crystalline form, including fragments of glossy scoriæ, are associated with the basaltic strata. These strata differ from the streams of basaltic lava forming the coast-plains, only in being more compact, and in the crystals of augite, and in the grains of olivine being of much greater size;—characters which, together with the appearance of the associated calcareous beds, induce me to believe that they are of submarine formation.

Some considerable masses of wacke, which are associated with these basaltic strata, and which likewise occur in the basal series on the coast, especially at Quail Island, are curious. They consist of a pale yellowish-green argillaceous substance, of a crumbling texture when dry, but unctuous when moist: in its purest form, it is of a beautiful green tint, with translucent edges, and occasionally with obscure traces of an original cleavage. Under the blowpipe it fuses very readily into a dark grey, and sometimes even black bead, which is slightly magnetic. From these characters, I naturally thought that it was one of the pale species, decomposed, of the genus augite;—a conclusion supported by the unaltered rock being full of large separate crystals of black augite, and of balls and irregular streaks of dark grey augitic rock. As the basalt ordinarily consists of augite, and of olivine often tarnished and of a dull red colour, I was led to examine the stages of decomposition of this latter mineral, and I found, to my surprise, that I could trace a nearly perfect gradation from unaltered olivine to the green wacke. Part of the same grain under the blowpipe would in some instances behave like olivine, its colour being only slightly changed, and part would give a black magnetic bead. Hence I can have no doubt that the greenish wacke originally existed as olivine; but great chemical changes must have been effected during the act of decomposition thus to have altered a very hard, transparent, infusible mineral, into a soft, unctuous, easily melted, argillaceous substance.[6]

[6] D'Aubuisson "Traité de Géognosie" (tome ii, p. 569) mentions, on the authority of M. Marcel de Serres, masses of green earth near Montpellier, which are supposed to be due to the decomposition of olivine. I do not, however, find, that the action of this mineral under the blowpipe being entirely altered, as it becomes decomposed, has been noticed; and the knowledge of this fact is important, as at first it appears highly improbable that a hard, transparent, refractory mineral should be changed into a soft, easily fused clay, like this of St. Jago. I shall hereafter describe a green substance, forming threads within the cells of some vesicular basaltic rocks in Van Diemen's Land, which behave under the blowpipe like the green wacke of St. Jago; but its occurrence in cylindrical threads, shows it cannot have resulted

from the decomposition of olivine, a mineral always existing in the form of grains or crystals.

The basal strata of these hills, as well as some neighbouring, separate, bare, rounded hillocks, consist of compact, fine-grained, non-crystalline (or so slightly as scarcely to be perceptible), ferruginous, feldspathic rocks, and generally in a state of semi-decomposition. Their fracture is exceedingly irregular, and splintery; yet small fragments are often very tough. They contain much ferruginous matter, either in the form of minute grains with a metallic lustre, or of brown hair-like threads: the rock in this latter case assuming a pseudo-brecciated structure. These rocks sometimes contain mica and veins of agate. Their rusty brown or yellowish colour is partly due to the oxides of iron, but chiefly to innumerable, microscopically minute, black specks, which, when a fragment is heated, are easily fused, and evidently are either hornblende or augite. These rocks, therefore, although at first appearing like baked clay or some altered sedimentary deposit, contain all the essential ingredients of trachyte; from which they differ only in not being harsh, and in not containing crystals of glassy feldspar. As is so often the case with trachytic formation, no stratification is here apparent. A person would not readily believe that these rocks could have flowed as lava; yet at St. Helena there are well-characterised streams (as will be described in an ensuing chapter) of nearly similar composition. Amidst the hillocks composed of these rocks, I found in three places, smooth conical hills of phonolite, abounding with fine crystals of glassy feldspar, and with needles of hornblende. These cones of phonolite, I believe, bear the same relation to the surrounding feldspathic strata which some masses of coarsely crystallised augitic rock, in another part of the island, bear to the surrounding basalt, namely, that both have been injected. The rocks of a feldspathic nature being anterior in origin to the basaltic strata, which cap them, as well as to the basaltic streams of the coast-plains, accords with the usual order of succession of these two grand divisions of the volcanic series.

The strata of most of these hills in the upper part, where alone the planes of division are distinguishable, are inclined at a small angle from the interior of the island towards the sea-coast. The inclination is not the same in each hill; in that marked A it is less than in B, D, or E; in C the strata are scarcely deflected from a horizontal plane, and in F (as far as I could judge without ascending it) they are slightly inclined in a reverse direction, that is, inwards and towards the centre of the island. Notwithstanding these differences of inclination, their correspondence in external form, and in the composition both of their upper and lower parts,—their relative position in one curved line, with their steepest sides turned inwards,—all seem to show that they originally formed parts of one platform; which platform, as before remarked, probably extended round a considerable portion of the circumference of the island. The upper strata certainly flowed as lava, and probably beneath the sea, as perhaps did the lower feldspathic masses: how then come these strata to hold their present position, and whence were they erupted?

In the centre of the island[7] there are lofty mountains, but they are separated from the steep inland flanks of these hills by a wide space of lower country: the interior mountains, moreover, seem to have been the source of those great streams of basaltic lava which, contracting as they pass between the bases of the hills in question, expand into the coast-plains. Round the shores of St. Helena there is a rudely formed ring of basaltic rocks, and at Mauritius there are remnants of another such a ring round part, if not round the whole, of the island; here again the same question immediately occurs, how came these masses to hold their present position, and whence were they erupted? The same answer, whatever it may be, probably applies in these three cases; and in a future chapter we shall recur to this subject.

[7] I saw very little of the inland parts of the island. Near the village of St. Domingo, there are magnificent cliffs of rather coarsely crystallised basaltic lava. Following the little stream in this valley, about a mile above the village, the base of the great cliff was formed of a compact fine-grained basalt, conformably covered by a bed of pebbles. Near Fuentes, I met with pap-formed hills of the compact feldspathic series of rocks.

Valleys near the coast.—These are broad, very flat, and generally bounded by low cliff-formed sides. Portions of the basaltic plain are sometimes nearly or quite isolated by them; of which fact, the space on which the town of Praya stands offers an instance. The great valley west of the town has its bottom filled up to a depth of more than twenty feet by well-rounded pebbles, which in some parts are firmly cemented together by white calcareous matter. There can be no doubt, from the form of these valleys, that they were scooped out by the waves of the sea, during that equable elevation of the land, of which the horizontal calcareous deposit, with its existing species of marine remains, gives evidence. Considering how well shells have been preserved in this stratum, it is singular that I could not find even a single small fragment of shell in the conglomerate at the bottom of the valleys. The bed of pebbles in the valley west of the town is intersected by a second valley joining it as a tributary, but even this valley appears much too wide and flat-bottomed to have been formed by the small quantity of water, which falls only during one short wet season; for at other times of the year these valleys are absolutely dry.

Recent conglomerate.—On the shores of Quail Island, I found fragments of brick, bolts of iron, pebbles, and large fragments of basalt, united by a scanty base of impure calcareous matter into a firm conglomerate. To show how exceedingly firm this recent conglomerate is, I may mention, that I endeavoured with a heavy geological hammer to knock out a thick bolt of iron, which was embedded a little above low-water mark, but was quite unable to succeed.

Chapter II
FERNANDO NORONHA; TERCEIRA; TAHITI, ETC.

> FERNANDO NORONHA.—Precipitous hill of phonolite. TERCEIRA.—Trachytic rocks: their singular decomposition by steam of high temperature. TAHITI.—Passage from wacke into trap; singular volcanic rock with the vesicles half-filled with mesotype. MAURITIUS.—Proofs of its recent elevation. Structure of its more ancient mountains; similarity with St. Jago. ST. PAUL'S ROCKS.—Not of volcanic origin. Their singular mineralogical composition.

Fernando Noronha.—During our short visit at this and the four following islands, I observed very little worthy of description. Fernando Noronha is situated in the Atlantic Ocean, in lat. 3° 50′ S., and 230 miles distant from the coast of South America. It consists of several islets, together nine miles in length by three in breadth. The whole seems to be of volcanic origin; although there is no appearance of any crater, or of any one central eminence. The most remarkable feature is a hill 1,000 feet high, of which the upper 400 feet consist of a precipitous, singularly shaped pinnacle, formed of columnar phonolite, containing numerous crystals of glassy feldspar, and a few needles of hornblende. From the highest accessible point of this hill, I could distinguish in different parts of the group several other conical hills, apparently of the same nature. At St. Helena there are similar, great, conical, protuberant masses of phonolite, nearly one thousand feet in height, which have been formed by the injection of fluid feldspathic lava into yielding strata. If this hill has had, as is probable, a similar origin, denudation has been here effected on an enormous scale. Near the base of this hill, I observed beds of white tuff, intersected by numerous dikes, some of amygdaloidal basalt and others of trachyte; and beds of slaty phonolite with the planes of cleavage directed N.W. and S.E. Parts of this rock, where the crystals were scanty, closely resembled common clay-slate, altered by the contact of a trap-dike. The lamination of rocks, which undoubtedly have once been fluid, appears to me a subject well deserving attention. On the beach there were numerous fragments of compact basalt, of which rock a distant façade of columns seemed to be formed.

Terceira in the Azores.—The central parts of this island consist of irregularly rounded mountains of no great elevation, composed of trachyte, which closely resembles in general character the trachyte of Ascension, presently to be described. This formation is in many parts overlaid, in the usual order of superposition, by streams of basaltic lava, which near the coast compose nearly the whole surface. The course which these streams have followed from their craters, can often be followed by the eye. The town of Angra is overlooked by a crateriform hill (Mount Brazil), entirely built of thin strata of fine-grained, harsh, brown-coloured tuff. The upper beds are seen to overlap the basaltic streams on which the town stands. This hill is almost identical in structure and composition with numerous crateriformed hills in the Galapagos Archipelago.

Effects of steam on the trachytic rocks.—In the central part of the island there is a spot, where steam is constantly issuing in jets from the bottom of a small ravine-like hollow, which has no exit, and which abuts against a range of trachytic mountains. The steam is emitted from several irregular fissures: it is scentless, soon blackens iron, and is of much too high temperature to be endured by the hand. The manner in which the solid trachyte is changed on the borders of these orifices is curious: first, the base becomes earthy, with red freckles evidently due to the oxidation of particles of iron; then it becomes soft; and lastly, even the crystals of glassy feldspar yield to the dissolving agent. After the mass is converted into clay, the oxide of iron seems to be entirely removed from some parts, which are left perfectly white, whilst in other neighbouring parts, which are of the brightest red colour, it seems to be deposited in greater quantity; some other masses are marbled with two distinct colours. Portions of the white clay, now that they are dry, cannot be distinguished by the eye from the finest prepared chalk; and when placed between the teeth they feel equally soft-grained; the inhabitants use this substance for white-washing their houses. The cause of the iron being dissolved in one part, and close by being again deposited, is obscure; but the fact has been observed in several other places.[1] In some half-decayed specimens, I found small, globular aggregations of yellow hyalite, resembling gum-arabic, which no doubt had been deposited by the steam.

> [1] Spallanzani, Dolomieu, and Hoffman have described similar cases in the Italian volcanic islands. Dolomieu says the iron at the Panza Islands is redeposited in the form of veins (p. 86 "Mémoire sur les Isles Ponces"). These authors likewise believe that the steam deposits silica: it is now experimentally known that vapour of a high temperature is able to dissolve silica.

As there is no escape for the rain-water, which trickles down the sides of the ravine-like hollow, whence the steam issues, it must all percolate downwards through the fissures at its bottom. Some of the inhabitants informed me that it was on record that flames (some luminous appearance?) had originally proceeded from these cracks, and that the flames had been succeeded by the steam; but I was not able to ascertain how long this was ago, or anything certain on the subject. When viewing the spot, I imagined that the injection of a large mass of rock. like the cone of phonolite at Fernando Noronha, in a semi-fluid state, by arching the surface might have caused a wedge-shaped hollow with cracks at the bottom, and that the rain-water percolating to the neighbourhood of the heated mass, would during many succeeding years be driven back in the form of steam.

Tahiti (Otaheite).—I visited only a part of the north-western side of this island, and this part is entirely composed of volcanic rocks. Near the coast there are several varieties of basalt, some abounding with large crystals of augite and tarnished olivine, others compact and earthy,—some slightly vesicular, and others occasionally amygdaloidal. These rocks are generally much decomposed, and to my surprise, I found in several sections that it was impossible to distinguish, even approximately, the line of separation between the decayed lava and the alternating beds of tuff. Since the specimens have become dry, it is rather more easy to distinguish the decomposed igneous rocks from the sedimentary tuffs. This gradation in character between rocks having such widely different origins, may I think be explained by the yielding under pressure of the softened sides of the vesicular cavities, which in many volcanic rocks occupy a large proportion of their bulk. As the vesicles generally increase in size and number in the upper parts of a stream of lava, so would the effects of their compression increase; the yielding, moreover, of each lower vesicle must tend to disturb all the softened matter above it. Hence we might expect to trace a perfect gradation from an unaltered crystalline rock to one in which all the particles (although originally forming part of the same solid mass) had undergone mechanical displacement; and such particles could hardly be distinguished from others of similar composition, which had been deposited as sediment. As lavas are sometimes laminated in their upper parts even horizontal lines, appearing like those of aqueous deposition, could not in all cases be relied on as a criterion of sedimentary origin. From these considerations it is not surprising that formerly many geologists believed in real transitions from aqueous deposits, through wacke, into igneous traps.

In the valley of Tia-auru, the commonest rocks are basalts with much olivine, and in some cases almost composed of large crystals of augite. I picked up some specimens, with much glassy feldspar, approaching in character to trachyte. There were also many large blocks of vesicular basalt, with the cavities beautifully lined with chabasie (?), and radiating bundles of mesotype. Some of these specimens presented a curious appearance, owing to a number of the vesicles being half filled up with a white, soft, earthy mesotypic mineral, which intumesced under the blowpipe in a remarkable manner. As the upper surfaces in all the half-filled cells are exactly parallel, it is evident that this substance has sunk to the bottom of each cell from its weight. Sometimes, however, it entirely fills the cells. Other cells are either quite filled, or lined, with small crystals, apparently of chabasie; these crystals, also, frequently line the upper half of the cells partly filled with the earthy mineral, as well as the upper surface of this substance itself, in which case the two minerals appear to blend into each other. I have never seen any other amygdaloid[2] with the cells half filled in the manner here described; and it is difficult to imagine the causes which determined the earthy mineral to sink from its gravity to the bottom of the cells, and the crystalline mineral to adhere in a coating of equal thickness round the sides of the cells.

> [2] MacCulloch, however, has described and given a plate of ("Geolog. Trans." 1st series, vol. iv, p. 225) a trap rock, with

cavities filled up horizontally with quartz and chalcedony. The upper halves of these cavities are often filled by layers, which follow each irregularity of the surface, and by little depending stalactites of the same siliceous substances.

The basic strata on the sides of the valley are gently inclined seaward, and I nowhere observed any sign of disturbance; the strata are separated from each other by thick, compact beds of conglomerate, in which the fragments are large, some being rounded, but most angular. From the character of these beds, from the compact and crystalline condition of most of the lavas, and from the nature of the infiltrated minerals, I was led to conjecture that they had originally flowed beneath the sea. This conclusion agrees with the fact that the Rev. W. Ellis found marine remains at a considerable height, which he believes were interstratified with volcanic matter; as is likewise described to be the case by Messrs. Tyerman and Bennett at Huaheine, an island in this same archipelago. Mr. Stutchbury also discovered near the summit of one of the loftiest mountains of Tahiti, at the height of several thousand feet, a stratum of semi-fossil coral. None of these remains have been specifically examined. On the coast, where masses of coral-rock would have afforded the clearest evidence, I looked in vain for any signs of recent elevation. For references to the above authorities, and for more detailed reasons for not believing that Tahiti has been recently elevated, I must refer to the "Structure and Distribution of Coral-Reefs."

Mauritius.—Approaching this island on the northern or north-western side, a curved chain of bold mountains, surmounted by rugged pinnacles, is seen to rise from a smooth border of cultivated land, which gently slopes down to the coast. At the first glance, one is tempted to believe that the sea lately reached the base of these mountains, and upon examination, this view, at least with respect to the inferior parts of the border, is found to be perfectly correct. Several authors[3] have described masses of upraised coral-rock round the greater part of the circumference of the island. Between Tamarin Bay and the Great Black River I observed, in company with Captain Lloyd, two hillocks of coral-rock, formed in their lower part of hard calcareous sandstone, and in their upper of great blocks, slightly aggregated, of Astræa and Madrepora, and of fragments of basalt; they were divided into beds dipping seaward, in one case at an angle of 8°, and in the other at 18°; they had a water-worn appearance, and they rose abruptly from a smooth surface, strewed with rolled débris of organic remains, to a height of about twenty feet. The Officier du Roi, in his most interesting tour in 1768 round the island, has described masses of upraised coral-rocks, still retaining that moat-like structure (see my "Coral Reefs") which is characteristic of the living reefs. On the coast northward of Port Louis, I found the lava concealed for a considerable space inland by a conglomerate of corals and shells, like those on the beach, but in parts consolidated by red ferruginous matter. M. Bory St. Vincent has described similar calcareous beds over nearly the whole of the plain of Pamplemousses. Near Port Louis, when turning over some large stones, which lay in the bed of a stream at the head of a protected creek, and at the height of some yards above the level of spring tides, I found several shells of serpula still adhering to their under sides.

[3] Captain Carmichael, in Hooker's "Bot. Misc.," vol. ii, p. 301. Captain Lloyd has lately, in the "Proceedings of the Geological Society" (vol. iii, p. 317), described carefully some of these masses. In the "Voyage à l'Isle de France, par un Officier du Roi," many interesting facts are given on this subject. Consult also "Voyage aux Quatre Isles d'Afrique, par M. Bory St. Vincent."

The jagged mountains near Port Louis rise to a height of between two and three thousand feet; they consist of strata of basalt, obscurely separated from each other by firmly aggregated beds of fragmentary matter; and they are intersected by a few vertical dikes. The basalt in some parts abounds with large crystals of augite and olivine, and is generally compact. The interior of the island forms a plain, raised probably about a thousand feet above the level of the sea, and composed of streams of lava which have flowed round and between the rugged basaltic mountains. These more recent lavas are also basaltic, but less compact, and some of them abound with feldspar, so that they even fuse into a pale coloured glass. On the banks of the Great River, a section is exposed nearly five hundred feet deep, worn through numerous thin sheets of the lava of this series, which are separated from each other by beds of scoriæ. They seem to have been of subaerial formation, and to have flowed from several points of eruption on the central platform, of which the Piton du Milieu is said to be the principal one. There are also several volcanic cones, apparently of this modern period, round the circumference of the island, especially at the northern end, where they form separate islets.

The mountains composed of the more compact and crystalline basalt, form the main skeleton of the island. M. Bailly[4] states that they all "se développent autour d'elle comme une ceinture d'immenses remparts, toutes affectant une pente plus ou moins enclinée vers le rivage de la mer; tandis, au contraire, que vers le centre de l'ile elles presentent une coupe abrupte, et souvent taillée à pic. Toutes ces montagnes sont formées de couches parallèles inclinées du centre de l'ile vers la mer." These statements have been disputed, though not in detail, by M. Quoy, in the voyage of Freycinet. As far as my limited means of observation went, I found them perfectly correct.[5] The mountains on the N.W. side of the island, which I examined, namely, La Pouce, Peter Botts, Corps de Garde, Les Mamelles, and apparently another farther southward, have precisely the external shape and stratification described by M. Bailly. They form about a quarter of his girdle of ramparts. Although these mountains now stand quite detached, being separated from each other by breaches, even several miles in width, through which deluges of lava have flowed from the interior of the island; nevertheless, seeing their close general similarity, one must feel convinced that they originally formed parts of one continuous mass. Judging from the beautiful map of the Mauritius, published by the Admiralty from a French MS., there is a range of mountains (M. Bamboo) on the opposite side of the island, which correspond in height, relative position, and external form, with those just described. Whether the girdle was ever complete may well be doubted; but from M. Bailly's statements, and my own observations, it may be safely concluded that mountains with precipitous inland flanks, and composed of strata dipping outwards, once extended round a considerable portion of the circumference of the island. The ring appears to have been oval and of vast size; its shorter axis, measured across from the inner sides of the mountains near Port Louis and those near Grand Port, being no less than thirteen geographical miles in length. M. Bailly boldly supposes that this enormous gulf, which has since been filled up to a great extent by streams of modern lava, was formed by the sinking in of the whole upper part of one great volcano.

[4] "Voyage aux Terres Australes," tome i, p. 54.

[5] M. Lesson, in his account of this island, in the "Voyage of the *Coquille*," seems to follow M. Bailly's views.

It is singular in how many respects those portions of St. Jago and of Mauritius which I visited agree in their geological history. At both islands, mountains of similar external form, stratification, and (at least in their upper beds) composition, follow in a curved chain the coast-line. These mountains in each case appear originally to have formed parts of one continuous mass. The basaltic strata of which they are composed, from their compact and crystalline structure, seem, when contrasted with the neighbouring basaltic streams of subaerial formation, to have flowed beneath the pressure of the sea, and to have been subsequently elevated. We may suppose that the wide breaches between the mountains were in both cases worn by the waves, during their gradual elevation—of which process, within recent times, there is abundant evidence on the coast-land of both islands. At both, vast streams of more recent basaltic lavas have flowed from the interior of the island, round and between the ancient basaltic hills; at both, moreover, recent cones of eruption are scattered around the circumference of the island; but at neither have eruptions taken place within the period of history. As remarked in the last chapter, it is probable that these ancient basaltic mountains, which resemble (at least in many respects) the basal and disturbed remnants of two gigantic volcanoes, owe their present form, structure, and position, to the action of similar causes.

St. Paul's Rocks.—This small island is situated in the Atlantic Ocean, nearly one degree north of the equator, and 540 miles distant from South America, in 29° 15′ west longitude. Its highest point is scarcely fifty feet above the level of the sea; its outline is irregular, and its entire circumference barely three-quarters of a mile. This little point of rock rises abruptly out of the ocean; and, except on its western side, soundings were not obtained, even at the short distance of a quarter of a mile from its shore. It is not of volcanic origin; and this circumstance, which is the most remarkable point in its history (as will hereafter be referred to), properly ought to exclude it from the present volume. It is composed of rocks, unlike any which I have met with, and which I cannot characterise by any name, and must therefore describe.

The simplest, and one of the most abundant kinds, is a very compact, heavy, greenish-black rock, having an angular, irregular fracture, with some points just hard enough to scratch glass, and infusible. This variety passes into others of paler green tints, less hard, but with a more crystalline fracture, and translucent on their edges; and these are fusible into a green enamel. Several other varieties are chiefly characterised by containing innumerable threads of dark-green serpentine, and by having calcareous matter in their interstices. These rocks have an obscure, concretionary structure, and are full of variously coloured angular pseudo fragments. These angular pseudo fragments consist of the first-described dark green rock, of a brown softer kind, of serpentine, and of a yellowish harsh stone, which, perhaps, is related to serpentine rock. There are other vesicular, calcareo-ferruginous, soft stones. There is no distinct stratification, but parts are imperfectly laminated; and the whole abounds with innumerable veins, and vein-like masses, both small and large. Of these vein-like masses, some calcareous ones, which contain minute fragments of shells, are clearly of subsequent origin to the others.

A glossy incrustation.—Extensive portions of these rocks are coated by a layer of a glossy polished substance, with a pearly lustre and of a greyish white colour; it follows all the inequalities of the surface, to which it is firmly attached. When examined with a lens, it is found to consist of numerous exceedingly thin layers, their aggregate thickness being about the tenth of an inch. It is considerably harder than calcareous spar, but can be scratched with a knife; under the blowpipe it scales off, decrepitates, slightly blackens, emits a fetid odour, and becomes strongly alkaline: it does not effervesce in acids.[6] I presume this substance has been deposited by water draining from the birds' dung, with which the rocks are covered. At Ascension, near a cavity in the rocks which was filled with a laminated mass of infiltrated birds' dung, I found some irregularly formed, stalactitical masses of apparently the same nature. These masses, when broken, had an earthy texture; but on their outsides, and especially at their extremities, they were formed of a pearly substance, generally in little globules, like the enamel of teeth, but more translucent, and so hard as just to scratch plate-glass. This substance slightly blackens under the blowpipe, emits a bad smell, then becomes quite white, swelling a little, and fuses into a dull white enamel; it does not become alkaline; nor does it effervesce in acids. The whole mass had a collapsed appearance, as if in the formation of the hard glossy crust the whole had shrunk much. At the Abrolhos Islands on the coast of Brazil, where also there is much birds' dung, I found a great quantity of a brown, arborescent substance adhering to some trap-rock. In its arborescent form, this substance singularly resembles some of the branched species of Nullipora. Under the blowpipe, it behaves like the specimens from Ascension; but it is less hard and glossy, and the surface has not the shrunk appearance.

[6] In my "Journal" I have described this substance; I then believed that it was an impure phosphate of lime.

Chapter III

ASCENSION.

Basaltic lavas.—Numerous craters truncated on the same side.—Singular structure of volcanic bombs.—Aeriform explosions.—Ejected granitic fragments.—Trachytic rocks.—Singular veins.—Jasper, its manner of formation.—Concretions in pumiceous tuff.—Calcareous deposits and frondescent incrustations on the coast.—Remarkable laminated beds, alternating with, and passing into, obsidian.—Origin of obsidian.—Lamination of volcanic rocks.

This island is situated in the Atlantic Ocean, in lat. 8° S., long. 14° W. It has the form of an irregular triangle (see map below), each side being about six miles in length. Its highest point is 2,870 feet[1] above the level of the sea. The whole is volcanic, and, from the absence of proofs to the contrary, I believe of subaerial origin. The fundamental rock is everywhere of a pale colour, generally compact, and of a feldspathic nature. In the S.E. portion of the island, where the highest land is situated, well characterised trachyte, and other congenerous rocks of that varying here and there a hill or single point of rock (one of which near the sea-coast, north of the Fort, is only two or three yards across) of the trachyte still remaining exposed.

[1] *Geographical Journal*, vol. v, p. 243.

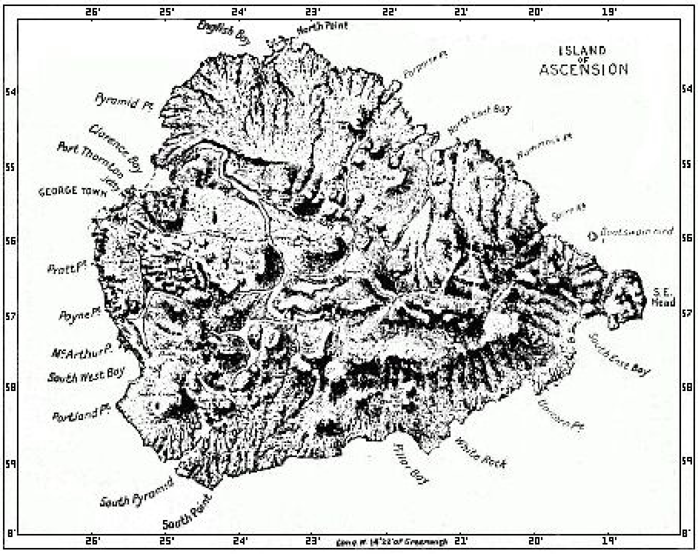


Plate IV.

Basaltic rocks.—The overlying basaltic lava is in some parts extremely vesicular, in others little so; it is of a black colour, but sometimes contains crystals of glassy feldspar, and seldom much olivine. These streams appear to have possessed singularly little fluidity; their side walls and lower ends being very steep, and even as much as between twenty and thirty feet in height. Their surface is extraordinarily rugged, and from a short distance appears as if studded with small craters. These projections consist of broad, irregularly conical, hillocks, traversed by fissures, and composed of the same unequally scoriaceous basalt with the surrounding streams, but having an obscure tendency to a columnar structure; they rise to a height between ten and thirty feet above the general surface, and have been formed, as I presume, by the heaping up of the viscid lava at points of greater resistance. At the base of several of these hillocks, and occasionally likewise on more level parts, solid ribs, composed of angulo-globular masses of basalt, resembling in size and outline arched sewers or gutters of brickwork, but not being hollow, project between two or three feet above the surface of the streams; what their origin may have been, I do not know. Many of the superficial fragments from these basaltic streams present singularly convoluted forms; and some specimens could hardly be distinguished from logs of dark-coloured wood without their bark.

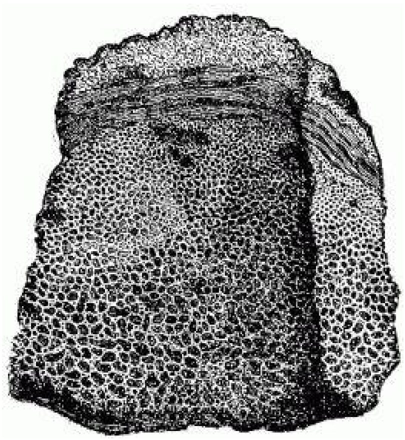
Many of the basaltic streams can be traced, either to points of eruption at the base of the great central mass of trachyte, or to separate, conical, red-coloured hills, which are scattered over the northern and western borders of the island. Standing on the central eminence, I counted between twenty and thirty of these cones of eruption. The greater number of them had their truncated summits cut off obliquely, and they all sloped towards the S.E., whence the trade-wind blows.[2] This structure no doubt has been caused by the ejected fragments and ashes being always blown, during eruptions, in greater quantity towards one side than towards the other. M. Moreau de Jonnes has made a similar observation with respect to the volcanic orifices in the West Indian Islands.

[2] M. Lesson in the "Zoology of the Voyage of the *Coquille*," p. 490 has observed this fact. Mr. Hennah ("Geolog. Proceedings," 1835, p. 189) further remarks that the most extensive beds of ashes at Ascension invariably occur on the leeward side of the island.

Volcanic bombs.—These occur in great numbers strewed on the ground, and some of them lie at considerable distances from any points of eruption. They vary in size from that of an apple to that of a man's body; they are either spherical or pear-shaped, or with the hinder part (corresponding to the tail of a comet) irregular, studded with projecting points, and even concave. Their surfaces are rough, and fissured with branching cracks; their internal structure is either irregularly scoriaceous and compact, or it presents a symmetrical and very curious appearance. An irregular segment of a bomb of this latter kind, of which I found several, is accurately represented in figure No. 3. Its size was about that of a man's head. The whole interior is coarsely cellular; the cells averaging in diameter about the tenth of an inch; but nearer the outside they gradually decrease in size. This part is succeeded by a well-defined shell of compact lava, having a nearly uniform thickness of about the third of an inch; and the shell is overlaid by a somewhat thicker coating of finely cellular lava (the cells varying from the fiftieth to the hundredth of an inch in diameter), which forms the external surface: the line separating the shell of compact lava from the outer scoriaceous crust is distinctly defined. This structure is very simply explained, if we suppose a mass of viscid, scoriaceous matter, to be projected with a rapid, rotatory motion through the air; for whilst the external crust, from cooling, became solidified (in the state we now see it), the centrifugal force, by relieving the pressure in the interior parts of the bomb, would allow the heated vapours to expand their cells; but these being driven by the same force against the already-hardened crust, would become, the nearer they were to this part, smaller and smaller or less expanded, until they became packed into a solid, concentric shell. As we know that chips from a grindstone[3] can be flirted off, when made to revolve with sufficient velocity, we need not doubt that the centrifugal force would have power to modify the structure of a softened bomb, in the manner here supposed. Geologists have remarked, that the external form of a bomb at once bespeaks the history of its aerial course, and few now see that the internal structure can speak, with almost equal plainness, of its rotatory movement.

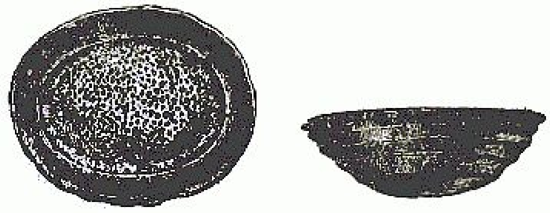
[3] Nichol's "Architecture of the Heavens."

No. 3



Fragment of a spherical volcanic bomb, with the inferior parts coarsely cellular, coated by a concentric layer of compact lava, and this again by a crust of finely cellular rock.

No. 4



Volcanic bomb of obsidian from Australia. The figure at left gives a front view; the figure at right a side view of the same object.

M. Bory St. Vincent[4] has described some balls of lava from the Isle of Bourbon, which have a closely similar structure. His explanation, however (if I understand it rightly), is very different from that which I have given; for he supposes that they have rolled, like snowballs, down the sides of the crater. M. Beudant,[5] also, has described some singular little balls of obsidian, never more than six or eight inches in diameter, which he found strewed on the surface of the ground: their form is always oval; sometimes they are much swollen in the middle, and even spindle-shaped: their surface is regularly marked with concentric ridges and furrows, all of which on the same ball are at right angles to one axis: their interior is compact and glassy. M. Beudant supposes that masses of lava, when soft, were shot into the air, with a rotatory movement round the same axis, and that the form and superficial ridges of the bombs were thus produced. Sir Thomas Mitchell has given me what at first appears to be the half of a much flattened oval ball of obsidian; it has a singular artificial-like appearance, which is well represented (of the natural size) in figure No. 4. It was found in its present state, on a great sandy plain between the rivers Darling and Murray, in Australia, and at the distance of several hundred miles from any known volcanic region. It seems to have been embedded in some reddish tufaceous matter; and may have been transported either by the aborigines or by natural means. The external saucer consists of compact obsidian, of a bottle-green colour, and is filled with finely cellular black lava, much less transparent and glassy than the obsidian. The external surface is marked with four or five not quite perfect ridges, which are represented rather too distinctly in figure No. 4. Here, then, we have the external structure described by M. Beudant, and the internal cellular condition of the bombs from Ascension. The lip of the saucer is slightly concave, exactly like the margin of a soup-plate, and its inner edge overlaps a little the central cellular lava. This structure is so symmetrical round the entire circumference, that one is forced to suppose that the bomb burst during its rotatory course, before being quite solidified, and that the lip and edges were thus slightly modified and turned inwards. It may be remarked that the superficial ridges are in planes, at right angles to an axis, transverse to the longer axis of the flattened oval: to explain this circumstance, we may suppose that when the bomb burst, the axis of rotation changed.

[4] "Voyage aux Quatre Isles d'Afrique" tome i, p. 222.

[5] "Voyage en Hongrie," tome ii, p. 214.

Aeriform explosions.—The flanks of Green Mountain and the surrounding country are covered by a great mass, some hundred feet in thickness, of loose fragments. The lower beds generally consist of fine-grained, slightly consolidated tuffs,[6] and the upper beds of great loose fragments, with alternating finer beds.[7] One white ribbon-like layer of decomposed, pumiceous breccia, was curiously bent into deep unbroken curves, beneath each of the large fragments in the superincumbent stratum. From the relative position of these beds, I presume that a narrow-mouthed crater, standing nearly in the position of Green Mountain, like a great air-gun, shot forth, before its final extinction, this vast accumulation of loose matter. Subsequently to this event, considerable dislocations have taken place, and an oval circus has been formed by subsidence. This sunken space lies at the north-eastern foot of Green Mountain, and is well represented in Map 2. Its longer axis, which is connected with a N.E. and S.W. line of fissure, is three-fifths of a nautical mile in length; its sides are nearly perpendicular, except in one spot, and about four hundred feet in height; they consist, in the lower part, of a pale basalt with feldspar, and in the upper part, of the tuff and loose ejected fragments; the bottom is smooth and level, and under almost any other climate a deep lake would have been formed here. From the thickness of the bed of loose fragments, with which the surrounding country is covered, the amount of aeriform matter necessary for their projection must have been enormous; hence we may suppose it probable that after the explosions vast subterranean caverns were left, and that the falling in of the roof of one of these produced the hollow here described. At the Galapagos Archipelago, pits of a similar character, but of a much smaller size, frequently occur at the bases of small cones of eruption.

[6] Some of this peperino, or tuff, is sufficiently hard not to be broken by the greatest force of the fingers.

[7] On the northern side of the Green Mountain a thin seam, about an inch in thickness, of compact oxide of iron, extends over a considerable area; it lies conformably in the lower part of the stratified mass of ashes and fragments. This substance is of a reddish-brown colour, with an almost metallic lustre; it is not magnetic, but becomes so after having been heated under the blowpipe, by which it is blackened and partly fused. This seam of compact stone, by intercepting the little rain-water which falls on the island, gives rise to a small dripping spring, first discovered by Dampier. It is the only fresh water on the island, so that the possibility of its being inhabited has entirely depended on the occurrence of this ferruginous layer.

Ejected granitic fragments.—In the neighbourhood of Green Mountain, fragments of extraneous rock are not unfrequently found embedded in the midst of masses of scoriæ. Lieutenant Evans, to whose kindness I am indebted for much information, gave me several specimens, and I found others myself. They nearly all have a granitic structure, are brittle, harsh to the touch, and apparently of altered colours. *First*, a white syenite, streaked and mottled with red; it consists of well-crystallised feldspar, numerous grains of quartz, and brilliant, though small, crystals of hornblende. The feldspar and hornblende in this and the succeeding cases have been determined by the reflecting goniometer, and the quartz by its action under the blowpipe. The feldspar in these ejected fragments, like the glassy kind in the trachyte, is from its cleavage a potash-feldspar. *Secondly*, a brick-red mass of feldspar, quartz, and small dark patches of a decayed mineral; one minute particle of which I was able to ascertain, by its cleavage, to be hornblende. *Thirdly*, a mass of confusedly crystallised white feldspar, with little nests of a dark-coloured mineral, often carious, externally rounded, having a glossy fracture, but no distinct cleavage: from comparison with the second specimen, I have no doubt that it is fused hornblende. *Fourthly*, a rock, which at first appears a simple aggregation of distinct and large-sized crystals of dusty-coloured Labrador feldspar;[8] but in their interstices there is some white granular feldspar, abundant scales of mica, a little altered hornblende, and, as I believe, no quartz. I have described these fragments in detail, because it is rare[9] to find granitic rocks ejected from volcanoes with their *minerals unchanged*, as is the case with the first specimen, and partially with the second. One other large fragment, found in another spot, is deserving of notice; it is a conglomerate, containing small fragments of granitic, cellular, and jaspery rocks, and of hornstone porphyries, embedded in a base of wacke, threaded by numerous thin layers of a concretionary pitchstone passing into obsidian. These layers are parallel, slightly tortuous, and short; they thin out at their ends, and resemble in form the layers of quartz in gneiss. It is probable that these small embedded fragments were not separately ejected, but were entangled in a fluid volcanic rock, allied to obsidian; and we shall presently see that several varieties of this latter series of rock assume a laminated structure.

[8] Professor Miller has been so kind as to examine this mineral. He obtained two good cleavages of 86° 30′ and 86° 50′. The mean of several, which I made, was 86° 30′. Professor Miller states that these crystals, when reduced to a fine powder, are soluble in hydrochloric acid, leaving some undissolved silex behind; the addition of oxalate of ammonia gives a copious precipitate of lime. He further remarks, that according to Von Kobell, anorthite (a mineral occurring in the ejected fragments at Mount Somma) is always white and transparent, so that if this be the case, these crystals from Ascension must be considered as Labrador feldspar. Professor Miller adds, that he has seen an account, in Erdmann's "Journal für tecnische Chemie," of a mineral ejected from a volcano which had the external characters of Labrador feldspar, but differed in the analysis from that given by mineralogists of this mineral: the author attributed this difference to an error in the analysis of Labrador feldspar, which is very old.

[9] Daubeny, in his work on Volcanoes (p. 386), remarks that this

is the case; and Humboldt, in his "Personal Narrative," vol. i, p. 236, says "In general, the masses of known primitive rocks, I mean those which perfectly resemble our granites, gneiss, and mica-slate, are very rare in lavas: the substances we generally denote by the name of granite, thrown out by Vesuvius, are mixtures of nepheline, mica, and pyroxene."

Trachytic series of rocks.—Those occupy the more elevated and central, and likewise the south-eastern, parts of the island. The trachyte is generally of a pale brown colour, stained with small darker patches; it contains broken and bent crystals of glassy feldspar, grains of specular iron, and black microscopical points, which latter, from being easily fused, and then becoming magnetic, I presume are hornblende. The greater number of the hills, however, are composed of a quite white, friable stone, appearing like a trachytic tuff. Obsidian, hornstone, and several kinds of laminated feldspathic rocks, are associated with the trachyte. There is no distinct stratification; nor could I distinguish a crateriform structure in any of the hills of this series. Considerable dislocations have taken place; and many fissures in these rocks are yet left open, or are only partially filled with loose fragments. Within the space,[10] mainly formed of trachyte, some basaltic streams have burst forth; and not far from the summit of Green Mountain, there is one stream of quite black, vesicular basalt, containing minute crystals of glassy feldspar, which have a rounded appearance.

[10] This space is nearly included by a line sweeping round Green Mountain, and joining the hills, called the Weather Port Signal, Holyhead, and that denominated (improperly in a geological sense) "the Crater of an old volcano."

The soft white stone above mentioned is remarkable from its singular resemblance, when viewed in mass, to a sedimentary tuff: it was long before I could persuade myself that such was not its origin; and other geologists have been perplexed by closely similar formations in trachytic regions. In two cases, this white earthy stone formed isolated hills; in a third, it was associated with columnar and laminated trachyte; but I was unable to trace an actual junction. It contains numerous crystals of glassy feldspar and black microscopical specks, and is marked with small darker patches, exactly as in the surrounding trachyte. Its basis, however, when viewed under the microscope, is generally quite earthy; but sometimes it exhibits a decidedly crystalline structure. On the hill marked "Crater of an old volcano," it passes into a pale greenish-grey variety, differing only in its colour, and in not being so earthy; the passage was in one case effected insensibly; in another, it was formed by numerous, rounded and angular, masses of the greenish variety, being embedded in the white variety;—in this latter case, the appearance was very much like that of a sedimentary deposit, torn up and abraded during the deposition of a subsequent stratum. Both these varieties are traversed by innumerable tortuous veins (presently to be described), which are totally unlike injected dikes, or indeed any other veins which I have ever seen. Both varieties include a few scattered fragments, large and small, of dark-coloured scoriaceous rocks, the cells of some of which are partially filled with the white earthy stone; they likewise include some huge blocks of a cellular porphyry.[11] These fragments project from the weathered surface, and perfectly resemble fragments embedded in a true sedimentary tuff. But as it is known that extraneous fragments of cellular rock are sometimes included in columnar trachyte, in phonolite, [12] and in other compact lavas, this circumstance is not any real argument for the sedimentary origin of the white earthy stone.[13] The insensible passage of the greenish variety into the white one, and likewise the more abrupt passage by fragments of the former being embedded in the latter, might result from slight differences in the composition of the same mass of molten stone, and from the abrading action of one such part still fluid on another part already solidified. The curiously formed veins have, I believe, been formed by siliceous matter being subsequently segregated. But my chief reason for believing that these soft earthy stones, with their extraneous fragments, are not of sedimentary origin, is the extreme improbability of crystals of feldspar, black microscopical specks, and small stains of a darker colour occurring in the same proportional numbers in an aqueous deposit, and in masses of solid trachyte. Moreover, as I have remarked, the microscope occasionally reveals a crystalline structure in the apparently earthy basis. On the other hand, the partial decomposition of such great masses of trachyte, forming whole mountains, is undoubtedly a circumstance of not easy explanation.

[11] The porphyry is dark coloured; it contains numerous, often

fractured, crystals of white opaque feldspar, also decomposing crystals of oxide of iron; its vesicles include masses of delicate, hair-like, crystals, apparently of analcime.

[12] D'Aubuisson, "Traité de Géognosie," tome ii, p. 548.

[13] Dr. Daubeny (on Volcanoes, p. 180) seems to have been led to believe that certain trachytic formations of Ischia and of the Puy de Dôme, which closely resemble these of Ascension, were of sedimentary origin, chiefly from the frequent presence in them "of scoriform portions, different in colour from the matrix." Dr. Daubeny adds, that on the other hand, Brocchi, and other eminent geologists, have considered these beds as earthy varieties of trachyte; he considers the subject deserving of further attention.

Veins in the earthy trachytic masses.—These veins are extraordinarily numerous, intersecting in the most complicated manner both coloured varieties of the earthy trachyte: they are best seen on the flanks of the "Crater of the old volcano." They contain crystals of glassy feldspar, black microscopical specks and little dark stains, precisely as in the surrounding rock; but the basis is very different, being exceedingly hard, compact, somewhat brittle, and of rather less easy fusibility. The veins vary much, and suddenly, from the tenth of an inch to one inch in thickness; they often thin out, not only on their edges, but in their central parts, thus leaving round, irregular apertures; their surfaces are rugged. They are inclined at every possible angle with the horizon, or are horizontal; they are generally curvilinear, and often interbranch one with another. From their hardness they withstand weathering, and projecting two or three feet above the ground, they occasionally extend some yards in length; these plate-like veins, when struck, emit a sound, almost like that of a drum, and they may be distinctly seen to vibrate; their fragments, which are strewed on the ground, clatter like pieces of iron when knocked against each other. They often assume the most singular forms; I saw a pedestal of the earthy trachyte, covered by a hemispherical portion of a vein, like a great umbrella, sufficiently large to shelter two persons. I have never met with, or seen described, any veins like these; but in form they resemble the ferruginous seams, due to some process of segregation, occurring not uncommonly in sandstones,—for instance, in the New Red sandstone of England. Numerous veins of jasper and of siliceous sinter, occurring on the summit of this same hill, show that there has been some abundant source of silica, and as these plate-like veins differ from the trachyte only in their greater hardness, brittleness, and less easy fusibility, it appears probable that their origin is due to the segregation or infiltration of siliceous matter, in the same manner as happens with the oxides of iron in many sedimentary rocks.

Siliceous sinter and jasper.—The siliceous sinter is either quite white, of little specific gravity, and with a somewhat pearly fracture, passing into pinkish pearl quartz; or it is yellowish white, with a harsh fracture, and it then contains an earthy powder in small cavities. Both varieties occur, either in large irregular masses in the altered trachyte, or in seams included in broad, vertical, tortuous, irregular veins of a compact, harsh stone of a dull red colour, appearing like a sandstone. This stone, however, is only altered trachyte; and a nearly similar variety, but often honeycombed, sometimes adheres to the projecting plate-like veins, described in the last paragraph. The jasper is of an ochre yellow or red colour; it occurs in large irregular masses, and sometimes in veins, both in the altered trachyte and in an associated mass of scoriaceous basalt. The cells of the scoriaceous basalt are lined or filled with fine, concentric layers of chalcedony, coated and studded with bright-red oxide of iron. In this rock, especially in the rather more compact parts, irregular angular patches of the red jasper are included, the edges of which insensibly blend into the surrounding mass; other patches occur having an intermediate character between perfect jasper and the ferruginous, decomposed, basaltic base. In these patches, and likewise in the large vein-like masses of jasper, there occur little rounded cavities, of exactly the same size and form with the air-cells, which in the scoriaceous basalt are filled and lined with layers of chalcedony. Small fragments of the jasper, examined under the microscope, seem to resemble the chalcedony with its colouring matter not separated into layers, but mingled in the siliceous paste, together with some impurities. I can understand these facts,—namely, the blending of the jasper into the semi-decomposed basalt,—its occurrence in angular patches, which clearly do not occupy pre-existing hollows in the rock,—and its containing little vesicles filled with chalcedony, like those in the scoriaceous lava,—only on the supposition that a fluid, probably the same fluid which deposited the chalcedony in the air-cells, removed in those parts where there were no cavities, the ingredients of the basaltic rock, and left in their place silica and iron, and thus produced the jasper. In some specimens of silicified wood, I have observed, that in the same manner as in the basalt, the solid parts were converted into a dark-coloured homogeneous stone, whereas the cavities formed by the larger sap-vessels (which may be compared with the air-vesicles in the basaltic lava) and other irregular hollows, apparently produced by decay, were filled with concentric layers of chalcedony; in this case, there can be little doubt that the same fluid deposited the homogeneous base and the chalcedonic layers. After these considerations, I cannot doubt but that the jasper of Ascension may be viewed as a volcanic rock silicified, in precisely the same sense as this term is applied to wood, when silicified; we are equally ignorant of the means by which every atom of wood, whilst in a perfect state, is removed and replaced by atoms of silica, as we are of the means by which the constituent parts of a volcanic rock could be thus acted on.[14] I was led to the careful examination of these rocks, and to the conclusion here given, from having heard the Rev. Professor Henslow express a similar opinion, regarding the origin in trap-rocks of many chalcedonies and agates. Siliceous deposits seem to be very general, if not of universal occurrence, in partially decomposed trachytic tuffs;[15] and as these hills, according to the view above given, consist of trachyte softened and altered in situ, the presence of free silica in this case may be added as one more instance to the list.

[14] Beudant ("Voyage en Hongrie," tome iii, pp. 502, 504) describes kidney-shaped masses of jasper-opal, which either blend into the surrounding trachytic conglomerate, or are embedded in it like chalk-flints; and he compares them with the fragments of opalised wood, which are abundant in this same formation. Beudant, however, appears to have viewed the process of their formation rather as one of simple infiltration than of molecular exchange; but the presence of a concretion, wholly different from the surrounding matter, if not formed in a pre-existing hollow, clearly seems to me to require, either a molecular or mechanical displacement of the atoms, which occupied the space afterwards filled by it. The jasper-opal of Hungary passes into chalcedony, and therefore in this case, as in that of Ascension, jasper seems to be intimately related in origin with chalcedony.

[15] Beudant ("Voyage Min.," tome iii, p. 507) enumerates cases in Hungary, Germany, Central France, Italy, Greece, and Mexico.

Concretions in pumiceous tuff.—The hill, marked in Map 2 "Crater of an old volcano," has no claims to this appellation, which I could discover, except in being surmounted by a circular, very shallow, saucer-like summit, nearly half a mile in diameter. This hollow has been nearly filled up with many successive sheets of ashes and scoriæ, of different colours, and slightly consolidated. Each successive saucer-shaped layer crops out all round the margin, forming so many rings of various colours, and giving to the hill a fantastic appearance. The outer ring is broad, and of a white colour; hence it resembles a course round which horses have been exercised, and has received the name of the Devil's Riding School, by which it is most generally known. These successive layers of ashes must have fallen over the whole surrounding country, but they have all been blown away except in this one hollow, in which probably moisture accumulated, either during an extraordinary year when rain fell, or during the storms often accompanying volcanic eruptions. One of the layers of a pinkish colour, and chiefly derived from small, decomposed fragments of pumice, is remarkable, from containing numerous concretions. These are generally spherical, from half an inch to three inches in diameter; but they are occasionally cylindrical, like those of iron-pyrites in the chalk of Europe. They consist of a very tough, compact, pale-brown stone, with a smooth and even fracture. They are divided into concentric layers by thin white partitions, resembling the external superficies; six or eight of such layers are distinctly defined near the outside; but those towards the inside generally become indistinct, and blend into a homogeneous mass. I presume that these concentric layers were formed by the shrinking of the concretion, as it became compact. The interior part is generally fissured by minute cracks or septaria, which are lined, both by black, metallic, and by other white and crystalline specks, the nature of which I was unable to ascertain. Some of the larger concretions consist of a mere spherical shell, filled with slightly consolidated ashes. The concretions contain a small proportion of carbonate of lime: a fragment placed under the blowpipe decrepitates, then whitens and fuses into a blebby enamel, but does not become caustic. The surrounding ashes do not contain any carbonate of lime; hence the concretions have probably been formed, as is so often the case, by the aggregation of this substance. I have not met with any account of similar concretions; and considering their great toughness and compactness, their occurrence in a bed, which probably has been subjected only to atmospheric moisture, is remarkable.

Formation of calcareous rocks on the sea-coast.—On several of the sea-beaches, there are immense accumulations of small, well-rounded particles of shells and corals, of white, yellowish, and pink colours, interspersed with a few volcanic particles. At the depth of a few feet, these are found cemented together into stone, of which the softer varieties are used for building; there are other varieties, both coarse and fine-grained, too hard for this purpose: and I saw one mass divided into even layers half an inch in thickness, which were so compact that when struck with a hammer they rang like flint. It is believed by the inhabitants, that the particles become united in the course of a single year. The union is effected by calcareous matter; and in the most compact varieties, each rounded particle of shell and volcanic rock can be distinctly seen to be enveloped in a husk of pellucid carbonate of lime. Extremely few perfect shells are embedded in these agglutinated masses; and I have examined even a large fragment under a microscope, without being able to discover the least vestige of striæ or other marks of external form: this shows how long each particle must have been rolled about, before its turn came to be embedded and cemented.[16] One of the most compact varieties, when placed in acid, was entirely dissolved, with the exception of some flocculent animal matter; its specific gravity was 2·63. The specific gravity of ordinary limestone varies from 2·6 to 2·75; pure Carrara marble was found by Sir H. De la Beche[17] to be 2·7. It is remarkable that these rocks of Ascension, formed close to the surface, should be nearly as compact as marble, which has undergone the action of heat and pressure in the plutonic regions.

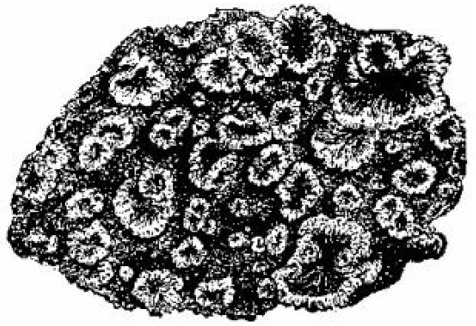
[16] The eggs of the turtle being buried by the parent, sometimes become enclosed in the solid rock. Mr. Lyell has given a figure (“Principles of Geology,” book iii, ch. 17) of some eggs, containing the bones of young turtles, found thus entombed.

[17] “Researches in Theoretical Geology,” p. 12.

The great accumulation of loose calcareous particles, lying on the beach near the Settlement, commences in the month of October, moving towards the S.W., which, as I was informed by Lieutenant Evans, is caused by a change in the prevailing direction of the currents. At this period the tidal rocks, at the S.W. end of the beach, where the calcareous sand is accumulating, and round which the currents sweep, become gradually coated with a calcareous incrustation, half an inch in thickness. It is quite white, compact, with some parts slightly spathose, and is firmly attached to the rock. After a short time it gradually disappears, being either redissolved, when the water is less charged with lime, or more probably is mechanically abraded. Lieutenant Evans has observed these facts, during the six years he has resided at Ascension. The incrustation varies in thickness in different years: in 1831 it was unusually thick. When I was there in July, there was no remnant of the incrustation; but on a point of basalt, from which the quarrymen had lately removed a mass of the calcareous freestone, the incrustation was perfectly preserved. Considering the position of the tidal-rocks, and the period at which they become coated, there can be no doubt that the movement and disturbance of the vast accumulation of calcareous particles, many of them being partially agglutinated together, cause the waves of the sea to be so highly charged with carbonate of lime, that they deposit it on the first objects against which they impinge. I have been informed by Lieutenant Holland, R.N., that this incrustation is formed on many parts of the coast, on most of which, I believe, there are likewise great masses of comminuted shells.

A frondescent calcareous incrustation.—In many respects this is a singular deposit; it coats throughout the year the tidal volcanic rocks, that project from the beaches composed of broken shells. Its general appearance is well represented in Figure 5; but the fronds or discs, of which it is composed, are generally so closely crowded together as to touch. These fronds have their sinuous edges finely crenulated, and they project over their pedestals or supports; their upper surfaces are either slightly concave, or slightly convex; they are highly polished, and of a dark grey or jet black colour; their form is irregular, generally circular, and from the tenth of an inch to one inch and a half in diameter; their thickness, or amount of their projection from the rock on which they stand, varies much, about a quarter of an inch being perhaps most usual. The fronds occasionally become more and more convex, until they pass into botryoidal masses with their summits fissured; when in this state, they are glossy and of an intense black, so as to resemble some fused metallic substance. I have shown the incrustation, both in this latter and in its ordinary state to several geologists, but not one could conjecture its origin, except that perhaps it was of volcanic nature!

No. 5



An incrustation of calcareous and animal matter, coating the tidal-rocks at Ascension.

The substance forming the fronds has a very compact and often almost crystalline fracture; the edges being translucent, and hard enough easily to scratch calcareous spar. Under the blowpipe it immediately becomes white, and emits a strong animal odour, like that from fresh shells. It is chiefly composed of carbonate of lime; when placed in muriatic acid it froths much, leaving a residue of sulphate of lime, and of an oxide of iron, together with a black powder, which is not soluble in heated acids. This latter substance seems to be carbonaceous, and is evidently the colouring matter. The sulphate of lime is extraneous, and occurs in distinct, excessively minute, lamellar plates, studded on the surface of the fronds, and embedded between the fine layers of which they are composed; when a fragment is heated in the blowpipe, these lamellæ are immediately rendered visible. The original outline of the fronds may often be traced, either to a minute particle of shell fixed in a crevice of the rock, or to several cemented together; these first become deeply corroded, by the dissolving power of the waves, into sharp ridges, and then are coated with successive layers of the glossy, grey, calcareous incrustation. The inequalities of the primary support affect the outline of every successive layer, in the same manner as may often be seen in bezoar-stones, when an object like a nail forms the centre of aggregation. The crenulated edges, however, of the frond appear to be due to the corroding power of the surf on its own deposit, alternating with fresh depositions. On some smooth basaltic rocks on the coast of St. Jago, I found an exceedingly thin layer of brown calcareous matter, which under a lens presented a miniature likeness of the crenulated and polished fronds of Ascension; in this case a basis was not afforded by any projecting extraneous particles. Although the incrustation at Ascension is persistent throughout the year; yet from the abraded appearance of some parts, and from the fresh appearance of other parts, the whole seems to undergo a round of decay and renovation, due probably to changes in the form of the shifting beach, and consequently in the action of the breakers: hence probably it is, that the incrustation never acquires a great thickness. Considering the position of the encrusted rocks in the midst of the calcareous beach, together with its composition, I think there can be no doubt that its origin is due to the dissolution and subsequent deposition of the matter composing the rounded particles of shells and corals.[18] From this source it derives its animal matter, which is evidently the colouring principle. The nature of the deposit, in its incipient stage, can often be well seen upon a fragment of white shell, when jammed between two of the fronds; it then appears exactly like the thinnest wash of a pale grey varnish. Its darkness varies a little, but the jet blackness of some of the fronds and of the botryoidal masses seems due to the translucency of the successive grey layers. There is, however, this singular circumstance, that when deposited on the under side of ledges of rock or in fissures, it appears always to be of a pale, pearly grey colour, even when of considerable thickness: hence one is led to suppose, that an abundance of light is necessary to the development of the dark colour, in the same manner as seems to be the case with the upper and exposed surfaces of the shells of living mollusca, which are always dark, compared with their under surfaces and with the parts habitually covered by the mantle of the animal. In this circumstance,—in the immediate loss of colour and in the odour emitted under the blowpipe,—in the degree of hardness and translucency of the edges,—and in the beautiful polish of the surface,[19] rivalling when in a fresh state that of the finest Oliva, there is a striking analogy between this inorganic incrustation and the shells of living molluscous animals.[20] This appears to me to be an interesting physiological fact.[21]

[18] The selenite, as I have remarked is extraneous, and must have been derived from the sea-water. It is an interesting circumstance thus to find the waves of the ocean, sufficiently charged with sulphate of lime, to deposit it on the rocks, against which they dash every tide. Dr. Webster has described ("Voyage of the *Chanticleer,*" vol. ii, p. 319) beds of gypsum and salt, as much as two feet in thickness, left by the evaporation of the spray on the rocks on the windward coast. Beautiful stalactites of selenite, resembling in form those of carbonate of lime, are formed near these beds. Amorphous masses of gypsum, also, occur in caverns in the interior of the island; and at Cross Hill (an old crater) I saw a considerable quantity of salt oozing from a pile of scoriæ. In these latter cases, the salt and gypsum appear to be volcanic products.)

[19] From the fact described in my "Journal of Researches" of a coating of oxide of iron, deposited by a streamlet on the rocks in its bed (like a nearly similar coating at the great cataracts of the Orinoco and Nile), becoming finely polished where the surf acts, I presume that the surf in this instance, also, is the polishing agent.)

[20] In the section descriptive of St. Paul's Rocks, I have described a glossy, pearly substance, which coats the rocks, and an allied stalactitical incrustation from Ascension, the crust of which resembles the enamel of teeth, but is hard enough to scratch plate-glass. Both these substances contain animal matter, and seem to have been derived from water in filtering through birds' dung.

[21] Mr. Horner and Sir David Brewster have described ("Philosophical Transactions," 1836, p. 65) a singular "artificial substance, resembling shell." It is deposited in fine, transparent, highly polished, brown-coloured laminæ, possessing peculiar optical properties, on the inside of a vessel, in which cloth, first prepared with glue and then with lime, is made to revolve rapidly in water. It is much softer, more transparent, and contains more animal matter, than the natural incrustation at Ascension; but we here again see the strong tendency which carbonate of lime and animal matter evince to form a solid substance allied to shell.

Singular laminated beds alternating with and passing into obsidian.—These beds occur within the trachytic district, at the western base of Green Mountain, under which they dip at a high inclination. They are only partially exposed, being covered up by modern ejections; from this cause, I was unable to trace their junction with the trachyte, or to discover whether they had flowed as a stream of lava, or had been injected amidst the overlying strata. There are three principal beds of obsidian, of which the thickest forms the base of the section. The alternating stony layers appear to me eminently curious, and shall be first described, and afterwards their passage into the obsidian. They have an extremely diversified appearance; five principal varieties may be noticed, but these insensibly blend into each other by endless gradations.

First.—A pale grey, irregularly and coarsely laminated,[22] harsh-feeling rock, resembling clay-slate which has been in contact with a trap-dike, and with a fracture of about the same degree of crystalline structure. This rock, as well as the following varieties, easily fuses into a pale glass. The greater part is honeycombed with irregular, angular, cavities, so that the whole has a curious appearance, and some fragments resemble in a remarkable manner silicified logs of decayed wood. This variety, especially where more compact, is often marked with thin whitish streaks, which are either straight or wrap round, one behind the other, the elongated carious hollows.

[22] This term is open to some misinterpretation, as it may be applied both to rocks divided into laminæ of exactly the same composition, and to layers firmly attached to each other, with no fissile tendency, but composed of different minerals, or of different shades of colour. The term "laminated," in this chapter, is applied in these latter senses; where a homogeneous rock splits, as in the former sense, in a given direction, like clay-slate, I have used the term "fissile."

Secondly.—A bluish grey or pale brown, compact, heavy, homogeneous stone, with an angular, uneven, earthy fracture; viewed, however, under a lens of high power, the fracture is seen to be distinctly crystalline, and even separate minerals can be distinguished.

Thirdly.—A stone of the same kind with the last, but streaked with numerous, parallel, slightly tortuous, white lines of the thickness of hairs. These white lines are more crystalline than the parts between them; and the stone splits along them: they frequently expand into exceedingly thin cavities, which are often only just perceptible with a lens. The matter forming the white lines becomes better crystallised in these cavities, and Professor Miller was fortunate enough, after several trials, to ascertain that the white crystals, which are the largest, were of quartz,[23] and that the minute green transparent needles were augite, or, as they would more generally be called, diopside: besides these crystals, there are some minute, dark specks without a trace of crystalline, and some fine, white, granular, crystalline matter which is probably feldspar. Minute fragments of this rock are easily fusible.

[23] Professor Miller informs me that the crystals which he measured had the faces *P, z, m* of the figure (147) given by Haidinger in his Translation of Mohs; and he adds, that it is remarkable, that none of them had the slightest trace of faces *r* of the regular six-sided prism.

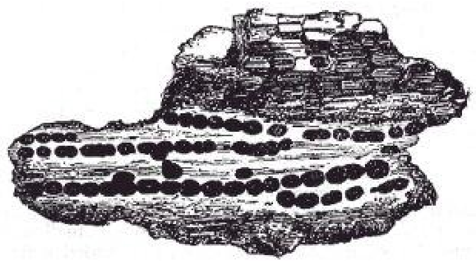
Fourthly.—A compact crystalline rock, banded in straight lines with innumerable layers of white and grey shades of colour, varying in width from the thirtieth to the two-hundredth of an inch; these layers seem to be composed chiefly of feldspar, and they contain numerous perfect crystals of glassy feldspar, which are placed lengthways; they are also thickly studded with microscopically minute, amorphous, black specks, which are placed in rows, either standing separately, or more frequently united, two or three or several together, into black lines, thinner than a hair. When a small fragment is heated in the blowpipe, the black specks are easily fused into black brilliant beads, which become magnetic,—characters that apply to no common mineral except hornblende or augite. With the black specks there are mingled some others of a red colour, which are magnetic before being heated, and no doubt are oxide of iron. Round two little cavities, in a specimen of this variety, I found the black specks aggregated into minute crystals, appearing like those of augite or hornblende, but too dull and small to be measured by the goniometer; in the specimen, also, I could distinguish amidst the crystalline feldspar, grains, which had the aspect of quartz. By trying with a parallel ruler, I found that the thin grey layers and the black hair-like lines were absolutely straight and parallel to each other. It is impossible to trace the gradation from the homogeneous grey rocks to these striped varieties, or indeed the character of the different layers in the same specimen, without feeling convinced that the more or less perfect whiteness of the crystalline feldspathic matter depends on the more or less perfect aggregation of diffused matter, into the black and red specks of hornblende and oxide of iron.

Fifthly.—A compact heavy rock, not laminated, with an irregular, angular, highly crystalline, fracture; it abounds with distinct crystals of glassy feldspar, and the crystalline feldspathic base is mottled with a black mineral, which on the weathered surface is seen to be aggregated into small crystals, some perfect, but the greater number imperfect. I showed this specimen to an experienced geologist, and asked him what it was; he answered, as I think every one else would have done, that it was a primitive greenstone. The weathered surface, also, of the banded variety in figure No. 4, strikingly resembles a worn fragment of finely laminated gneiss.

These five varieties, with many intermediate ones, pass and repass into each other. As the compact varieties are quite subordinate to the others, the whole may be considered as laminated or striped. The laminæ, to sum up their characteristics, are either quite straight, or slightly tortuous, or convoluted; they are all parallel to each other, and to the intercalating strata of obsidian; they are generally of extreme thinness; they consist either of an apparently homogeneous, compact rock, striped with different shades of grey and brown colours, or of crystalline feldspathic layers in a more or less perfect state of purity, and of different thicknesses, with distinct crystals of glassy feldspar placed lengthways, or of very thin layers chiefly composed of minute crystals of quartz and augite, or composed of black and red specks of an augitic mineral and of an oxide of iron, either not crystallised or imperfectly so. After having fully described the obsidian, I shall return to the subject of the lamination of rocks of the trachytic series.

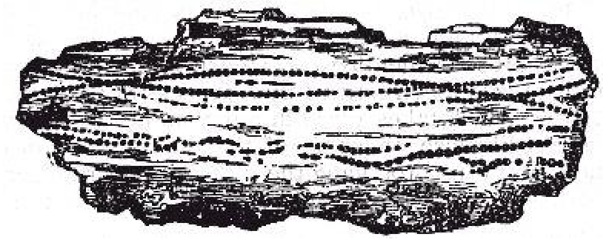
The passage of the foregoing beds into the strata of glassy obsidian is effected in several ways: first, angulo-modular masses of obsidian, both large and small, abruptly appear disseminated in a slaty, or in an amorphous, pale-coloured, feldspathic rock, with a somewhat pearly fracture. Secondly, small irregular nodules of the obsidian, either standing separately, or united into thin layers, seldom more than the tenth of an inch in thickness, alternate repeatedly with very thin layers of a feldspathic rock, which is striped with the finest parallel zones of colour, like an agate, and which sometimes passes into the nature of pitchstone; the interstices between the nodules of obsidian are generally filled by soft white matter, resembling pumiceous ashes. Thirdly, the whole substance of the bounding rock suddenly passes into an angulo-concretionary mass of obsidian. Such masses (as well as the small nodules) of obsidian are of a pale green colour, and are generally streaked with different shades of colour, parallel to the laminæ of the surrounding rock; they likewise generally contain minute white sphærulites, of which half is sometimes embedded in a zone of one shade of colour, and half in a zone of another shade. The obsidian assumes its jet black colour and perfectly conchoidal fracture, only when in large masses; but even in these, on careful examination and on holding the specimens in different lights, I could generally distinguish parallel streaks of different shades of darkness.

No. 6



Opaque brown sphærulites, drawn on an enlarged scale. The upper ones are externally marked with parallel ridges. The internal radiating structure of the lower ones, is much too plainly represented.

No. 7



A layer, formed by the union of minute brown sphærulites, intersecting two other similar layers: the whole represented of nearly the natural size.

One of the commonest transitional rocks deserves in several respects a further description. It is of a very complicated nature, and consists of numerous thin, slightly tortuous layers of a pale-coloured feldspathic stone, often passing into an imperfect pitchstone, alternating with layers formed of numberless little globules of two varieties of obsidian, and of two kinds of sphærulites, embedded in a soft or in a hard pearly base. The sphærulites are either white and translucent, or dark brown and opaque; the former are quite spherical, of small size, and distinctly radiated from their centre. The dark brown sphærulites are less perfectly round, and vary in diameter from the twentieth to the thirtieth of an inch; when broken they exhibit towards their centres, which are whitish, an obscure radiating structure; two of them when united sometimes have only one central point of radiation; there is occasionally a trace of or a hollow crevice in their centres. They stand either separately, or are united two or three or many together into irregular groups, or more commonly into layers, parallel to the stratification of the mass. This union in many cases is so perfect, that the two sides of the layer thus formed, are quite even; and these layers, as they become less brown and opaque, cannot be distinguished from the alternating layers of the pale-coloured feldspathic stone. The sphærulites, when not united, are generally compressed in the plane of the lamination of the mass; and in this same plane, they are often marked internally, by zones of different shades of colour, and externally by small ridges and furrows. In the upper part of figure No. 6, the sphærulites with the parallel ridges and furrows are represented on an enlarged scale, but they are not well executed; and in the lower part, their usual manner of grouping is shown. In another specimen, a thin layer formed of the brown sphærulites closely united together, intersects, as represented in figure No. 7, a layer of similar composition; and after running for a short space in a slightly curved line, again intersects it, and likewise a second layer lying a little way beneath that first intersected. The small nodules also of obsidian are sometimes externally marked with ridges and furrows, parallel to the lamination of the mass, but always less plainly than the sphærulites. These obsidian nodules are generally angular, with their edges blunted: they are often impressed with the form of the adjoining sphærulites, than which they are always larger; the separate nodules seldom appear to have drawn each other out by exerting a mutually attractive force. Had I not found in some cases, a distinct centre of attraction in these nodules of obsidian, I should have been led to have considered them as residuary matter, left during the formation of the pearlstone, in which they are embedded, and of the sphærulitic globules.

The sphærulites and the little nodules of obsidian in these rocks so closely resemble, in general form and structure, concretions in sedimentary deposits, that one is at once tempted to attribute to them an analogous origin. They resemble ordinary concretions in the following respects: in their external form,—in the union of two or three, or of several, into an irregular mass, or into an even-sided layer,—in the occasional intersection of one such layer by another, as in the case of chalk-flints,—in the presence of two or three kinds of nodules, often close together, in the same basis,—in their fibrous, radiating structure, with occasional hollows in their centres,—in the co-existence of a laminary, concretionary, and radiating structure, as is so well developed in the concretions of magnesian limestone, described by Professor Sedgwick.[24] Concretions in sedimentary deposits, it is known, are due to the separation from the surrounding mass of the whole or part of some mineral substance, and its aggregation round certain points of attraction. Guided by this fact, I have endeavoured to discover whether obsidian and the sphærulites (to which may be added marekanite and pearlstone, both of them occurring in nodular concretions in the trachytic series) differ in their constituent parts, from the minerals generally composing trachytic rocks. It appears from three analyses, that obsidian contains on an average 76 per cent of silica; from one analysis, that sphærulites contain 79·12; from two, that marekanite contains 79·25; and from two other analyses, that pearlstone contains 75·62 of silica.[25] Now, the constituent parts of trachyte, as far as they can be distinguished consist of feldspar, containing 65·21 of silica; or of albite, containing 69·09; of hornblende, containing 55·27,[26] and of oxide of iron: so that the foregoing glassy concretionary substances all contain a larger proportion of silica than that occurring in ordinary feldspathic or trachytic rocks. D'Aubuisson,[27] also, has remarked on the large proportion of silica compared with alumina, in six analyses of obsidian and pearlstone given in Brongniart's "Mineralogy." Hence I conclude, that the foregoing concretions have been formed by a process of aggregation, strictly analogous to that which takes place in aqueous deposits, acting chiefly on the silica, but likewise on some of the other elements of the surrounding mass, and thus producing the different concretionary varieties. From the well-known effects of rapid cooling[28] in giving glassiness of texture, it is probably necessary that the entire mass, in cases like that of Ascension, should have cooled at a certain rate; but considering the repeated and complicated alterations of nodules and thin layers of a glassy texture with other layers quite stony or crystalline, all within the space of a few feet or even inches, it is hardly possible that they could have cooled at different rates, and thus have acquired their different textures.

[24] "Geological Transactions," vol. 3, part i, p. 37.

[25] The foregoing analyses are taken from Beudant "Traité de Minéralogie," tome ii, p. 113; and one analysis of obsidian from Phillips's "Mineralogy."

[26] These analyses are taken from Von Kobell's "Grundzüge der Mineralogie," 1838.

[27] "Traité de Géogn.," tome ii, p. 535.

[28] This is seen in the manufacture of common glass, and in Gregory Watts's experiments on molten trap; also on the natural surfaces of lava-streams, and on the side-walls of dikes.

The natural sphærulites in these rocks[29] very closely resemble those produced in glass, when slowly cooled. In some fine specimens of partially devitrified glass, in the possession of Mr. Stokes, the sphærulites are united into straight layers with even sides, parallel to each other, and to one of the outer surfaces, exactly as in the obsidian. These layers sometimes interbranch and form loops; but I did not see any case of actual intersection. They form the passage from the perfectly glassy portions, to those nearly homogeneous and stony, with only an obscure concretionary structure. In the same specimen, also, sphærulites differing slightly in colour and in structure, occur embedded close together. Considering these facts, it is some confirmation of the view above given of the concretionary origin of the obsidian and natural sphærulites, to find that M. Dartigues,[30] in his curious paper on this subject, attributes the production of sphærulites in glass, to the different ingredients obeying their own laws of attraction and becoming aggregated. He is led to believe that this takes place, from the difficulty in remelting sphærulitic glass, without the whole be first thoroughly pounded and mixed together; and likewise from the fact, that the change takes place most readily in glass composed of many ingredients. In confirmation of M. Dartigues' view, I may remark, that M. Fleuriau de Bellevue[31] found that the sphærulitic portions of devitrified glass were acted on both by nitric acid and under the blowpipe, in a different manner from the compact paste in which they were embedded.

[29] I do not know whether it is generally known, that bodies having exactly the same appearance as sphærulites, sometimes occur in agates. Mr. Robert Brown showed me in an agate, formed within a cavity in a piece of silicified wood, some little specks, which were only just visible to the naked eye: these specks, when placed by him under a lens of high power, presented a beautiful appearance: they were perfectly circular, and consisted of the finest fibres of a brown colour, radiating with great exactness from a common centre. These little radiating stars are occasionally intersected, and portions are quite cut off by the fine, ribbon-like zones of colour in the agate. In the obsidian of Ascension, the halves of a sphærulite often lie in different zones of colour, but they are not cut off by them, as in the agate.

[30] *Journal de Physique,* tome 59 (1804), pp. 10, 12.

[31] *Idem,* tome 60 (1805), p. 418.

Comparison of the obsidian beds and alternating strata of ascension, with those of other countries.—I have been struck with much surprise, how closely the excellent description of the obsidian rocks of Hungary, given by Beudant,[32] and that by Humboldt, of the same formation in Mexico and Peru,[33] and likewise the descriptions given by several authors[34] of the trachytic regions in the Italian islands, agree with my observations at Ascension. Many passages might have been transferred without alteration from the works of the above authors, and would have been applicable to this island. They all agree in the laminated and stratified character of the whole series; and Humboldt speaks of some of the beds of obsidian being ribboned like jasper.[35] They all agree in the nodular or concretionary character of the obsidian, and of the passage of these nodules into layers. They all refer to the repeated alterations, often in undulatory planes, of glassy, pearly, stony, and crystalline layers: the crystalline layers, however, seem to be much more perfectly developed at Ascension, than in the above-named countries. Humboldt compares some of the stony beds, when viewed from a distance, to strata of a schistose sandstone. Sphærulites are described as occurring abundantly in all cases; and they everywhere seem to mark the passage, from the perfectly glassy to the stony and crystalline beds. Beudant's account[36] of his "perlite lithoide globulaire" in every, even the most trifling particular, might have been written for the little brown sphærulitic globules of the rocks of Ascension.

[32] "Voyage en Hongrie," tome i, p. 330; tome ii, pp. 221 and 315; tome iii, pp. 369, 371, 377, 381.

[33] "Essai Géognostique," pp. 176, 326, 328.

[34] P. Scrope, in "Geological Transactions," vol. ii (second series) p. 195. Consult, also, Dolomieu's "Voyage aux Isles Lipari," and D'Aubuisson, "Traité de Géogn.," tome ii, p. 534.

[35] In Mr. Stokes' fine collection of obsidians from Mexico, I observe that the sphærulites are generally much larger than those of Ascension; they are generally white, opaque, and are united into distinct layers: there are many singular varieties, different from

any at Ascension. The obsidians are finely zoned, in quite straight or curved lines, with exceedingly slight differences of tint, of cellularity, and of more or less perfect degrees of glassiness. Tracing some of the less perfectly glassy zones, they are seen to become studded with minute white sphærulites, which become more and more numerous, until at last they unite and form a distinct layer: on the other hand, at Ascension, only the brown sphærulites unite and form layers; the white ones always being irregularly disseminated. Some specimens at the Geological Society, said to belong to an obsidian formation from Mexico, have an earthy fracture, and are divided in the finest parallel laminæ, by specks of a black mineral, like the augitic or hornblendic specks in the rocks at Ascension.

[36] Beudant's "Voyage," tome iii, p. 373.

From the close similarity in so many respects, between the obsidian formations of Hungary, Mexico, Peru, and of some of the Italian islands, with that of Ascension, I can hardly doubt that in all these cases, the obsidian and the sphærulites owe their origin to a concretionary aggregation of the silica, and of some of the other constituent elements, taking place whilst the liquified mass cooled at a certain required rate. It is, however, well-known, that in several places, obsidian has flowed in streams like lava; for instance, at Teneriffe, at the Lipari Islands, and at Iceland.[37] In these cases, the superficial parts are the most perfectly glassy, the obsidian passing at the depth of a few feet into an opaque stone. In an analysis by Vauquelin of a specimen of obsidian from Hecla, which probably flowed as lava, the proportion of silica is nearly the same as in the nodular or concretionary obsidian from Mexico. It would be interesting to ascertain, whether the opaque interior portions and the superficial glassy coating contained the same proportional constituent parts: we know from M. Dufrénoy[38] that the exterior and interior parts of the same stream of lava sometimes differ considerably in their composition. Even should the whole body of the stream of obsidian turn out to be similarly composed with nodular obsidian, it would only be necessary, in accordance with the foregoing facts, to suppose that lava in these instances had been erupted with its ingredients mixed in the same proportion, as in the concretionary obsidian.

[37] For Teneriffe, see von Buch, "Descript. des Isles Canaries," pp. 184 and 190; for the Lipari Islands, see Dolomieu's "Voyage," p. 34; for Iceland, see Mackenzie's "Travels," p. 369.

[38] "Mémoires pour servir a une Descript. Géolog. de la France," tome iv, p. 371.

Lamination of volcanic rocks of the trachytic series.

We have seen that, in several and widely distant countries, the strata alternating with beds of obsidian, are highly laminated. The nodules, also, both large and small, of the obsidian, are zoned with different shades of colour; and I have seen a specimen from Mexico in Mr. Stokes' collection, with its external surface weathered[39] into ridges and furrows, corresponding with the zones of different degrees of glassiness: Humboldt,[40] moreover, found on the Peak of Teneriffe, a stream of obsidian divided by very thin, alternating, layers of pumice. Many other lavas of the feldspathic series are laminated; thus, masses of common trachyte at Ascension are divided by fine earthy lines, along which the rock splits, separating thin layers of slightly different shades of colour; the greater number, also, of the embedded crystals of glassy feldspar are placed lengthways in the same direction. Mr. P. Scrope[41] has described a remarkable columnar trachyte in the Panza Islands, which seems to have been injected into an overlying mass of trachytic conglomerate: it is striped with zones, often of extreme tenuity, of different textures and colours; the harder and darker zones appearing to contain a larger proportion of silica. In another part of the island, there are layers of pearlstone and pitchstone, which in many respects resemble those of Ascension. The zones in the columnar trachyte are generally contorted; they extend uninterruptedly for a great length in a vertical direction, and apparently parallel to the walls of the dike-like mass. Von Buch[42] has described at Teneriffe, a stream of lava containing innumerable thin, plate-like crystals of feldspar, which are arranged like white threads, one behind the other, and which mostly follow the same direction. Dolomieu[43] also states, that the grey lavas of the modern cone of

Vulcano, which have a vitreous texture, are streaked with parallel white lines: he further describes a solid pumice-stone which possesses a fissile structure, like that of certain micaceous schists. Phonolite, which I may observe is often, if not always, an injected rock, also, often has a fissile structure; this is generally due to the parallel position of the embedded crystals of feldspar, but sometimes, as at Fernando Noronha, seems to be nearly independent of their presence.[44] From these facts we see, that various rocks of the feldspathic series have either a laminated or fissile structure, and that it occurs both in masses which have injected into overlying strata, and in others which have flowed as streams of lava.

[39] MacCulloch states ("Classification of Rocks," p. 531), that the exposed surfaces of the pitchstone dikes in Arran are furrowed "with undulating lines, resembling certain varieties of marbled paper, and which evidently result from some corresponding difference of laminar structure."

[40] "Personal Narrative," vol. i, p. 222.

[41] "Geological Transactions," vol. ii (second series), p. 195.

[42] "Description des Iles Canaries," p. 184.

[43] "Voyage aux Isles de Lipari," pp. 35 and 85.

[44] In this case, and in that of the fissile pumice-stone, the structure is very different from that in the foregoing cases, where the laminæ consist of alternate layers of different composition or texture. In some sedimentary formations, however, which apparently are homogeneous and fissile, as in glossy clay-slate, there is reason to believe, according to D'Aubuisson, that the laminæ are really due to excessively thin, alternating, layers of mica.

The laminæ of the beds, alternating with the obsidian at Ascension, dip at a high angle under the mountain, at the base of which they are situated; and they do not appear as if they had been inclined by violence. A high inclination is common to these beds in Mexico, Peru, and in some of the Italian islands:[45] on the other hand, in Hungary, the layers are horizontal; the laminæ, also, of some of the lava-streams above referred to, as far as I can understand the descriptions given of them, appear to be highly inclined or vertical. I doubt whether in any of these cases, the laminæ have been tilted into their present position; and in some instances, as in that of the trachyte described by Mr. Scrope, it is almost certain that they have been originally formed with a high inclination. In many of these cases, there is evidence that the mass of liquified rock has moved in the direction of the laminæ. At Ascension, many of the air-cells have a drawn out appearance, and are crossed by coarse semi-glassy fibres, in the direction of the laminæ; and some of the layers, separating the sphærulitic globules, have a scored appearance, as if produced by the grating of the globules. I have seen a specimen of zoned obsidian from Mexico, in Mr. Stokes' collection, with the surfaces of the best-defined layers streaked or furrowed with parallel lines; and these lines or streaks precisely resembled those, produced on the surface of a mass of artificial glass by its having been poured out of a vessel. Humboldt, also, has described little cavities, which he compares to the tails of comets, behind sphærulites in laminated obsidian rocks from Mexico, and Mr. Scrope has described other cavities behind fragments embedded in his laminated trachyte, and which he supposes to have been produced during the movement of the mass.[46] From such facts, most authors have attributed the lamination of these volcanic rocks to their movement whilst liquified. Although it is easy to perceive, why each separate air-cell, or each fibre in pumice-stone,[47] should be drawn out in the direction of the moving mass; it is by no means at first obvious why such air-cells and fibres should be arranged by the movement, in the same planes, in laminæ absolutely straight and parallel to each other, and often of extreme tenuity; and still less obvious is it, why such layers should come to be of slightly different composition and of different textures.

[45] See Phillips' "Mineralogy," for the Italian Islands, p. 136. For Mexico and Peru, see Humboldt's "Essai Géognostique." Mr. Edwards also describes the high inclination of the obsidian rocks of the Cerro del Navaja in Mexico in the *Proc. of the Geolog. Soc.* June 1838.

[46] "Geological Transactions," vol. ii (second series), p. 200 etc. These embedded fragments, in some instances, consist of the laminated trachyte broken off and "enveloped in those parts,

which still remained liquid.” Beudant, also, frequently refers in his great work on “Hungary” (tome iii, p. 386), to trachytic rocks, irregularly spotted with fragments of the same varieties, which in other parts form the parallel ribbons. In these cases, we must suppose, that after part of the molten mass had assumed a laminated structure, a fresh irruption of lava broke up the mass, and involved fragments, and that subsequently the whole became relaminated.

[47] Dolomieu’s “Voyage,” p. 64.

In endeavouring to make out the cause of the lamination of these igneous feldspathic rocks, let us return to the facts so minutely described at Ascension. We there see, that some of the thinnest layers are chiefly formed by numerous, exceedingly minute, though perfect, crystals of different minerals; that other layers are formed by the union of different kinds of concretionary globules, and that the layers thus formed, often cannot be distinguished from the ordinary feldspathic and pitchstone layers, composing a large portion of the entire mass. The fibrous radiating structure of the sphærulites seems, judging from many analogous cases, to connect the concretionary and crystalline forces: the separate crystals, also, of feldspar all lie in the same parallel planes.[48] These allied forces, therefore, have played an important part in the lamination of the mass, but they cannot be considered the primary force; for the several kinds of nodules, both the smallest and largest, are internally zoned with excessively fine shades of colour, parallel to the lamination of the whole; and many of them are, also, externally marked in the same direction with parallel ridges and furrows, which have not been produced by weathering.

[48] The formation, indeed, of a large crystal of any mineral in a rock of mixed composition implies an aggregation of the requisite atoms, allied to concretionary action. The cause of the crystals of feldspar in these rocks of Ascension, being all placed lengthways, is probably the same with that which elongates and flattens all the brown sphærulitic globules (which behave like feldspar under the blowpipe) in this same direction.

Some of the finest streaks of colour in the stony layers, alternating with the obsidian, can be distinctly seen to be due to an incipient crystallisation of the constituent minerals. The extent to which the minerals have crystallised can, also, be distinctly seen to be connected with the greater or less size, and with the number, of the minute, flattened, crenulated air-cavities or fissures. Numerous facts, as in the case of geodes, and of cavities in silicified wood, in primary rocks, and in veins, show that crystallisation is much favoured by space. Hence, I conclude, that, if in a mass of cooling volcanic rock, any cause produced in parallel planes a number of minute fissures or zones of less tension (which from the pent-up vapours would often be expanded into crenulated air-cavities), the crystallisation of the constituent parts, and probably the formation of concretions, would be superinduced or much favoured in such planes; and thus, a laminated structure of the kind we are here considering would be generated.

That some cause does produce parallel zones of less tension in volcanic rocks, during their consolidation, we must admit in the case of the thin alternate layers of obsidian and pumice described by Humboldt, and of the small, flattened, crenulated air-cells in the laminated rocks of Ascension; for on no other principle can we conceive why the confined vapours should through their expansion form air-cells or fibres in separate, parallel planes, instead of irregularly throughout the mass. In Mr. Stokes’ collection, I have seen a beautiful example of this structure, in a specimen of obsidian from Mexico, which is shaded and zoned, like the finest agate, with numerous, straight, parallel layers, more or less opaque and white, or almost perfectly glassy; the degree of opacity and glassiness depending on the number of microscopically minute, flattened air-cells; in this case, it is scarcely possible to doubt but that the mass, to which the fragment belonged, must have been subjected to some, probably prolonged, action, causing the tension slightly to vary in the successive planes.

Several causes appear capable of producing zones of different tension, in masses semi-liquified by heat. In a fragment of devitrified glass, I have observed layers of sphærulites which appeared, from the manner in which they were abruptly bent, to have been produced by the simple contraction of the mass in the vessel, in which it cooled. In certain dikes on Mount Etna, described by M. Elie de Beaumont,[49] as bordered by alternating bands of scoriaceous and compact rock, one is led to suppose that the stretching movement of the surrounding strata, which originally produced the fissures, continued whilst the injected rock remained fluid. Guided, however, by Professor Forbes'[50] clear description of the zoned structure of glacier-ice, far the most probable explanation of the laminated structure of these feldspathic rocks appears to be, that they have been stretched whilst slowly flowing onwards in a pasty condition, [51] in precisely the same manner as Professor Forbes believes, that the ice of moving glaciers is stretched and fissured. In both cases, the zones may be compared to those in the finest agates; in both, they extend in the direction in which the mass has flowed, and those exposed on the surface are generally vertical: in the ice, the porous laminæ are rendered distinct by the subsequent congelation of infiltrated water, in the stony feldspathic lavas, by subsequent crystalline and concretionary action. The fragment of glassy obsidian in Mr. Stokes' collection, which is zoned with minute air-cells must strikingly resemble, judging from Professor Forbes' descriptions, a fragment of the zoned ice; and if the rate of cooling and nature of the mass had been favourable to its crystallisation or to concretionary action, we should here have had the finest parallel zones of different composition and texture. In glaciers, the lines of porous ice and of minute crevices seem to be due to an incipient stretching, caused by the central parts of the frozen stream moving faster than the sides and bottom, which are retarded by friction: hence in glaciers of certain forms and towards the lower end of most glaciers, the zones become horizontal. May we venture to suppose that in the feldspathic lavas with horizontal laminæ, we see an analogous case? All geologists, who have examined trachytic regions, have come to the conclusion, that the lavas of this series have possessed an exceedingly imperfect fluidity; and as it is evident that only matter thus characterised would be subject to become fissured and to be formed into zones of different tensions, in the manner here supposed, we probably see the reason why augitic lavas, which appear generally to have possessed a high degree of fluidity, are not,[52] like the feldspathic lavas, divided into laminæ of different composition and texture. Moreover, in the augitic series, there never appears to be any tendency to concretionary action, which we have seen plays an important part in the lamination of rocks, of the trachytic series, or at least in rendering that structure apparent.

[49] "Mém. pour servir," etc., tome iv, p. 131.

[50] *Edinburgh New Phil. Journal,* 1842, p. 350.

[51] I presume that this is nearly the same explanation which Mr. Scrope had in his mind, when he speaks ("Geolog. Transact.," vol. ii, second series, p. 228) of the ribboned structure of his trachytic rocks, having arisen, from "a linear extension of the mass, while in a state of imperfect liquidity, coupled with a concretionary process."

[52] Basaltic lavas, and many other rocks, are not unfrequently divided into thick laminæ or plates, of the same composition, which are either straight or curved; these being crossed by vertical lines of fissure, sometimes become united into columns. This structure seems related, in its origin, to that by which many rocks, both igneous and sedimentary, become traversed by parallel systems of fissures.

Whatever may be thought of the explanation here advanced of the laminated structure of the rocks of the trachytic series, I venture to call the attention of geologists to the simple fact, that in a body of rock at Ascension, undoubtedly of volcanic origin, layers often of extreme tenuity, quite straight, and parallel to each other, have been produced;—some composed of distinct crystals of quartz and diopside, mingled with amorphous augitic specks and granular feldspar,—others entirely composed of these black augitic specks, with granules of oxide of iron,—and lastly, others formed of crystalline feldspar, in a more or less perfect state of purity, together with numerous crystals of feldspar, placed lengthways. At this island, there is reason to believe, and in some analogous cases, it is certainly known, that the laminæ have originally been formed with their present high inclination. Facts of this nature are manifestly of importance, with relation to the structural origin of that grand series of plutonic rocks, which like the volcanic have undergone the action of heat, and which consist of alternate layers of quartz, feldspar, mica and other minerals.

Chapter IV
ST. HELENA

Lavas of the feldspathic, basaltic, and submarine series.—Section of Flagstaff Hill and of the Barn.—Dikes.—Turk's Cap and Prosperous Bays.—Basaltic ring.—Central crateriform ridge, with an internal ledge and a parapet. Cones of phonolite. Superficial beds of calcareous sandstone.—Extinct land-shells.—Beds of detritus.—Elevation of the land.—Denudation.—Craters of elevation.

The whole island is of volcanic origin; its circumference, according to Beatson,[1] is about twenty-eight miles. The central and largest part consists of rocks of a feldspathic nature, generally decomposed to an extraordinary degree; and when in this state, presenting a singular assemblage of alternating, red, purple, brown, yellow, and white, soft, argillaceous beds. From the shortness of our visit, I did not examine these beds with care; some of them, especially those of the white, yellow, and brown shades, originally existed as streams of lava, but the greater number were probably ejected in the form of scoriæ and ashes: other beds of a purple tint, porphyritic with crystal-shaped patches of a white, soft substance, which are now unctuous, and yield, like wax, a polished streak to the nail, seem once to have existed as solid claystone-porphyries: the red argillaceous beds generally have a brecciated structure, and no doubt have been formed by the decomposition of scoriæ. Several extensive streams, however, belonging to this series, retain their stony character; these are either of a blackish-green colour, with minute acicular crystals of feldspar, or of a very pale tint, and almost composed of minute, often scaly, crystals of feldspar, abounding with microscopical black specks; they are generally compact and laminated; others, however, of similar composition, are cellular and somewhat decomposed. None of these rocks contain large crystals of feldspar, or have the harsh fracture peculiar to trachyte. These feldspathic lavas and tuffs are the uppermost or those last erupted; innumerable dikes, however, and great masses of molten rock, have subsequently been injected into them. They converge, as they rise, towards the central curved ridge, of which one point attains the elevation of 2,700 feet. This ridge is the highest land in the island; and it once formed the northern rim of a great crater, whence the lavas of this series flowed: from its ruined condition, from the southern half having been removed, and from the violent dislocation which the whole island has undergone, its structure is rendered very obscure.

[1] Governor Beatson's "Account of St. Helena."

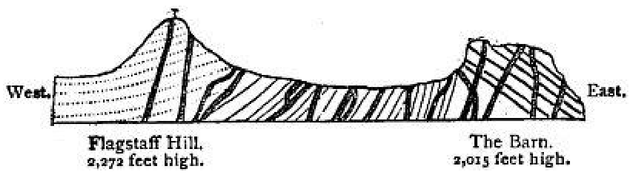
Basaltic series.—The margin of the island is formed by a rude circle of great, black, stratified, ramparts of basalt, dipping seaward, and worn into cliffs, which are often nearly perpendicular, and vary in height from a few hundred feet to two thousand. This circle, or rather horse-shoe shaped ring, is open to the south, and is breached by several other wide spaces. Its rim or summit generally projects little above the level of the adjoining inland country; and the more recent feldspathic lavas, sloping down from the central heights, generally abut against and overlap its inner margin; on the north-western side of the island, however, they appear (judging from a distance) to have flowed over and concealed portions of it. In some parts, where the basaltic ring has been breached, and the black ramparts stand detached, the feldspathic lavas have passed between them, and now overhang the sea-coast in lofty cliffs. The basaltic rocks are of a black colour and thinly stratified; they are generally highly vesicular, but occasionally compact; some of them contain numerous crystals of glassy feldspar and octahedrons of titaniferous iron; others abound with crystals of augite and grains of olivine. The vesicles are frequently lined with minute crystals (of chabasie?) and even become amygdaloidal with them. The streams are separated from each other by cindery matter, or by a bright red, friable, saliferous tuff, which is marked by successive lines like those of aqueous deposition; and sometimes it has an obscure, concretionary structure. The rocks of this basaltic series occur nowhere except near the coast. In most volcanic districts the trachytic lavas are of anterior origin to the basaltic; but here we see, that a great pile of rock, closely related in composition to the trachytic family, has been erupted subsequently to the basaltic strata: the number, however, of dikes, abounding with large crystals of augite, with which the feldspathic lavas have been injected, shows perhaps some tendency to a return to the more usual order of superposition.

Basal submarine lavas.—The lavas of this basal series lie immediately beneath both the basaltic and feldspathic rocks. According to Mr. Seale, [2] they may be seen at intervals on the sea-beach round the entire island. In the sections which I examined, their nature varied much; some of the strata abound with crystals of augite; others are of a brown colour, either laminated or in a rubbly condition; and many parts are highly amygdaloidal with calcareous matter. The successive sheets are either closely united together, or are separated from each other by beds of scoriaceous rock and of laminated tuff, frequently containing well-rounded fragments. The interstices of these beds are filled with gypsum and salt; the gypsum also sometimes occurring in thin layers. From the large quantity of these two substances, from the presence of rounded pebbles in the tuffs, and from the abundant amygdaloids, I cannot doubt that these basal volcanic strata flowed beneath the sea. This remark ought perhaps to be extended to a part of the superincumbent basaltic rocks; but on this point, I was not able to obtain clear evidence. The strata of the basal series, whenever I examined them, were intersected by an extraordinary number of dikes.

> [2] "Geognosy of the Island of St. Helena." Mr. Seale has constructed a gigantic model of St. Helena, well worth visiting, which is now deposited at Addiscombe College, in Surrey.

Flagstaff Hill and the Barn.—I will now describe some of the more remarkable sections, and will commence with these two hills, which form the principal external feature on the north-eastern side of the island. The square, angular outline, and black colour of the Barn, at once show that it belongs to the basaltic series; whilst the smooth, conical figure, and the varied bright tints of Flagstaff Hill, render it equally clear, that it is composed of the softened, feldspathic rocks. These two lofty hills are connected (as is shown in figure No. 8) by a sharp ridge, which is composed of the rubbly lavas of the basal series. The strata of this ridge dip westward, the inclination becoming less and less towards the Flagstaff; and the upper feldspathic strata of this hill can be seen, though with some difficulty, to dip conformably to the W.S.W. Close to the Barn, the strata of the ridge are nearly vertical, but are much obscured by innumerable dikes; under this hill, they probably change from being vertical into being inclined into an opposite direction; for the upper or basaltic strata, which are about eight hundred or one thousand feet in thickness, are inclined north-eastward, at an angle between thirty and forty degrees.

No. 8



The double lines represent the basaltic strata; the single, the basal submarine strata; the dotted, the upper feldspathic strata; the dikes are shaded transversely.

This ridge, and likewise the Barn and Flagstaff Hills, are interlaced by dikes, many of which preserve a remarkable parallelism in a N.N.W. and S.S.E. direction. The dikes chiefly consist of a rock, porphyritic with large crystals of augite; others are formed of a fine-grained and brown-coloured trap. Most of these dikes are coated by a glossy layer,[3] from one to two-tenths of an inch in thickness, which, unlike true pitchstone, fuses into a black enamel; this layer is evidently analogous to the glossy superficial coating of many lava streams. The dikes can often be followed for great lengths both horizontally and vertically, and they seem to preserve a nearly uniform thickness:[4] Mr. Seale states, that one near the Barn, in a height of 1,260 feet, decreases in width only four inches,—from nine feet at the bottom, to eight feet and eight inches at the top. On the ridge, the dikes appear to have been guided in their course, to a considerable degree, by the alternating soft and hard strata: they are often firmly united to the harder strata, and they preserve their parallelism for such great lengths, that in very many instances it was impossible to conjecture, which of the beds were dikes, and which streams of lava. The dikes, though so numerous on this ridge, are even more numerous in the valleys a little south of it, and to a degree I never saw equalled anywhere else: in these valleys they extend in less regular lines, covering the ground with a network, like a spider's web, and with some parts of the surface even appearing to consist wholly of dikes, interlaced by other dikes.

[3] This circumstance has been observed (Lyell, "Principles of Geology," vol. iv, chap. x, p. 9) in the dikes of the Atrio del Cavallo, but apparently it is not of very common occurrence. Sir G. Mackenzie, however, states (p. 372, "Travels in Iceland") that all the veins in Iceland have a "black vitreous coating on their sides." Captain Carmichael, speaking of the dikes in Tristan d'Acunha, a volcanic island in the Southern Atlantic, says ("Linnæan Transactions," vol. xii, p. 485) that their sides, "where they come in contact with the rocks, are invariably in a semi-vitrified state."

[4] "Geognosy of the Island of St. Helena," plate 5.

From the complexity produced by the dikes, from the high inclination and anticlinal dip of the strata of the basal series, which are overlaid, at the opposite ends of the short ridge, by two great masses of different ages and of different composition, I am not surprised that this singular section has been misunderstood. It has even been supposed to form part of a crater; but so far is this from having been the case, that the summit of Flagstaff Hill once formed the lower extremity of a sheet of lava and ashes, which were erupted from the central, crateriform ridge. Judging from the slope of the contemporaneous streams in an adjoining and undisturbed part of the island, the strata of the Flagstaff Hill must have been upturned at least twelve hundred feet, and probably much more, for the great truncated dikes on its summit show that it has been largely denuded. The summit of this hill now nearly equals in height the crateriform ridge; and before having been denuded, it was probably higher than this ridge, from which it is separated by a broad and much lower tract of country; we here, therefore, see that the lower extremities of a set of lava-streams have been tilted up to as great a height as, or perhaps greater height than, the crater, down the flanks of which they originally flowed. I believe that dislocations on so grand a scale are extremely rare[5] in volcanic districts. The formation of such numbers of dikes in this part of the island shows that the surface must here have been stretched to a quite extraordinary degree: this stretching, on the ridge between Flagstaff and Barn Hills, probably took place subsequently (though perhaps immediately so) to the strata being tilted; for had the strata at that time extended horizontally, they would in all probability have been fissured and injected transversely, instead of in the planes of their stratification. Although the space between the Barn and Flagstaff Hill presents a distinct anticlinal line extending north and south, and though most of the dikes range with much regularity in the same line, nevertheless, at only a mile due south of the ridge the strata lie undisturbed. Hence the disturbing force seems to have acted under a point, rather than along a line. The manner in which it has acted, is probably explained by the structure of Little Stony-top, a mountain 2,000 feet high, situated a few miles southward of the Barn; we there see, even from a distance, a dark-coloured, sharp, wedge of compact columnar rock, with the bright-coloured feldspathic strata, sloping away on each side from its uncovered apex. This wedge, from which it derives its name of Stony-top, consists of a body of rock, which has been injected whilst liquified into the overlying strata; and if we may suppose that a similar body of rock lies injected, beneath the ridge connecting the Barn and Flagstaff, the structure there exhibited would be explained.

[5] M. Constant Prevost ("Mém. de la Soc. Géolog.," tome ii) observes that "les produits volcaniques n'ont que localement et rarement même dérangé le sol, à travers lequel ils se sont fait jour."

No. 9

The double lines represent the basaltic strata; the single, the basal submarine strata; the dotted, the upper feldspathic strata.

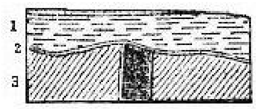
Turk's Cap and Prosperous Bays.—Prosperous Hill is a great, black, precipitous mountain, situated two miles and a half south of the Barn, and composed, like it, of basaltic strata. These rest, in one part, on the brown-coloured, porphyritic beds of the basal series, and in another part, on a fissured mass of highly scoriaceous and amygdaloidal rock, which seems to have formed a small point of eruption beneath the sea, contemporaneously with the basal series. Prosperous Hill, like the Barn, is traversed by many dikes, of which the greater number range north and south, and its strata dip, at an angle of about 20 degrees, rather obliquely from the island towards the sea. The space between Prosperous Hill and the Barn, as represented in figure No. 9, consists of lofty cliffs, composed of the lavas of the upper or feldspathic series, which rest, though unconformably, on the basal submarine strata, as we have seen that they do at Flagstaff Hill. Differently, however, from in that hill, these upper strata are nearly horizontal, gently rising towards the interior of the island; and they are composed of greenish-black, or more commonly, pale brown, compact lavas, instead of softened and highly coloured matter. These brown-coloured, compact lavas, consist almost entirely of small glimmering scales, or of minute acicular crystals, of feldspar, placed close by the side of each other, and abounding with minute black specks, apparently of hornblende. The basaltic strata of Prosperous Hill project only a little above the level of the gently-sloping, feldspathic streams, which wind round and abut against their upturned edges. The inclination of the basaltic strata seems to be too great to have been caused by their having flowed down a slope, and they must have been tilted into their present position before the eruption of the feldspathic streams.

Basaltic ring.—Proceeding round the Island, the lavas of the upper series, southward of Prosperous Hill, overhang the sea in lofty precipices. Further on, the headland, called Great Stony-top, is composed, as I believe, of basalt; as is Long Range Point, on the inland side of which the coloured beds abut. On the southern side of the island, we see the basaltic strata of the South Barn, dipping obliquely seaward at a considerable angle; this headland, also, stands a little above the level of the more modern, feldspathic lavas. Further on, a large space of coast, on each side of Sandy Bay, has been much denuded, and there seems to be left only the basal wreck of the great, central crater. The basaltic strata reappear, with their seaward dip, at the foot of the hill, called Man-and-Horse; and thence they are continued along the whole north-western coast to Sugar-Loaf Hill, situated near to the Flagstaff; and they everywhere have the same seaward inclination, and rest, in some parts at least, on the lavas of the basal series. We thus see that the circumference of the island is formed by a much-broken ring, or rather, a horse-shoe, of basalt, open to the south, and interrupted on the eastern side by many wide breaches. The breadth of this marginal fringe on the north-western side, where alone it is at all perfect, appears to vary from a mile to a mile and a half. The basaltic strata, as well as those of the subjacent basal series, dip, with a moderate inclination, where they have not been subsequently disturbed, towards the sea. The more broken state of the basaltic ring round the eastern half, compared with the western half of the island, is evidently due to the much greater denuding power of the waves on the eastern or windward side, as is shown by the greater height of the cliffs on that side, than to leeward. Whether the margin of basalt was breached, before or after the eruption of the lavas of the upper series, is doubtful; but as separate portions of the basaltic ring appear to have been tilted before that event, and from other reasons, it is more probable, that some at least of the breaches were first formed. Reconstructing in imagination, as far as is possible, the ring of basalt, the internal space or hollow, which has since been filled up with the matter erupted from the great central crater, appears to have been of an oval figure, eight or nine miles in length by about four miles in breadth, and with its axis directed in a N.E. and S.W. line, coincident with the present longest axis of the island.

The central curved ridge.—This ridge consists, as before remarked, of grey feldspathic lavas, and of red, brecciated, argillaceous tuffs, like the beds of the upper coloured series. The grey lavas contain numerous, minute, black, easily fusible specks; and but very few large crystals of feldspar. They are generally much softened; with the exception of this character, and of being in many parts highly cellular, they are quite similar to those great sheets of lava which overhang the coast at Prosperous Bay. Considerable intervals of time appear to have elapsed, judging from the marks of denudation, between the formation of the successive beds, of which this ridge is composed. On the steep northern slope, I observed in several sections a much worn undulating surface of red tuff, covered by grey, decomposed, feldspathic lavas, with only a thin earthy layer interposed between them. In an adjoining part, I noticed a trap-dike, four feet wide, cut off and covered up by the feldspathic lava, as is represented in figure No. 9. The ridge ends on the eastern side in a hook, which is not represented clearly enough in any map which I have seen; towards the western end, it gradually slopes down and divides into several subordinate ridges. The best defined portion between Diana's Peak and Nest Lodge, which supports the highest pinnacles in the island varying from 2,000 to 2,700 feet, is rather less than three miles long in a straight line. Throughout this space the ridge has a uniform appearance and structure; its curvature resembles that of the coast-line of a great bay, being made up of many smaller curves, all open to the south. The northern and outer side is supported by narrow ridges or buttresses, which slope down to the adjoining country. The inside is much steeper, and is almost precipitous; it is formed of the basset edges of the strata, which gently decline outwards. Along some parts of the inner side, a little way beneath the summit, a flat ledge extends, which imitates in outline the smaller curvatures of the crest. Ledges of this kind occur not unfrequently within volcanic craters, and their formation seems to be due to the sinking down of a level sheet of hardened lava, the edges of which remain (like the ice round a pool, from which the water has been drained) adhering to the sides.[6]

[6] A most remarkable instance of this structure is described in Ellis "Polynesian Researches" (second edition), where an admirable drawing is given of the successive ledges or terraces, on the borders of the immense crater at Hawaii, in the Sandwich Islands.

No. 10



1—Grey feldspathic lava.
2—A layer, one inch in thickness, of a reddish earthy matter.
3—Brecciated, red, argillaceous tuff.

In some parts, the ridge is surmounted by a wall or parapet, perpendicular on both sides. Near Diana's Peak this wall is extremely narrow. At the Galapagos Archipelago I observed parapets, having a quite similar structure and appearance, surmounting several of the craters; one, which I more particularly examined, was composed of glossy, red scoriæ firmly cemented together; being externally perpendicular, and extending round nearly the whole circumference of the crater, it rendered it almost inaccessible. The Peak of Teneriffe and Cotopaxi, according to Humboldt, are similarly constructed; he states[7] that "at their summits a circular wall surrounds the crater, which wall, at a distance, has the appearance of a small cylinder placed on a truncated cone. On Cotopaxi[8] this peculiar structure is visible to the naked eye at more than two thousand toises' distance; and no person has ever reached its crater. On the Peak of Teneriffe, the parapet is so high, that it would be impossible to reach the caldera, if on the eastern side there did not exist a breach." The origin of these circular parapets is probably due to the heat or vapours from the crater, penetrating and hardening the sides to a nearly equal depth, and afterwards to the mountain being slowly acted on by the weather, which would leave the hardened part, projecting in the form of a cylinder or circular parapet.

[7] "Personal Narrative," vol. i, p. 171.

[8] Humboldt's "Picturesque Atlas," folio, pl. 10.

From the points of structure in the central ridge, now enumerated,—namely, from the convergence towards it of the beds of the upper series,—from the lavas there becoming highly cellular,—from the flat ledge, extending along its inner and precipitous side, like that within some still active craters,—from the parapet-like wall on its summit,—and lastly, from its peculiar curvature, unlike that of any common line of elevation, I cannot doubt that this curved ridge forms the last remnant of a great crater. In endeavouring, however, to trace its former outline, one is soon baffled; its western extremity gradually slopes down, and, branching into other ridges, extends to the sea-coast; the eastern end is more curved, but it is only a little better defined. Some appearances lead me to suppose that the southern wall of the crater joined the present ridge near Nest Lodge; in this case the crater must have been nearly three miles long, and about a mile and a half in breadth. Had the denudation of the ridge and the decomposition of its constituent rocks proceeded a few steps further, and had this ridge, like several other parts of the island, been broken up by great dikes and masses of injected matter, we should in vain have endeavoured to discover its true nature. Even now we have seen that at Flagstaff Hill the lower extremity and most distant portion of one sheet of the erupted matter has been upheaved to as great a height as the crater down which it flowed, and probably even to a greater height. It is interesting thus to trace the steps by which the structure of a volcanic district becomes obscured, and finally obliterated: so near to this last stage is St. Helena, that I believe no one has hitherto suspected that the central ridge or axis of the island is the last wreck of the crater, whence the most modern volcanic streams were poured forth.

The great hollow space or valley southward of the central curved ridge, across which the half of the crater must once have extended, is formed of bare, water-worn hillocks and ridges of red, yellow, and brown rocks, mingled together in chaos-like confusion, interlaced by dikes, and without any regular stratification. The chief part consists of red decomposing scoriæ, associated with various kinds of tuff and yellow argillaceous beds, full of broken crystals, those of augite being particularly large. Here and there masses of highly cellular and amygdaloidal lavas protrude. From one of the ridges in the midst of the valley, a conical precipitous hill, called Lot, boldly stands up, and forms a most singular and conspicuous object. It is composed of phonolite, divided in one part into great curved laminæ, in another, into angular concretionary balls, and in a third part into outwardly radiating columns. At its base the strata of lava, tuff, and scoriæ, dip away on all sides;[9] the uncovered portion is 197 feet[10] in height, and its horizontal section gives an oval figure. The phonolite is of a greenish-grey colour, and is full of minute acicular crystals of feldspar; in most parts it has a conchoidal fracture, and is sonorous, yet it is crenulated with minute air-cavities. In a S.W. direction from Lot, there are some other remarkable columnar pinnacles, but of a less regular shape, namely, Lot's Wife, and the Asses' Ears, composed of allied kinds of rock. From their flattened shape, and their relative position to each other, they are evidently connected on the same line of fissure. It is, moreover, remarkable that this same N.E. and S.W. line, joining Lot and Lot's Wife, if prolonged would intersect Flagstaff Hill, which, as before stated, is crossed by numerous dikes running in this direction, and which has a disturbed structure, rendering it probable that a great body of once fluid rock lies injected beneath it.

[9] Abich in his "Views of Vesuvius" (plate vi), has shown the manner in which beds, under nearly similar circumstances, are tilted up. The upper beds are more turned up than the lower; and he accounts for this, by showing that the lava insinuates itself horizontally between the lower beds.

[10] This height is given by Mr. Seale in his Geognosy of the island. The height of the summit above the level of the sea is said to be 1,444 feet.

In this same great valley there are several other conical masses of injected rock (one, I observed, was composed of compact greenstone), some of which are not connected, as far as is apparent, with any line of dike; whilst others are obviously thus connected. Of these dikes, three or four great lines stretch across the valley in a N.E. and S.W. direction, parallel to that one connecting the Asses' Ears, Lot's Wife, and probably Lot. The number of these masses of injected rock is a remarkable feature in the geology of St. Helena. Besides those just mentioned, and the hypothetical one beneath Flagstaff Hill, there is Little Stony-top and others, as I have reason to believe, at the Man-and-Horse, and at High Hill. Most of these masses, if not all of them, have been injected subsequently to the last volcanic eruptions from the central crater. The formation of conical bosses of rock on lines of fissure, the walls of which are in most cases parallel, may probably be attributed to inequalities in the tension, causing small transverse fissures, and at these points of intersection the edges of the strata would naturally yield, and be easily turned upwards. Finally, I may remark, that hills of phonolite everywhere are apt[11] to assume singular and even grotesque shapes, like that of Lot: the peak at Fernando Noronha offers an instance; at St. Jago, however, the cones of phonolite, though tapering, have a regular form. Supposing, as seems probable, that all such hillocks or obelisks have originally been injected, whilst liquified, into a mould formed by yielding strata, as certainly has been the case with Lot, how are we to account for the frequent abruptness and singularity of their outlines, compared with similarly injected masses of greenstone and basalt? Can it be due to a less perfect degree of fluidity, which is generally supposed to be characteristic of the allied trachytic lavas?

[11] D'Aubuisson, in his "Traité de Géognosie" (tome ii, p. 540) particularly remarks that this is the case.

Superficial deposits.—Soft calcareous sandstone occurs in extensive, though thin, superficial beds, both on the northern and southern shores of the island. It consists of very minute, equal-sized, rounded particles of shells, and other organic bodies, which partially retain their yellow, brown, and pink colours, and occasionally, though very rarely, present an obscure trace of their original external forms. I in vain endeavoured to find a single unrolled fragment of a shell. The colour of the particles is the most obvious character by which their origin can be recognised, the tints being affected (and an odour produced) by a moderate heat, in the same manner as in fresh shells. The particles are cemented together, and are mingled with some earthy matter: the purest masses, according to Beatson, contain 70 per cent of carbonate of lime. The beds, varying in thickness from two or three feet to fifteen feet, coat the surface of the ground; they generally lie on that side of the valley which is protected from the wind, and they occur at the height of several hundred feet above the level of the sea. Their position is the same which sand, if now drifted by the trade-wind, would occupy; and no doubt they thus originated, which explains the equal size and minuteness of the particles, and likewise the entire absence of whole shells, or even of moderately-sized fragments. It is remarkable that at the present day there are no shelly beaches on any part of the coast, whence calcareous dust could be drifted and winnowed; we must, therefore, look back to a former period when before the land was worn into the present great precipices, a shelving coast, like that of Ascension, was favourable to the accumulation of shelly detritus. Some of the beds of this limestone are between six hundred and seven hundred feet above the sea; but part of this height may possibly be due to an elevation of the land, subsequent to the accumulation of the calcareous sand.

The percolation of rain-water has consolidated parts of these beds into a solid rock, and has formed masses of dark brown, stalagmitic limestone. At the Sugar-Loaf quarry, fragments of rock on the adjoining slopes[12] have been thickly coated by successive fine layers of calcareous matter. It is singular, that many of these pebbles have their entire surfaces coated, without any point of contact having been left uncovered; hence, these pebbles must have been lifted up by the slow deposition between them of the successive films of carbonate of lime. Masses of white, finely oolitic rock are attached to the outside of some of these coated pebbles. Von Buch has described a compact limestone at Lanzarote, which seems perfectly to resemble the stalagmitic deposition just mentioned: it coats pebbles, and in parts is finely oolitic: it forms a far-extended layer, from one inch to two or three feet in thickness, and it occurs at the height of 800 feet above the sea, but only on that side of the island exposed to the violent north-western winds. Von Buch remarks,[13] that it is not found in hollows, but only on the unbroken and inclined surfaces of the mountain. He believes, that it has been deposited by the spray which is borne over the whole island by these violent winds. It appears, however, to me much more probable that it has been formed, as at St. Helena, by the percolation of water through finely comminuted shells: for when sand is blown on a much-exposed coast, it always tends to accumulate on broad, even surfaces, which offer a uniform resistance to the winds. At the neighbouring island, moreover, of Feurteventura,[14] there is an earthy limestone, which, according to Von Buch, is quite similar to specimens which he has seen from St. Helena, and which he believes to have been formed by the drifting of shelly detritus.

[12] In the earthy detritus on several parts of this hill, irregular masses of very impure, crystallised sulphate of lime occur. As this substance is now being abundantly deposited by the surf at Ascension, it is possible that these masses may thus have originated; but if so, it must have been at a period when the land stood at a much lower level. This earthy selenite is now found at a height of between six hundred and seven hundred feet.

[13] "Description des Isles Canaries," p. 293.

[14] *Idem,* pp. 314 and 374.

The upper beds of the limestone, at the above-mentioned quarry on the Sugar-Loaf Hill, are softer, finer-grained and less pure, than the lower beds. They abound with fragments of land-shells, and with some perfect ones; they contain, also, the bones of birds, and the large eggs,[15] apparently of water-fowl. It is probable that these upper beds remained long in an unconsolidated form, during which time, these terrestrial productions were embedded. Mr. G. R. Sowerby has kindly examined three species of land-shells, which I procured from this bed, and has described them in detail. One of them is a Succinea, identical with a species now living abundantly on the island; the two others, namely, *Cochlogena fossilis* and *Helix biplicata*, are not known in a recent state: the latter species was also found in another and different locality, associated with a species of Cochlogena which is undoubtedly extinct.

[15] Colonel Wilkes, in a catalogue presented with some specimens to the Geological Society, states that as many as ten eggs were found by one person. Dr. Buckland has remarked ("Geolog. Trans.," vol. v, p. 474) on these eggs.

Beds of extinct land-shells.—Land-shells, all of which appear to be species now extinct, occur embedded in earth, in several parts of the island. The greater number have been found at a considerable height on Flagstaff Hill. On the N.W. side of this hill, a rain-channel exposes a section of about twenty feet in thickness, of which the upper part consists of black vegetable mould, evidently washed down from the heights above, and the lower part of less black earth, abounding with young and old shells, and with their fragments: part of this earth is slightly consolidated by calcareous matter, apparently due to the partial decomposition of some of the shells. Mr. Seale, an intelligent resident, who first called attention to these shells, gave me a large collection from another locality, where the shells appear to have been embedded in very black earth. Mr. G. R. Sowerby has examined these shells, and has described them. There are seven species, namely, one Cochlogena, two species of the genus Cochlicopa, and four of Helix; none of these are known in a recent state, or have been found in any other country. The smaller species were picked out of the inside of the large shells of the *Cochlogena aurisvulpina.* This last-mentioned species is in many respects a very singular one; it was classed, even by Lamarck, in a marine genus, and having thus been mistaken for a sea-shell, and the smaller accompanying species having been overlooked, the exact localities where it was found have been measured, and the elevation of this island thus deduced! It is very remarkable that all the shells of this species found by me in one spot, form a distinct variety, as described by Mr. Sowerby, from those procured from another locality by Mr. Seale. As this Cochlogena is a large and conspicuous shell, I particularly inquired from several intelligent countrymen whether they had ever seen it alive; they all assured me that they had not, and they would not even believe that it was a land animal: Mr. Seale, moreover, who was a collector of shells all his life at St. Helena, never met with it alive. Possibly some of the smaller species may turn out to be yet living kinds; but, on the other hand, the two land-shells which are now living on the island in great numbers, do not occur embedded, as far as is yet known, with the extinct species. I have shown in my "Journal,"[16] that the extinction of these land-shells possibly may not be an ancient event; as a great change took place in the state of the island about one hundred and twenty years ago, when the old trees died, and were not replaced by young ones, these being destroyed by the goats and hogs, which had run wild in numbers, from the year 1502. Mr. Seale states, that on Flagstaff Hill, where we have seen that the embedded land-shells are especially numerous, traces are everywhere discoverable, which plainly indicate that it was once thickly clothed with trees; at present not even a bush grows there. The thick bed of black vegetable mould which covers the shell-bed, on the flanks of this hill, was probably washed down from the upper part, as soon as the trees perished, and the shelter afforded by them was lost.

[16] "Journal of Researches," p. 582.

Elevation of the land.—Seeing that the lavas of the basal series, which are of submarine origin, are raised above the level of the sea, and at some places to the height of many hundred feet, I looked out for superficial signs of the elevation of the land. The bottoms of some of the gorges, which descend to the coast, are filled up to the depth of about a hundred feet, by rudely divided layers of sand, muddy clay, and fragmentary masses; in these beds, Mr. Seale has found the bones of the tropic-bird and of the albatross; the former now rarely, and the latter never visiting the island. From the difference between these layers, and the sloping piles of detritus which rest on them, I suspect that they were deposited, when the gorges stood beneath the sea. Mr. Seale, moreover, has shown that some of the fissure-like gorges[17] become, with a concave outline, gradually rather wider at the bottom than at the top; and this peculiar structure was probably caused by the wearing action of the sea, when it entered the lower part of these gorges. At greater heights, the evidence of the rise of the land is even less clear: nevertheless, in a bay-like depression on the table-land behind Prosperous Bay, at the height of about a thousand feet, there are flat-topped masses of rock, which it is scarcely conceivable, could have been insulated from the surrounding and similar strata, by any other agency than the denuding action of a sea-beach. Much denudation, indeed, has been effected at great elevations, which it would not be easy to explain by any other means: thus, the flat summit of the Barn, which is 2,000 feet high, presents, according to Mr. Seale, a perfect network of truncated dikes; on hills like the Flagstaff, formed of soft rock, we might suppose that the dikes had been worn down and cut off by meteoric agency, but we can hardly suppose this possible with the hard, basaltic strata of the Barn.

[17] A fissure-like gorge, near Stony-top, is said by Mr. Seale to be 840 feet deep, and only 115 feet in width.

Coast denudation.—The enormous cliffs, in many parts between one and two thousand feet in height, with which this prison-like island is surrounded, with the exception of only a few places, where narrow valleys descend to the coast, is the most striking feature in its scenery. We have seen that portions of the basaltic ring, two or three miles in length by one or two miles in breadth, and from one to two thousand feet in height, have been wholly removed. There are, also, ledges and banks of rock, rising out of profoundly deep water, and distant from the present coast between three and four miles, which, according to Mr. Seale, can be traced to the shore, and are found to be the continuations of certain well-known great dikes. The swell of the Atlantic Ocean has obviously been the active power in forming these cliffs; and it is interesting to observe that the lesser, though still great, height of the cliffs on the leeward and partially protected side of the island (extending from the Sugar-Loaf Hill to South West Point), corresponds with the lesser degree of exposure. When reflecting on the comparatively low coasts of many volcanic islands, which also stand exposed in the open ocean, and are apparently of considerable antiquity, the mind recoils from an attempt to grasp the number of centuries of exposure, necessary to have ground into mud and to have dispersed the enormous cubic mass of hard rock which has been pared off the circumference of this island. The contrast in the superficial state of St. Helena, compared with the nearest island, namely, Ascension, is very striking. At Ascension, the surfaces of the lava-streams are glossy, as if just poured forth, their boundaries are well defined, and they can often be traced to perfect craters, whence they were erupted; in the course of many long walks, I did not observe a single dike; and the coast round nearly the entire circumference is low, and has been eaten back (though too much stress must not be placed on this fact, as the island may have been subsiding) into a little wall only from ten to thirty feet high. Yet during the 340 years, since Ascension has been known, not even the feeblest signs of volcanic action have been recorded.[18] On the other hand, at St. Helena, the course of no one stream of lava can be traced, either by the state of its boundaries or of its superficies; the mere wreck of one great crater is left; not the valleys only, but the surfaces of some of the highest hills, are interlaced by worn-down dikes, and, in many places, the denuded summits of great cones of injected rock stand exposed and naked; lastly, as we have seen, the entire circuit of the island has been deeply worn back into the grandest precipices.

[18] In the *Nautical Magazine* for 1835, p. 642, and for 1838, p. 361, and in the "Comptes Rendus," April 1838, accounts are given of a series of volcanic phenomena—earthquakes—troubled water—floating scoriæ and columns of smoke—which have been observed at intervals since the middle of the last century, in a space of open sea between longitudes 20° and 22° west, about half a degree south of the equator. These facts seem to show, that an island or an archipelago is in process of formation in the middle of the Atlantic: a line joining St. Helena and Ascension, prolonged, intersects this slowly nascent focus of volcanic action.

Craters of Elevation.

There is much resemblance in structure and in geological history between St. Helena, St. Jago, and Mauritius. All three islands are bounded (at least in the parts which I was able to examine) by a ring of basaltic mountains, now much broken, but evidently once continuous. These mountains have, or apparently once had, their escarpments steep towards the interior of the island, and their strata dip outwards. I was able to ascertain, only in a few cases, the inclination of the beds; nor was this easy, for the stratification was generally obscure, except when viewed from a distance. I feel, however, little doubt that, according to the researches of M. Elie de Beaumont, their average inclination is greater than that which they could have acquired, considering their thickness and compactness, by flowing down a sloping surface. At St. Helena, and at St. Jago, the basaltic strata rest on older and probably submarine beds of different composition. At all three islands, deluges of more recent lavas have flowed from the centre of the island, towards and between the basaltic mountains; and at St. Helena the central platform has been filled up by them. All three islands have been raised in mass. At Mauritius the sea, within a late geological period, must have reached to the foot of the basaltic mountains, as it now does at St. Helena; and at St. Jago it is cutting back the intermediate plain towards them. In these three islands, but especially at St. Jago and at Mauritius, when, standing on the summit of one of the old basaltic mountains, one looks in vain towards the centre of the island,—the point towards which the strata beneath one's feet, and of the mountains on each side, rudely converge,—for a source whence these strata could have been erupted; but one sees only a vast hollow platform stretched beneath, or piles of matter of more recent origin.

These basaltic mountains come, I presume, into the class of Craters of elevation: it is immaterial whether the rings were ever completely formed, for the portions which now exist have so uniform a structure, that, if they do not form fragments of true craters, they cannot be classed with ordinary lines of elevation. With respect to their origin, after having read the works of Mr. Lyell,[19] and of MM. C. Prevost and Virlet, I cannot believe that the great central hollows have been formed by a simple dome-shaped elevation, and the consequent arching of the strata. On the other hand, I have very great difficulty in admitting that these basaltic mountains are merely the basal fragments of great volcanoes, of which the summits have either been blown off, or more probably swallowed up by subsidence. These rings are, in some instances, so immense, as at St. Jago and at Mauritius, and their occurrence is so frequent, that I can hardly persuade myself to adopt this explanation. Moreover, I suspect that the following circumstances, from their frequent concurrence, are someway connected together,—a connection not implied in either of the above views: namely, first, the broken state of the ring; showing that the now detached portions have been exposed to great denudation, and in some cases, perhaps, rendering it probable that the ring never was entire; secondly, the great amount of matter erupted from the central area after or during the formation of the ring; and thirdly, the elevation of the district in mass. As far as relates to the inclination of the strata being greater than that which the basal fragments of ordinary volcanoes would naturally possess, I can readily believe that this inclination might have been slowly acquired by that amount of elevation, of which, according to M. Elie de Beaumont, the numerous upfilled fissures or dikes are the evidence and the measure,—a view equally novel and important, which we owe to the researches of that geologist on Mount Etna.

[19] "Principles of Geology" (fifth edit.), vol. ii, p. 171.

A conjecture, including the above circumstances, occurred to me, when,— with my mind fully convinced, from the phenomena of 1835 in South America,[20] that the forces which eject matter from volcanic orifices and raise continents in mass are identical,—I viewed that part of the coast of St. Jago, where the horizontally upraised, calcareous stratum dips into the sea, directly beneath a cone of subsequently erupted lava. The conjecture is that, during the slow elevation of a volcanic district or island, in the centre of which one or more orifices continue open, and thus relieve the subterranean forces, the borders are elevated more than the central area; and that the portions thus upraised do not slope gently into the central, less elevated area, as does the calcareous stratum under the cone at St. Jago, and as does a large part of the circumference of Iceland,[21] but that they are separated from it by curved faults. We might expect, from what we see along ordinary faults, that the strata on the upraised side, already dipping outwards from their original formation as lava-streams, would be tilted from the line of fault, and thus have their inclination increased. According to this hypothesis, which I am tempted to extend only to some few cases, it is not probable that the ring would ever be formed quite perfect; and from the elevation being slow, the upraised portions would generally be exposed to much denudation, and hence the ring become broken; we might also expect to find occasional inequalities in the dip of the upraised masses, as is the case at St. Jago. By this hypothesis the elevation of the districts in mass, and the flowing of deluges of lava from the central platforms, are likewise connected together. On this view the marginal basaltic mountains of the three foregoing islands might still be considered as forming "Craters of elevation;" the kind of elevation implied having been slow, and the central hollow or platform having been formed, not by the arching of the surface, but simply by that part having been upraised to a less height.

[20] I have given a detailed account of these phenomena, in a paper read before the Geological Society in March 1838. At the instant of time, when an immense area was convulsed and a large tract elevated, the districts immediately surrounding several of the great vents in the Cordillera remained quiescent; the subterranean forces being apparently relieved by the eruptions, which then recommenced with great violence. An event of somewhat the same kind, but on an infinitely smaller scale, appears to have taken place, according to Abich ("Views of Vesuvius," plates i and ix), within the great crater of Vesuvius, where a platform on one side of a fissure was raised in mass twenty feet, whilst on the other side, a train of small volcanoes burst forth in eruption.

[21] It appears, from information communicated to me in the most obliging manner by M. E. Robert, that the circumferential parts of Iceland, which are composed of ancient basaltic strata alternating with tuff, dip inland, thus forming a gigantic saucer. M. Robert found that this was the case, with a few and quite local exceptions, for a space of coast several hundred miles in length. I find this statement corroborated, as far as regards one place, by Mackenzie in his "Travels" (p. 377), and in another place by some MS. notes kindly lent me by Dr. Holland. The coast is deeply indented by creeks, at the head of which the land is generally low. M. Robert informs me, that the inwardly dipping strata appear to extend as far as this line, and that their inclination usually corresponds with the slope of the surface, from the high coast-mountains to the low land at the head of these creeks. In the section described by Sir G. Mackenzie, the dip is 120. The interior parts of the island chiefly consist, as far as is known, of recently erupted matter. The great size, however, of Iceland, equalling the bulkiest part of England, ought perhaps to exclude it from the class of islands we have been considering; but I cannot avoid suspecting that if the coast-mountains, instead of gently sloping into the less elevated central area, had been separated from it by irregularly curved faults, the strata would have been tilted seaward, and a "Crater of elevation," like that of St. Jago or that of Mauritius, but of much vaster dimensions, would have been formed. I will only further remark, that the frequent occurrence of extensive lakes at the foot of large volcanoes, and the frequent association of volcanic and fresh-water strata, seem to indicate that the areas around volcanoes are apt to be depressed beneath the level of the adjoining country, either from having been less elevated, or from the effects of subsidence.

Chapter V
GALAPAGOS ARCHIPELAGO.

Chatham Island.—Craters composed of a peculiar kind of tuff.—Small basaltic craters, with hollows at their bases.—Albemarle Island, fluid lavas, their composition.—Craters of tuff, inclination of their exterior diverging strata, and structure of their interior converging strata.—James Island, segment of a small basaltic crater; fluidity and composition of its lava-streams, and of its ejected fragments.—Concluding remarks on the craters of tuff, and on the breached condition of their southern sides.—Mineralogical composition of the rocks of the archipelago.—Elevation of the land. Direction of the fissures of eruption.

This archipelago is situated under the equator, at a distance of between five and six hundred miles from the west coast of South America. It consists of five principal islands, and of several small ones, which together are equal in area,[1] but not in extent of land, to Sicily, conjointly with the Ionian Islands. They are all volcanic: on two, craters have been seen in eruption, and on several of the other islands, streams of lava have a recent appearance. The larger islands are chiefly composed of solid rock, and they rise with a tame outline to a height of between one and four thousand feet. They are sometimes, but not generally, surmounted by one principal orifice. The craters vary in size from mere spiracles to huge caldrons several miles in circumference; they are extraordinarily numerous, so that I should think, if enumerated, they would be found to exceed two thousand; they are formed either of scoriæ and lava, or of a brown-coloured tuff; and these latter craters are in several respects remarkable. The whole group was surveyed by the officers of the *Beagle.* I visited myself four of the principal islands, and received specimens from all the others. Under the head of the different islands I will describe only that which appears to me deserving of attention.

[1] I exclude from this measurement, the small volcanic islands of Culpepper and Wenman, lying seventy miles northward of the group. Craters were visible on all the islands of the group, except on Towers Island, which is one of the lowest; this island is, however, formed of volcanic rocks.

No. 11

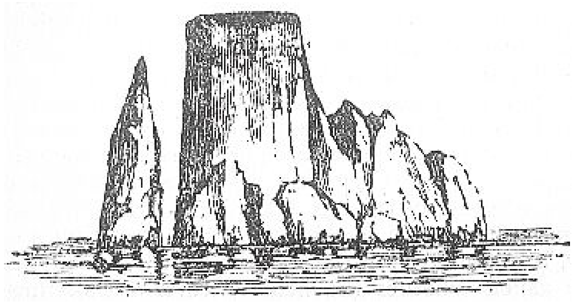
Galapagos Archipelago

CHATHAM ISLAND. *Craters composed of a singular kind of tuff.*—Towards the eastern end of this island there occur two craters composed of two kinds of tuff; one kind being friable, like slightly consolidated ashes; and the other compact, and of a different nature from anything which I have met with described. This latter substance, where it is best characterised, is of a yellowish-brown colour, translucent, and with a lustre somewhat resembling resin; it is brittle, with an angular, rough, and very irregular fracture, sometimes, however, being slightly granular, and even obscurely crystalline: it can readily be scratched with a knife, yet some points are hard enough just to mark common glass; it fuses with ease into a blackish-green glass. The mass contains numerous broken crystals of olivine and augite, and small particles of black and brown scoriæ; it is often traversed by thin seams of calcareous matter. It generally affects a nodular or concretionary structure. In a hand specimen, this substance would certainly be mistaken for a pale and peculiar variety of pitchstone; but when seen in mass its stratification, and the numerous layers of fragments of basalt, both angular and rounded, at once render its subaqueous origin evident. An examination of a series of specimens shows that this resin-like substance results from a chemical change on small particles of pale and dark-coloured scoriaceous rocks; and this change could be distinctly traced in different stages round the edges of even the same particle. The position near the coast of all the craters composed of this kind of tuff or peperino, and their breached condition, renders it probable that they were all formed when standing immersed in the sea; considering this circumstance, together with the remarkable absence of large beds of ashes in the whole archipelago, I think it highly probable that much the greater part of the tuff has originated from the trituration of fragments of the grey, basaltic lavas in the mouths of craters standing in the sea. It may be asked whether the heated water within these craters has produced this singular change in the small scoriaceous particles and given to them their translucent, resin-like fracture. Or has the associated lime played any part in this change? I ask these questions from having found at St. Jago, in the Cape de Verde Islands, that where a great stream of molten lava has flowed over a calcareous bottom into the sea, the outermost film, which in other parts resembles pitchstone, is changed, apparently by its contact with the carbonate of lime, into a resin-like substance, precisely like the best characterised specimens of the tuff from this archipelago.[2]

[2] The concretions containing lime, which I have described at Ascension, as formed in a bed of ashes, present some degree of resemblance to this substance, but they have not a resinous fracture. At St. Helena, also, I found veins of a somewhat similar, compact, but non-resinous substance, occurring in a bed of pumiceous ashes, apparently free from calcareous matter: in neither of these cases could heat have acted.

To return to the two craters: one of them stands at the distance of a league from the coast, the intervening tract consisting of a calcareous tuff, apparently of submarine origin. This crater consists of a circle of hills some of which stand quite detached, but all have a very regular, quâ-quâ versal dip, at an inclination of between thirty and forty degrees. The lower beds, to the thickness of several hundred feet, consist of the resin-like stone, with embedded fragments of lava. The upper beds, which are between thirty and forty feet in thickness, are composed of a thinly stratified, fine-grained, harsh, friable, brown-coloured tuff, or peperino.[3] A central mass without any stratification, which must formerly have occupied the hollow of the crater, but is now attached only to a few of the circumferential hills, consists of a tuff, intermediate in character between that with a resin-like, and that with an earthy fracture. This mass contains white calcareous matter in small patches. The second crater (520 feet in height) must have existed until the eruption of a recent, great stream of lava, as a separate islet; a fine section, worn by the sea, shows a grand funnel-shaped mass of basalt, surrounded by steep, sloping flanks of tuff, having in parts an earthy, and in others a semi-resinous fracture. The tuff is traversed by several broad, vertical dikes, with smooth and parallel sides, which I did not doubt were formed of basalt, until I actually broke off fragments. These dikes, however, consist of tuff like that of the surrounding strata, but more compact, and with a smoother fracture; hence we must conclude, that fissures were formed and filled up with the finer mud or tuff from the crater, before its interior was occupied, as it now is, by a solidified pool of basalt. Other fissures have been subsequently formed, parallel to these singular dikes, and are merely filled with loose rubbish. The change from ordinary scoriaceous particles to the substance with a semi-resinous fracture, could be clearly followed in portions of the compact tuff of these dikes.

[3] Those geologists who restrict the term of “tuff” to ashes of a white colour, resulting from the attrition of feldspathic lavas, would call these brown-coloured strata “peperino.”



The Kicker Rock, 400 feet high.

At the distance of a few miles from these two craters, stands the Kicker Rock, or islet, remarkable from its singular form. It is unstratified, and is composed of compact tuff, in parts having the resin-like fracture. It is probable that this amorphous mass, like that similar mass in the case first described, once filled up the central hollow of a crater, and that its flanks, or sloping walls, have since been worn quite away by the sea, in which it stands exposed.

Small basaltic craters.—A bare, undulating tract, at the eastern end of Chatham Island, is remarkable from the number, proximity, and form of the small basaltic craters with which it is studded. They consist, either of a mere conical pile, or, but less commonly, of a circle, of black and red, glossy scoriæ, partially cemented together. They vary in diameter from thirty to one hundred and fifty yards, and rise from about fifty to one hundred feet above the level of the surrounding plain. From one small eminence, I counted sixty of these craters, all of which were within a third of a mile from each other, and many were much closer. I measured the distance between two very small craters, and found that it was only thirty yards from the summit-rim of one to the rim of the other. Small streams of black, basaltic lava, containing olivine and much glassy feldspar, have flowed from many, but not from all of these craters. The surfaces of the more recent streams were exceedingly rugged, and were crossed by great fissures; the older streams were only a little less rugged; and they were all blended and mingled together in complete confusion. The different growth, however, of the trees on the streams, often plainly marked their different ages. Had it not been for this latter character, the streams could in few cases have been distinguished; and, consequently, this wide undulatory tract might have (as probably many tracts have) been erroneously considered as formed by one great deluge of lava, instead of by a multitude of small streams, erupted from many small orifices.

In several parts of this tract, and especially at the base of the small craters, there are circular pits, with perpendicular sides, from twenty to forty feet deep. At the foot of one small crater, there were three of these pits. They have probably been formed, by the falling in of the roofs of small caverns.[4] In other parts, there are mammiform hillocks, which resemble great bubbles of lava, with their summits fissured by irregular cracks, which appeared, upon entering them, to be very deep; lava has not flowed from these hillocks. There are, also, other very regular, mammiform hillocks, composed of stratified lava, and surmounted by circular, steep-sided hollows, which, I suppose have been formed by a body of gas, first, arching the strata into one of the bubble-like hillocks, and then, blowing off its summit. These several kinds of hillocks and pits, as well as the numerous, small, scoriaceous craters, all show that this tract has been penetrated, almost like a sieve, by the passage of heated vapours. The more regular hillocks could only have been heaved up, whilst the lava was in a softened state.[5]

[4] (M. Elie de Beaumont has described ("Mém. pour servir," etc., tome iv, p. 113) many "petits cirques d'eboulement" on Etna, of some of which the origin is historically known.

[5] Sir G. Mackenzie ("Travels in Iceland," pp. 389 to 392) has described a plain of lava at the foot of Hecla, everywhere heaved up into great bubbles or blisters. Sir George states that this cavernous lava composes the uppermost stratum; and the same fact is affirmed by Von Buch ("Descript. des Isles Canaries," p. 159), with respect to the basaltic stream near Rialejo, in Teneriffe. It appears singular that it should be the upper streams that are chiefly cavernous, for one sees no reason why the upper and lower should not have been equally affected at different times;—have the inferior streams flowed beneath the pressure of the sea, and thus been flattened, after the passage through them, of bodies of gas?

ALBEMARLE ISLAND.—This island consists of five, great, flat-topped craters, which, together with the one on the adjoining island of Narborough, singularly resemble each other, in form and height. The southern one is 4,700 feet high, two others are 3,720 feet, a third only 50 feet higher, and the remaining ones apparently of nearly the same height. Three of these are situated on one line, and their craters appear elongated in nearly the same direction. The northern crater, which is not the largest, was found by the triangulation to measure, externally, no less than three miles and one-eighth of a mile in diameter. Over the lips of these great, broad caldrons, and from little orifices near their summits, deluges of black lava have flowed down their naked sides.

Fluidity of different lavas.—Near Tagus or Banks' Cove, I examined one of these great streams of lava, which is remarkable from the evidence of its former high degree of fluidity, especially when its composition is considered. Near the sea-coast this stream is several miles in width. It consists of a black, compact base, easily fusible into a black bead, with angular and not very numerous air-cells, and thickly studded with large, fractured crystals of glassy albite,[6] varying from the tenth of an inch to half an inch in diameter. This lava, although at first sight appearing eminently porphyritic, cannot properly be considered so, for the crystals have evidently been enveloped, rounded, and penetrated by the lava, like fragments of foreign rock in a trap-dike. This was very clear in some specimens of a similar lava, from Abingdon Island, in which the only difference was, that the vesicles were spherical and more numerous. The albite in these lavas is in a similar condition with the leucite of Vesuvius, and with the olivine, described by Von Buch,[7] as projecting in great balls from the basalt of Lanzarote. Besides the albite, this lava contains scattered grains of a green mineral, with no distinct cleavage, and closely resembling olivine;[8] but as it fuses easily into a green glass, it belongs probably to the augitic family: at James Island, however, a similar lava contained true olivine. I obtained specimens from the actual surface, and from a depth of four feet, but they differed in no respect. The high degree of fluidity of this lava-stream was at once evident, from its smooth and gently sloping surface, from the manner in which the main stream was divided by small inequalities into little rills, and especially from the manner in which its edges, far below its source, and where it must have been in some degree cooled, thinned out to almost nothing; the actual margin consisting of loose fragments, few of which were larger than a man's head. The contrast between this margin, and the steep walls, above twenty feet high, bounding many of the basaltic streams at Ascension, is very remarkable. It has generally been supposed that lavas abounding with large crystals, and including angular vesicles,[9] have possessed little fluidity; but we see that the case has been very different at Albemarle Island. The degree of fluidity in different lavas, does not seem to correspond with any *apparent* corresponding amount of difference in their composition: at Chatham Island, some streams, containing much glassy albite and some olivine, are so rugged, that they may be compared to a sea frozen during a storm; whilst the great stream at Albemarle Island is almost as smooth as a lake when ruffled by a breeze. At James Island, black basaltic lava, abounding with small grains of olivine, presents an intermediate degree of roughness; its surface being glossy, and the detached fragments resembling, in a very singular manner, folds of drapery, cables, and pieces of the bark of trees.[10]

[6] In the Cordillera of Chile, I have seen lava very closely resembling this variety at the Galapagos Archipelago. It contained, however, besides the albite, well-formed crystals of augite, and the base (perhaps in consequence of the aggregation of the augitic particles) was a shade lighter in colour. I may here remark, that in all these cases, I call the feldspathic crystals, *albite*, from their cleavage-planes (as measured by the reflecting goniometer) corresponding with those of that mineral. As, however, other species of this genus have lately been discovered to cleave in nearly the same planes with albite, this determination must be considered as only provisional. I examined the crystals in the lavas of many different parts of the Galapagos group, and I found that none of them, with the exception of some crystals from one part of James Island, cleaved in the direction of orthite or potash-feldspar.

[7] "Description des Isles Canaries," p. 295.

[8] Humboldt mentions that he mistook a green augitic mineral, occurring in the volcanic rocks of the Cordillera of Quito, for olivine.

[9] The irregular and angular form of the vesicles is probably

caused by the unequal yielding of a mass composed, in almost equal proportion, of solid crystals and of a viscid base. It certainly seems a general circumstance, as might have been expected, that in lava, which has possessed a high degree of fluidity, *as well as an even-sized grain*, the vesicles are internally smooth and spherical.

[10] A specimen of basaltic lava, with a few small broken crystals of albite, given me by one of the officers, is perhaps worthy of description. It consists of cylindrical ramifications, some of which are only the twentieth of an inch in diameter, and are drawn out into the sharpest points. The mass has not been formed like a stalactite, for the points terminate both upwards and downwards. Globules, only the fortieth of an inch in diameter, have dropped from some of the points, and adhere to the adjoining branches. The lava is vesicular, but the vesicles never reach the surface of the branches, which are smooth and glossy. As it is generally supposed that vesicles are always elongated in the direction of the movement of the fluid mass, I may observe, that in these cylindrical branches, which vary from a quarter to only the twentieth of an inch in diameter, every air-cell is spherical.

Craters of tuff.—About a mile southward of Banks' Cove, there is a fine elliptic crater, about five hundred feet in depth, and three-quarters of a mile in diameter. Its bottom is occupied by a lake of brine, out of which some little crateriform hills of tuff rise. The lower beds are formed of compact tuff, appearing like a subaqueous deposit; whilst the upper beds, round the entire circumference, consist of a harsh, friable tuff, of little specific gravity, but often containing fragments of rock in layers. This upper tuff contains numerous pisolitic balls, about the size of small bullets, which differ from the surrounding matter, only in being slightly harder and finer grained. The beds dip away very regularly on all sides, at angles varying, as I found by measurement, from twenty-five to thirty degrees. The external surface of the crater slopes at a nearly similar inclination, and is formed by slightly convex ribs, like those on the shell of a pecten or scallop, which become broader as they extend from the mouth of the crater to its base. These ribs are generally from eight to twenty feet in breadth, but sometimes they are as much as forty feet broad; and they resemble old, plastered, much flattened vaults, with the plaster scaling off in plates: they are separated from each other by gullies, deepened by alluvial action. At their upper and narrow ends, near the mouth of the crater, these ribs often consist of real hollow passages, like, but rather smaller than, those often formed by the cooling of the crust of a lava-stream, whilst the inner parts have flowed onward; —of which structure I saw many examples at Chatham Island. There can be no doubt but that these hollow ribs or vaults have been formed in a similar manner, namely, by the setting or hardening of a superficial crust on streams of mud, which have flowed down from the upper part of the crater. In another part of this same crater, I saw open concave gutters between one and two feet wide, which appear to have been formed by the hardening of the lower surface of a mud stream, instead of, as in the former case, of the upper surface. From these facts I think it is certain that the tuff must have flowed as mud.[11] This mud may have been formed either within the crater, or from ashes deposited on its upper parts, and afterwards washed down by torrents of rain. The former method, in most of the cases, appears the more probable one; at James Island, however, some beds of the friable kind of tuff extend so continuously over an uneven surface, that probably they were formed by the falling of showers of ashes.

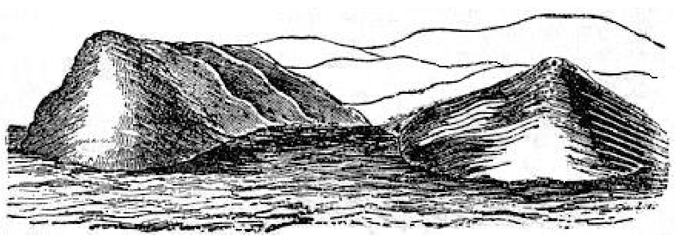
[11] This conclusion is of some interest, because M. Dufrenoy ("Mém. pour servir," tome iv, p. 274) has argued from strata of tuff, apparently of similar composition with that here described, being inclined at angles between 18° and 20°, that Monte Nuevo and some other craters of Southern Italy have been formed by upheaval. From the facts given above, of the vaulted character of the separate rills, and from the tuff not extending in horizontal sheets round these crateriform hills, no one will suppose that the strata have here been produced by elevation; and yet we see that their inclination is above 20°, and often as much as 30°. The consolidated strata also, of the internal talus, as will be immediately seen, dips at an angle of above 30°.

Within this same crater, strata of coarse tuff, chiefly composed of fragments of lava, abut, like a consolidated talus, against the inside walls. They rise to a height of between one hundred and one hundred and fifty feet above the surface of the internal brine-lake; they dip inwards, and are inclined at an angle varying from thirty to thirty-six degrees. They appear to have been formed beneath water, probably at a period when the sea occupied the hollow of the crater. I was surprised to observe that beds having this great inclination did not, as far as they could be followed, thicken towards their lower extremities.

Banks' Cove.—This harbour occupies part of the interior of a shattered crater of tuff larger than that last described. All the tuff is compact, and includes numerous fragments of lava; it appears like a subaqueous deposit. The most remarkable feature in this crater is the great development of strata converging inwards, as in the last case, at a considerable inclination, and often deposited in irregular curved layers. These interior converging beds, as well as the proper, diverging crateriform strata, are represented in figure No. 13, a rude, sectional sketch of the headlands, forming this Cove. The internal and external strata differ little in composition, and the former have evidently resulted from the wear and tear, and redeposition of the matter forming the external crateriform strata. From the great development of these inner beds, a person walking round the rim of this crater might fancy himself on a circular anticlinal ridge of stratified sandstone and conglomerate. The sea is wearing away the inner and outer strata, and especially the latter; so that the inwardly converging strata will, perhaps, in some future age, be left standing alone—a case which might at first perplex a geologist.[12]

[12] I believe that this case actually occurs in the Azores, where Dr. Webster ("Description," p. 185) has described a basin-formed, little island, composed of *strata of tuff*, dipping inwards and bounded externally by steep sea-worn cliffs. Dr. Daubeny supposes (on Volcanoes, p. 266), that this cavity must have been formed by a circular subsidence. It appears to me far more probable, that we here have strata which were originally deposited within the hollow of a crater, of which the exterior walls have since been removed by the sea.

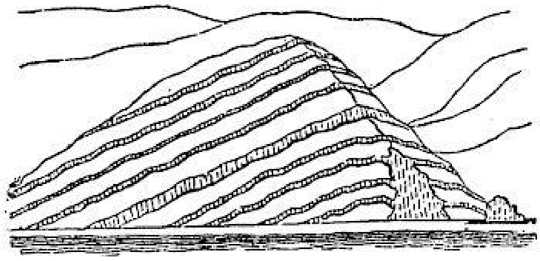
No. 13



A sectional sketch of the headlands forming Banks' Cove, showing the diverging craterform strata, and the converging stratified talus. The highest point of these hills is 817 feet above the sea.

JAMES ISLAND.—Two craters of tuff on this island are the only remaining ones which require any notice. One of them lies a mile and a half inland from Puerto Grande: it is circular, about the third of a mile in diameter, and 400 feet in depth. It differs from all the other tuff-craters which I examined, in having the lower part of its cavity, to the height of between one hundred and one hundred and fifty feet, formed by a precipitous wall of basalt, giving to the crater the appearance of having burst through a solid sheet of rock. The upper part of this crater consists of strata of the altered tuff, with a semi-resinous fracture. Its bottom is occupied by a shallow lake of brine, covering layers of salt, which rest on deep black mud. The other crater lies at the distance of a few miles, and is only remarkable from its size and perfect condition. Its summit is 1,200 feet above the level of the sea, and the interior hollow is 600 feet deep. Its external sloping surface presented a curious appearance from the smoothness of the wide layers of tuff, which resembled a vast plastered floor. Brattle Island is, I believe, the largest crater in the Archipelago composed of tuff; its interior diameter is nearly a nautical mile. At present it is in a ruined condition, consisting of little more than half a circle open to the south; its great size is probably due, in part, to internal degradation, from the action of the sea.

No. 14



Segment of a very small orifice of eruption, on the beach of Fresh-water Bay.

Segment of a basaltic crater.—One side of Fresh-water Bay, in James Island, is bounded by a promontory, which forms the last wreck of a great crater. On the beach of this promontory, a quadrant-shaped segment of a small subordinate point of eruption stands exposed. It consists of nine separate little streams of lava piled upon each other; and of an irregular pinnacle, about fifteen feet high, of reddish-brown, vesicular basalt, abounding with large crystals of glassy albite, and with fused augite. This pinnacle, and some adjoining paps of rock on the beach, represent the axis of the crater. The streams of lava can be followed up a little ravine, at right angles to the coast, for between ten and fifteen yards, where they are hidden by detritus: along the beach they are visible for nearly eighty yards, and I do not believe that they extend much further. The three lower streams are united to the pinnacle; and at the point of junction (as shown in figure No. 14, a rude sketch made on the spot), they are slightly arched, as if in the act of flowing over the lip of the crater. The six upper streams no doubt were originally united to this same column before it was worn down by the sea. The lava of these streams is of similar composition with that of the pinnacle, excepting that the crystals of albite appear to be more comminuted, and the grains of fused augite are absent. Each stream is separated from the one above it by a few inches, or at most by one or two feet in thickness, of loose fragmentary scoriæ, apparently derived from the abrasion of the streams in passing over each other. All these streams are very remarkable from their thinness. I carefully measured several of them; one was eight inches thick, but was firmly coated with three inches above, and three inches below, of red scoriaceous rock (which is the case with all the streams), making altogether a thickness of fourteen inches: this thickness was preserved quite uniformly along the entire length of the section. A second stream was only eight inches thick, including both the upper and lower scoriaceous surfaces. Until examining this section, I had not thought it possible that lava could have flowed in such uniformly thin sheets over a surface far from smooth. These little streams closely resemble in composition that great deluge of lava at Albemarle Island, which likewise must have possessed a high degree of fluidity.

Pseudo-extraneous, ejected fragments.—In the lava and in the scoriæ of this little crater, I found several fragments, which, from their angular form, their granular structure, their freedom from air-cells, their brittle and burnt condition, closely resembled those fragments of primary rocks which are occasionally ejected, as at Ascension, from volcanoes. These fragments consist of glassy albite, much mackled, and with very imperfect cleavages, mingled with semi-rounded grains, having tarnished, glossy surfaces, of a steel-blue mineral. The crystals of albite are coated by a red oxide of iron, appearing like a residual substance; and their cleavage-planes also are sometimes separated by excessively fine layers of this oxide, giving to the crystals the appearance of being ruled like a glass micrometer. There was no quartz. The steel-blue mineral, which is abundant in the pinnacle, but which disappears in the streams derived from the pinnacle, has a fused appearance, and rarely presents even a trace of cleavage; I obtained, however, one measurement, which proved that it was augite; and in one other fragment, which differed from the others, in being slightly cellular, and in gradually blending into the surrounding matrix the small grains of this mineral were tolerably well crystallised. Although there is so wide a difference in appearance between the lava of the little streams, and especially of their red scoriaceous crusts, and one of these angular ejected fragments, which at first sight might readily be mistaken for syenite, yet I believe that the lava has originated from the melting and movement of a mass of rock of absolutely similar composition with the fragments. Besides the specimen above alluded to, in which we see a fragment becoming slightly cellular, and blending into the surrounding matrix, some of the grains of the steel-blue augite also have their surfaces becoming very finely vesicular, and passing into the nature of the surrounding paste; other grains are throughout, in an intermediate condition. The paste seems to consist of the augite more perfectly fused, or, more probably, merely disturbed in its softened state by the movement of the mass, and mingled with the oxide of iron and with finely comminuted, glassy albite. Hence probably it is that the fused albite, which is abundant in the pinnacle, disappears in the streams. The albite is in exactly the same state, with the exception of most of the crystals being smaller in the lava and in the embedded fragments; but in the fragments they appear to be less abundant: this, however, would naturally happen from the intumescence of the augitic base, and its consequent apparent increase in bulk. It is interesting thus to trace the steps by which a compact granular rock becomes converted into a vesicular, pseudo-porphyritic lava, and finally into red scoriæ. The structure and composition of the embedded fragments show that they are parts either of a mass of primary rock which has undergone considerable change from volcanic action, or more probably of the crust of a body of cooled and crystallised lava, which has afterwards been broken up and re-liquified; the crust being less acted on by the renewed heat and movement.

Concluding remarks on the tuff-craters.—These craters, from the peculiarity of the resin-like substance which enters largely into their composition, from their structure, their size and number, present the most striking feature in the geology of this Archipelago. The majority of them form either separate islets, or promontories attached to the larger islands; and those which now stand at some little distance from the coast are worn and breached, as if by the action of the sea. From this general circumstance of their position, and from the small quantity of ejected ashes in any part of the Archipelago, I am led to conclude, that the tuff has been chiefly produced, by the grinding together of fragments of lava within active craters, communicating with the sea. In the origin and composition of the tuff, and in the frequent presence of a central lake of brine and of layers of salt, these craters resemble, though on a gigantic scale, the "salses," or hillocks of mud, which are common in some parts of Italy and in other countries.[13] Their closer connection, however, in this Archipelago, with ordinary volcanic action, is shown by the pools of solidified basalt, with which they are sometimes filled up.

[13] D'Aubuisson's "Traité de Géognosie," tome i, p. 189. I may remark, that I saw at Terceira, in the Azores, a crater of tuff or peperino, very similar to these of the Galapagos Archipelago. From the description given in Freycinet "Voyage," similar ones occur at the Sandwich Islands; and probably they are present in many other places.

It at first appears very singular, that all the craters formed of tuff have their southern sides, either quite broken down and wholly removed, or much lower than the other sides. I saw and received accounts of twenty-eight of these craters; of these, twelve form separate islets,[14] and now exist as mere crescents quite open to the south, with occasionally a few points of rock marking their former circumference: of the remaining sixteen, some form promontories, and others stand at a little distance inland from the shore; but all have their southern sides either the lowest, or quite broken down. Two, however, of the sixteen had their northern sides also low, whilst their eastern and western sides were perfect. I did not see, or hear of, a single exception to the rule, of these craters being broken down or low on the side, which faces a point of the horizon between S.E. and S.W. This rule does not apply to craters composed of lava and scoriæ. The explanation is simple: at this Archipelago, the waves from the trade-wind, and the swell propagated from the distant parts of the open ocean, coincide in direction (which is not the case in many parts of the Pacific), and with their united forces attack the southern sides of all the islands; and consequently the southern slope, even when entirely formed of hard basaltic rock, is invariably steeper than the northern slope. As the tuff-craters are composed of a soft material, and as probably all, or nearly all, have at some period stood immersed in the sea, we need not wonder that they should invariably exhibit on their exposed sides the effects of this great denuding power. Judging from the worn condition of many of these craters, it is probable that some have been entirely washed away. As there is no reason to suppose, that the craters formed of scoriæ and lava were erupted whilst standing in the sea, we can see why the rule does not apply to them. At Ascension, it was shown that the mouths of the craters, which are there all of terrestrial origin, have been affected by the trade-wind; and this same power might here, also, aid in making the windward and exposed sides of some of the craters originally the lowest.

[14] These consist of the three Crossman Islets, the largest of which is 600 feet in height; Enchanted Island; Gardner Island (760 feet high); Champion Island (331 feet high); Enderby Island; Brattle Island; two islets near Indefatigable Island; and one near James Island. A second crater near James Island (with a salt lake in its centre) has its southern side only about twenty feet high, whilst the other parts of the circumference are about three hundred feet in height.

Mineralogical composition of the rocks.—In the northern islands, the basaltic lavas seem generally to contain more albite than they do in the southern half of the Archipelago; but almost all the streams contain some. The albite is not unfrequently associated with olivine. I did not observe in any specimen distinguishable crystals of hornblende or augite; I except the fused grains in the ejected fragments, and in the pinnacle of the little crater, above described. I did not meet with a single specimen of true trachyte; though some of the paler lavas, when abounding with large crystals of the harsh and glassy albite, resemble in some degree this rock; but in every case the basis fuses into a black enamel. Beds of ashes and far-ejected scoriæ, as previously stated, are almost absent; nor did I see a fragment of obsidian or of pumice. Von Buch[15] believes that the absence of pumice on Mount Etna is consequent on the feldspar being of the Labrador variety; if the presence of pumice depends on the constitution of the feldspar, it is remarkable, that it should be absent in this archipelago, and abundant in the Cordillera of South America, in both of which regions the feldspar is of the albitic variety. Owing to the absence of ashes, and the general indecomposable character of the lava in this Archipelago, the islands are slowly clothed with a poor vegetation, and the scenery has a desolate and frightful aspect.

[15] “Description des Isles Canaries,” p. 328.

Elevation of the land.—Proofs of the rising of the land are scanty and imperfect. At Chatham Island, I noticed some great blocks of lava, cemented by calcareous matter, containing recent shells; but they occurred at the height of only a few feet above high-water mark. One of the officers gave me some fragments of shells, which he found embedded several hundred feet above the sea, in the tuff of two craters, distant from each other. It is possible, that these fragments may have been carried up to their present height in an eruption of mud; but as, in one instance, they were associated with broken oyster-shells, almost forming a layer, it is more probable that the tuff was uplifted with the shells in mass. The specimens are so imperfect that they can be recognised only as belonging to recent marine genera. On Charles Island, I observed a line of great rounded blocks, piled on the summit of a vertical cliff, at the height of fifteen feet above the line, where the sea now acts during the heaviest gales. This appeared, at first, good evidence in favour of the elevation of the land; but it was quite deceptive, for I afterwards saw on an adjoining part of this same coast, and heard from eye-witnesses, that wherever a recent stream of lava forms a smooth inclined plane, entering the sea, the waves during gales have the power of *rolling up rounded* blocks to a great height, above the line of their ordinary action. As the little cliff in the foregoing case is formed by a stream of lava, which, before being worn back, must have entered the sea with a gently sloping surface, it is possible or rather it is probable, that the rounded boulders, now lying on its summit, are merely the remnants of those which had been *rolled up* during storms to their present height.

Direction of the fissures of eruption.—The volcanic orifices in this group cannot be considered as indiscriminately scattered. Three great craters on Albermarle Island form a well-marked line, extending N.W. by N. and S.E. by S. Narborough Island, and the great crater on the rectangular projection of Albemarle Island, form a second parallel line. To the east, Hood’s Island, and the islands and rocks between it and James Island, form another nearly parallel line, which, when prolonged, includes Culpepper and Wenman Islands, lying seventy miles to the north. The other islands lying further eastward, form a less regular fourth line. Several of these islands, and the vents on Albemarle Island, are so placed, that they likewise fall on a set of rudely parallel lines, intersecting the former lines at right angles; so that the principal craters appear to lie on the points where two sets of fissures cross each other. The islands themselves, with the exception of Albemarle Island, are not elongated in the same direction with the lines on which they stand. The direction of these islands is nearly the same with that which prevails in so remarkable a manner in the numerous archipelagoes of the great Pacific Ocean. Finally, I may remark, that amongst the Galapagos Islands there is no one dominant vent much higher than all the others, as may be observed in many volcanic archipelagoes: the highest is the great mound on the south-western extremity of Albemarle Island, which exceeds by barely a thousand feet several other neighbouring craters.

Chapter VI

TRACHYTE AND BASALT.—DISTRIBUTION OF VOLCANIC ISLES.

The sinking of crystals in fluid lava.—Specific gravity of the constituent parts of trachyte and of basalt, and their consequent separation.—Obsidian.—Apparent non-separation of the elements of plutonic rocks.—Origin of trap-dikes in the plutonic series.—Distribution of volcanic islands; their prevalence in the great oceans.—They are generally arranged in lines.—The central volcanoes of Von Buch doubtful.—Volcanic islands bordering continents.—Antiquity of volcanic islands, and their elevation in mass.—Eruptions on parallel lines of fissure within the same geological period.

On the separation of the constituent minerals of lava, according to their specific gravities.—One side of Fresh-water Bay, in James Island, is formed by the wreck of a large crater, mentioned in the last chapter, of which the interior has been filled up by a pool of basalt, about two hundred feet in thickness. This basalt is of a grey colour, and contains many crystals of glassy albite, which become much more numerous in the lower, scoriaceous part. This is contrary to what might have been expected, for if the crystals had been originally disseminated in equal numbers, the greater intumescence of this lower scoriaceous part would have made them appear fewer in number. Von Buch[1] has described a stream of obsidian on the Peak of Teneriffe, in which the crystals of feldspar become more and more numerous, as the depth or thickness increases, so that near the lower surface of the stream the lava even resembles a primary rock. Von Buch further states, that M. Dree, in his experiments in melting lava, found that the crystals of feldspar always tended to precipitate themselves to the bottom of the crucible. In these cases, I presume there can be no doubt[2] that the crystals sink from their weight. The specific gravity of feldspar varies[3] from 2·4 to 2·58, whilst obsidian seems commonly to be from 2·3 to 2·4; and in a fluidified state its specific gravity would probably be less, which would facilitate the sinking of the crystals of feldspar. At James Island, the crystals of albite, though no doubt of less weight than the grey basalt, in the parts where compact, might easily be of greater specific gravity than the scoriaceous mass, formed of melted lava and bubbles of heated gas.

[1] "Description des Isles Canaries," pp. 190 and 191.

[2] In a mass of molten iron, it is found (*Edinburgh New Philosophical Journal*, vol. xxiv, p. 66) that the substances, which have a closer affinity for oxygen than iron has, rise from the interior of the mass to the surface. But a similar cause can hardly apply to the separation of the crystals of these lava-streams. The cooling of the surface of lava seems, in some cases, to have affected its composition; for Dufrenoy ("Mém. pour servir," tome iv, p. 271) found that the interior parts of a stream near Naples contained two-thirds of a mineral which was acted on by acids, whilst the surface consisted chiefly of a mineral unattackable by acids.

[3] I have taken the specific gravities of the simple minerals from Von Kobell, one of the latest and best authorities, and of the rocks from various authorities. Obsidian, according to Phillips, is 2·35; and Jameson says it never exceeds 2·4; but a specimen from Ascension, weighed by myself, was 2·42.

The sinking of crystals through a viscid substance like molten rock, as is unequivocally shown to have been the case in the experiments of M. Drée, is worthy of further consideration, as throwing light on the separation of the trachytic and basaltic series of lavas. Mr. P. Scrope has speculated on this subject; but he does not seem to have been aware of any positive facts, such as those above given; and he has overlooked one very necessary element, as it appears to me, in the phenomenon—namely, the existence of either the lighter or heavier mineral in globules or in crystals. In a substance of imperfect fluidity, like molten rock, it is hardly credible, that the separate, infinitely small atoms, whether of feldspar, augite, or of any other mineral, would have power from their slightly different gravities to overcome the friction caused by their movement; but if the atoms of any one of these minerals became, whilst the others remained fluid, united into crystals or granules, it is easy to perceive that from the lessened friction, their sinking or floating power would be greatly increased. On the other hand, if all the minerals became granulated at the same time, it is scarcely possible, from their mutual resistance, that any separation could take place. A valuable, practical discovery, illustrating the effect of the granulation of one element in a fluid mass, in aiding its separation, has lately been made: when lead containing a small proportion of silver, is constantly stirred whilst cooling, it becomes granulated, and the grains of imperfect crystals of nearly pure lead sink to the bottom, leaving a residue of melted metal much richer in silver; whereas if the mixture be left undisturbed, although kept fluid for a length of time, the two metals show no signs of separating.[4] The sole use of the stirring seems to be, the formation of detached granules. The specific gravity of silver is 10·4, and of lead 11·35: the granulated lead, which sinks, is never absolutely pure, and the residual fluid metal contains, when richest, only 1/119 part of silver. As the difference in specific gravity, caused by the different proportions of the two metals, is so exceedingly small, the separation is probably aided in a great degree by the difference in gravity between the lead, when granular though still hot, and when fluid.

[4] A full and interesting account of this discovery, by Mr. Pattinson, was read before the British Association in September 1838. In some alloys, according to Turner ("Chemistry," p. 210), the heaviest metal sinks, and it appears that this takes place whilst both metals are fluid. Where there is a considerable difference in gravity, as between iron and the slag formed during the fusion of the ore, we need not be surprised at the atoms separating, without either substance being granulated.

In a body of liquified volcanic rock, left for some time without any violent disturbance, we might expect, in accordance with the above facts, that if one of the constituent minerals became aggregated into crystals or granules, or had been enveloped in this state from some previously existing mass, such crystals or granules would rise or sink, according to their specific gravity. Now we have plain evidence of crystals being embedded in many lavas, whilst the paste or basis has continued fluid. I need only refer, as instances, to the several, great, pseudo-porphyritic streams at the Galapagos Islands, and to the trachytic streams in many parts of the world, in which we find crystals of feldspar bent and broken by the movement of the surrounding, semi-fluid matter. Lavas are chiefly composed of three varieties of feldspar, varying in specific gravity from 2·4 to 2·74; of hornblende and augite, varying from 3·0 to 3·4; of olivine, varying from 3·3 to 3·4; and lastly, of oxides of iron, with specific gravities from 4·8 to 5·2. Hence crystals of feldspar, enveloped in a mass of liquified, but not highly vesicular lava, would tend to rise to the upper parts; and crystals or granules of the other minerals, thus enveloped, would tend to sink. We ought not, however, to expect any perfect degree of separation in such viscid materials. Trachyte, which consists chiefly of feldspar, with some hornblende and oxide of iron, has a specific gravity of about 2·45;[5] whilst basalt, composed chiefly of augite and feldspar, often with much iron and olivine, has a gravity of about 3·0. Accordingly we find, that where both trachytic and basaltic streams have proceeded from the same orifice, the trachytic streams have generally been first erupted owing, as we must suppose, to the molten lava of this series having accumulated in the upper parts of the volcanic focus. This order of eruption has been observed by Beudant, Scrope, and by other authors; three instances, also, have been given in this volume. As the later eruptions, however, from most volcanic mountains, burst through their basal parts, owing to the increased height and weight of the internal column of molten rock, we see why, in most cases, only the lower flanks of the central, trachytic masses, are enveloped by basaltic streams. The separation of the ingredients of a mass of lava, would, perhaps, sometimes take place within the body of a volcanic mountain, if lofty and of great dimensions, instead of within the underground focus; in which case, trachytic streams might be poured forth, almost contemporaneously, or at short recurrent intervals, from its summit, and basaltic streams from its base: this seems to have taken place at Teneriffe.[6] I need only further remark, that from violent disturbances the separation of the two series, even under otherwise favourable conditions, would naturally often be prevented, and likewise their usual order of eruption be inverted. From the high degree of fluidity of most basaltic lavas, these perhaps, alone, would in many cases reach the surface.

[5] Trachyte from Java was found by Von Buch to be 2·47; from Auvergne, by De la Beche, it was 2·42; from Ascension, by myself,

it was 2·42. Jameson and other authors give to basalt a specific gravity of 3·0; but specimens from Auvergne were found, by De la Beche, to be only 2·78; and from the Giant's Causeway, to be 2·91.

[6] Consult Von Buch's well-known and admirable "Description Physique" of this island, which might serve as a model of descriptive geology.

As we have seen that crystals of feldspar, in the instance described by Von Buch, sink in obsidian, in accordance with their known greater specific gravity, we might expect to find in every trachytic district, where obsidian has flowed as lava, that it had proceeded from the upper or highest orifices. This, according to Von Buch, holds good in a remarkable manner both at the Lipari Islands and on the Peak of Teneriffe; at this latter place obsidian has never flowed from a less height than 9,200 feet. Obsidian, also, appears to have been erupted from the loftiest peaks of the Peruvian Cordillera. I will only further observe, that the specific gravity of quartz varies from 2·6 to 2·8; and therefore, that when present in a volcanic focus, it would not tend to sink with the basaltic bases; and this, perhaps, explains the frequent presence, and the abundance of this mineral, in the lavas of the trachytic series, as observed in previous parts of this volume.

An objection to the foregoing theory will, perhaps, be drawn from the plutonic rocks not being separated into two evidently distinct series, of different specific gravities; although, like the volcanic, they have been liquified. In answer, it may first be remarked, that we have no evidence of the atoms of any one of the constituent minerals in the plutonic series having been aggregated, whilst the others remained fluid, which we have endeavoured to show is an almost necessary condition of their separation; on the contrary, the crystals have generally impressed each other with their forms.[7]

[7] The crystalline paste of phonolite is frequently penetrated by long needles of hornblende; from which it appears that the hornblende, though the more fusible mineral, has crystallised before, or at the same time with a more refractory substance. Phonolite, as far as my observations serve, in every instance appears to be an injected rock, like those of the plutonic series; hence probably, like these latter, it has generally been cooled without repeated and violent disturbances. Those geologists who have doubted whether granite could have been formed by igneous liquefaction, because minerals of different degrees of fusibility impress each other with their forms, could not have been aware of the fact of crystallised hornblende penetrating phonolite, a rock undoubtedly of igneous origin. The viscidity, which it is now known, that both feldspar and quartz retain at a temperature much below their points of fusion, easily explains their mutual impressment. Consult on this subject Mr. Horner's paper on Bonn, "Geolog. Transact.," vol. iv, p. 439; and "L'Institut," with respect to quartz, 1839, p. 161.

In the second place, the perfect tranquillity, under which it is probable that the plutonic masses, buried at profound depths, have cooled, would, most likely, be highly unfavourable to the separation of their constituent minerals; for, if the attractive force, which during the progressive cooling draws together the molecules of the different minerals, has power sufficient to keep them together, the friction between such half-formed crystals or pasty globules would effectually prevent the heavier ones from sinking, or the lighter ones from rising. On the other hand, a small amount of disturbance, which would probably occur in most volcanic foci, and which we have seen does not prevent the separation of granules of lead from a mixture of molten lead and silver, or crystals of feldspar from streams of lava, by breaking and dissolving the less perfectly formed globules, would permit the more perfect and therefore unbroken crystals, to sink or rise, according to their specific gravity.

Although in plutonic rocks two distinct species, corresponding to the trachytic and basaltic series, do not exist, I much suspect that a certain amount of separation of their constituent parts has often taken place. I suspect this from having observed how frequently dikes of greenstone and basalt intersect widely extended formations of granite and the allied metamorphic rocks. I have never examined a district in an extensive granitic region without discovering dikes; I may instance the numerous trap-dikes, in several districts of Brazil, Chile, and Australia, and at the Cape of Good Hope: many dikes likewise occur in the great granitic tracts of India, in the north of Europe, and in other countries. Whence, then, has the greenstone and basalt, forming these dikes, come? Are we to suppose, like some of the elder geologists, that a zone of trap is uniformly spread out beneath the granitic series, which composes, as far as we know, the foundations of the earth's crust? Is it not more probable, that these dikes have been formed by fissures penetrating into partially cooled rocks of the granitic and metamorphic series, and by their more fluid parts, consisting chiefly of hornblende, oozing out, and being sucked into such fissures? At Bahia, in Brazil, in a district composed of gneiss and primitive greenstone, I saw many dikes, of a dark augitic (for one crystal certainly was of this mineral) or hornblendic rock, which, as several appearances clearly proved, either had been formed before the surrounding mass had become solid, or had together with it been afterwards thoroughly softened.[8] On both sides of one of these dikes, the gneiss was penetrated, to the distance of several yards, by numerous, curvilinear threads or streaks of dark matter, which resembled in form clouds of the class called cirrhi-comæ; some few of these threads could be traced to their junction with the dike. When examining them, I doubted whether such hair-like and curvilinear veins could have been injected, and I now suspect, that instead of having been injected from the dike, they were its feeders. If the foregoing views of the origin of trap-dikes in widely extended granitic regions far from rocks of any other formation, be admitted as probable, we may further admit, in the case of a great body of plutonic rock, being impelled by repeated movements into the axis of a mountain-chain, that its more liquid constituent parts might drain into deep and unseen abysses; afterwards, perhaps, to be brought to the surface under the form, either of injected masses of greenstone and augitic porphyry,[9] or of basaltic eruptions. Much of the difficulty which geologists have experienced when they have compared the composition of volcanic with plutonic formations, will, I think, be removed, if we may believe that most plutonic masses have been, to a certain extent, drained of those comparatively weighty and easily liquified elements, which compose the trappean and basaltic series of rocks.

[8] Portions of these dikes have been broken off, and are now surrounded by the primary rocks, with their laminæ conformably winding round them. Dr. Hubbard also (*Silliman's Journal,* vol. xxxiv, p. 119), has described an interlacement of trap-veins in the granite of the White Mountains, which he thinks must have been formed when both rocks were soft.

[9] Mr. Phillips ("Lardner's Encyclop.," vol. ii, p. 115) quotes Von Buch's statement, that augitic porphyry ranges parallel to, and is found constantly at the base of, great chains of mountains. Humboldt, also, has remarked the frequent occurrence of trap-rock, in a similar position; of which fact I have observed many examples at the foot of the Chilian Cordillera. The existence of granite in the axes of great mountain chains is always probable, and I am tempted to suppose, that the laterally injected masses of augitic porphyry and of trap, bear nearly the same relation to the granitic axes which basaltic lavas bear to the central trachytic masses, round the flanks of which they have so frequently been erupted.

On the distribution of volcanic islands.—During my investigations on coral-reefs, I had occasion to consult the works of many voyagers, and I was invariably struck with the fact, that with rare exceptions, the innumerable islands scattered throughout the Pacific, Indian, and Atlantic Oceans, were composed either of volcanic, or of modern coral-rocks. It would be tedious to give a long catalogue of all the volcanic islands; but the exceptions which I have found are easily enumerated: in the Atlantic, we have St. Paul's Rock, described in this volume, and the Falkland Islands, composed of quartz and clay-slate; but these latter islands are of considerable size, and lie not very far from the South American coast:[10] in the Indian Ocean, the Seychelles (situated in a line prolonged from Madagascar) consist of granite and quartz: in the Pacific Ocean, New Caledonia, an island of large size, belongs (as far as is known) to the primary class. New Zealand, which contains much volcanic rock and some active volcanoes, from its size cannot be classed with the small islands, which we are now considering. The presence of a small quantity of non-volcanic rock, as of clay-slate on three of the Azores,[11] or of tertiary limestone at Madeira, or of clay-slate at Chatham Island in the Pacific, or of lignite at Kerguelen Land, ought not to exclude such islands or archipelagoes, if formed chiefly of erupted matter, from the volcanic class.

[10] Judging from Forster's imperfect observation, perhaps Georgia is not volcanic. Dr. Allan is my informant with regard to the Seychelles. I do not know of what formation Rodriguez, in the Indian Ocean, is composed.

[11] This is stated on the authority of Count V. de Bedemar, with respect to Flores and Graciosa (Charlsworth, "Magazine of Nat. Hist.," vol. i, p. 557). St. Maria has no volcanic rock, according to Captain Boyd (Von Buch "Descript.," p. 365). Chatham Island has been described by Dr. Dieffenbach in the "Geographical Journal," 1841, p. 201. As yet we have received only imperfect notices on Kerguelen Land, from the Antarctic Expedition.

The composition of the numerous islands scattered through the great oceans being with such rare exceptions volcanic, is evidently an extension of that law, and the effect of those same causes, whether chemical or mechanical, from which it results, that a vast majority of the volcanoes now in action stand either as islands in the sea, or near its shores. This fact of the ocean-islands being so generally volcanic is also interesting in relation to the nature of the mountain-chains on our continents, which are comparatively seldom volcanic; and yet we are led to suppose that where our continents now stand an ocean once extended. Do volcanic eruptions, we may ask, reach the surface more readily through fissures formed during the first stages of the conversion of the bed of the ocean into a tract of land?

Looking at the charts of the numerous volcanic archipelagoes, we see that the islands are generally arranged either in single, double, or triple rows, in lines which are frequently curved in a slight degree.[12] Each separate island is either rounded, or more generally elongated in the same direction with the group in which it stands, but sometimes transversely to it. Some of the groups which are not much elongated present little symmetry in their forms; M. Virlet[13] states that this is the case with the Grecian Archipelago: in such groups I suspect (for I am aware how easy it is to deceive oneself on these points), that the vents are generally arranged on one line, or on a set of short parallel lines, intersecting at nearly right angles another line, or set of lines. The Galapagos Archipelago offers an example of this structure, for most of the islands and the chief orifices on the largest island are so grouped as to fall on a set of lines ranging about N.W. by N., and on another set ranging about W.S.W.: in the Canary Archipelago we have a simpler structure of the same kind: in the Cape de Verde group, which appears to be the least symmetrical of any oceanic volcanic archipelago, a N.W. and S.E. line formed by several islands, if prolonged, would intersect at right angles a curved line, on which the remaining islands are placed. Von Buch[14] has classed all volcanoes under two heads, namely, *central volcanoes*, round which numerous eruptions have taken place on all sides, in a manner almost regular, and *volcanic chains.* In the examples given of the first class, as far as position is concerned, I can see no grounds for their being called "central;" and the evidence of any difference in mineralogical nature between *central volcanoes* and *volcanic chains* appears slight. No doubt some one island in most small volcanic archipelagoes is apt to be considerably higher than the others; and in a similar manner, whatever the cause may be, that on the same island one vent is generally higher than all the others. Von Buch does not include in his class of volcanic chains small archipelagoes, in which the islands are admitted by him, as at the Azores, to be arranged in lines; but when viewing on a map of the world how perfect a series exists from a few volcanic islands placed in a row to a train of linear archipelagoes following each other in a straight line, and so on to a great wall like the Cordillera of America, it is difficult to believe that there exists any essential difference between short and long volcanic chains. Von Buch[15] states that his volcanic chains surmount, or are closely connected with, mountain-ranges of primary formation: but if trains of linear archipelagoes are, in the course of time, by the long-continued action of the elevatory and volcanic forces, converted into mountain-ranges, it would naturally result that the inferior primary rocks would often be uplifted and brought into view.

[12] Professors William and Henry Darwin Rogers have lately insisted much, in a memoir read before the American Association, on the regularly curved lines of elevation in parts of the Appalachian range.

[13] "Bulletin de la Soc. Géolog.," tome iii, p. 110.

[14] "Description des Isles Canaries," p. 324.

[15] *Idem,* p. 393.

Some authors have remarked that volcanic islands occur scattered, though at very unequal distances, along the shores of the great continents, as if in some measure connected with them. In the case of

Juan Fernandez, situated 330 miles from the coast of Chile, there was undoubtedly a connection between the volcanic forces acting under this island and under the continent, as was shown during the earthquake of 1835. The islands, moreover, of some of the small volcanic groups which thus border continents, are placed in lines, related to those along which the adjoining shores of the continents trend; I may instance the lines of intersection at the Galapagos, and at the Cape de Verde Archipelagoes, and the best marked line of the Canary Islands. If these facts be not merely accidental, we see that many scattered volcanic islands and small groups are related not only by proximity, but in the direction of the fissures of eruption to the neighbouring continents—a relation, which Von Buch considers, characteristic of his great volcanic chains.

In volcanic archipelagoes, the orifices are seldom in activity on more than one island at a time; and the greater eruptions usually recur only after long intervals. Observing the number of craters, that are usually found on each island of a group, and the vast amount of matter which has been erupted from them, one is led to attribute a high antiquity even to those groups, which appear, like the Galapagos, to be of comparatively recent origin. This conclusion accords with the prodigious amount of degradation, by the slow action of the sea, which their originally sloping coasts must have suffered, when they are worn back, as is so often the case, into grand precipices. We ought not, however, to suppose, in hardly any instance, that the whole body of matter, forming a volcanic island, has been erupted at the level, on which it now stands: the number of dikes, which seem invariably to intersect the interior parts of every volcano, show, on the principles explained by M. Elie de Beaumont, that the whole mass has been uplifted and fissured. A connection, moreover, between volcanic eruptions and contemporaneous elevations in mass[16] has, I think, been shown to exist in my work on Coral-Reefs, both from the frequent presence of upraised organic remains, and from the structure of the accompanying coral-reefs. Finally, I may remark, that in the same Archipelago, eruptions have taken place within the historical period on more than one of the parallel lines of fissure: thus, at the Galapagos Archipelago, eruptions have taken place from a vent on Narborough Island, and from one on Albemarle Island, which vents do not fall on the same line; at the Canary Islands, eruptions have taken place in Teneriffe and Lanzarote; and at the Azores, on the three parallel lines of Pico, St. Jorge, and Terceira. Believing that a mountain-axis differs essentially from a volcano, only in plutonic rocks having been injected, instead of volcanic matter having been ejected, this appears to me an interesting circumstance; for we may infer from it as probable, that in the elevation of a mountain-chain, two or more of the parallel lines forming it may be upraised and injected within the same geological period.

[16] A similar conclusion is forced on us, by the phenomena, which accompanied the earthquake of 1835, at Concepcion, and which are detailed in my paper (vol. v, p. 601) in the "Geological Transactions."

Chapter VII

AUSTRALIA; NEW ZEALAND; CAPE OF GOOD HOPE.

New South Wales.—Sandstone formation.—Embedded pseudo-fragments of shale.—Stratification.—Current-cleavage.—Great valleys.—Van Diemen's Land.—Palæozoic formation.—Newer formation with volcanic rocks.—Travertin with leaves of extinct plants.—Elevation of the land.—New Zealand.—King George's Sound.—Superficial ferruginous beds.—Superficial calcareous deposits, with casts of branches.—Their origin from drifted particles of shells and corals.—Their extent.—Cape of Good Hope.—Junction of the granite and clay-slate.—Sandstone formation.

The *Beagle*, in her homeward voyage, touched at New Zealand, Australia, Van Diemen's Land, and the Cape of Good Hope. In order to confine the Third Part of these Geological Observations to South America, I will here briefly describe all that I observed at these places worthy of the attention of geologists.

New South Wales.—My opportunities of observation consisted of a ride of ninety geographical miles to Bathurst, in a W.N.W. direction from Sydney. The first thirty miles from the coast passes over a sandstone country, broken up in many places by trap-rocks, and separated by a bold escarpment overhanging the river Nepean, from the great sandstone platform of the Blue Mountains. This upper platform is 1,000 feet high at the edge of the escarpment, and rises in a distance of twenty-five miles to between three and four thousand feet above the level of the sea. At this distance the road descends to a country rather less elevated, and composed in chief part of primary rocks. There is much granite, in one part passing into a red porphyry with octagonal crystals of quartz, and intersected in some places by trap-dikes. Near the Downs of Bathurst I passed over much pale-brown, glossy clay-slate, with the shattered laminæ running north and south; I mention this fact, because Captain King informs me that, in the country a hundred miles southward, near Lake George, the mica-slate ranges so invariably north and south that the inhabitants take advantage of it in finding their way through the forests.

The sandstone of the Blue Mountains is at least 1,200 feet thick, and in some parts is apparently of greater thickness; it consists of small grains of quartz, cemented by white earthy matter, and it abounds with ferruginous veins. The lower beds sometimes alternate with shales and coal: at Wolgan I found in carbonaceous shale leaves of the *Glossopteris Brownii*, a fern which so frequently accompanies the coal of Australia. The sandstone contains pebbles of quartz; and these generally increase in number and size (seldom, however, exceeding an inch or two in diameter) in the upper beds: I observed a similar circumstance in the grand sandstone formation at the Cape of Good Hope. On the South American coast, where tertiary and supra-tertiary beds have been extensively elevated, I repeatedly noticed that the uppermost beds were formed of coarser materials than the lower: this appears to indicate that, as the sea became shallower, the force of the waves or currents increased. On the lower platform, however, between the Blue Mountains and the coast, I observed that the upper beds of the sandstone frequently passed into argillaceous shale,—the effect, probably, of this lower space having been protected from strong currents during its elevation. The sandstone of the Blue Mountains evidently having been of mechanical origin, and not having suffered any metamorphic action, I was surprised at observing that, in some specimens, nearly all the grains of quartz were so perfectly crystallised with brilliant facets that they evidently had not in their *present* form been aggregated in any previously existing rock.[1] It is difficult to imagine how these crystals could have been formed; one can hardly believe that they were separately precipitated in their present crystallised state. Is it possible that rounded grains of quartz may have been acted on by a fluid corroding their surfaces, and depositing on them fresh silica? I may remark that, in the sandstone formation of the Cape of Good Hope, it is evident that silica has been profusely deposited from aqueous solution.

[1] I have lately seen, in a paper by Smith (the father of English geologists), in the *Magazine of Natural History*, that the grains of

quartz in the millstone grit of England are often crystallised. Sir David Brewster, in a paper read before the British Association, 1840, states, that in old decomposed glass, the silex and metals separate into concentric rings, and that the silex regains its crystalline structure, as is shown by its action on light.

In several parts of the sandstone I noticed patches of shale which might at the first glance have been mistaken for extraneous fragments; their horizontal laminæ, however, being parallel with those of the sandstone, showed that they were the remnants of thin, continuous beds. One such fragment (probably the section of a long narrow strip) seen in the face of a cliff, was of greater vertical thickness than breadth, which proves that this bed of shale must have been in some slight degree consolidated, after having been deposited, and before being worn away by the currents. Each patch of the shale shows, also, how slowly many of the successive layers of sandstone were deposited. These pseudo-fragments of shale will perhaps explain, in some cases, the origin of apparently extraneous fragments in crystalline metamorphic rocks. I mention this, because I found near Rio de Janeiro a well-defined angular fragment, seven yards long by two yards in breadth, of gneiss containing garnets and mica in layers, enclosed in the ordinary, stratified, porphyritic gneiss of the country. The laminæ of the fragment and of the surrounding matrix ran in exactly the same direction, but they dipped at different angles. I do not wish to affirm that this singular fragment (a solitary case, as far as I know) was originally deposited in a layer, like the shale in the Blue Mountains, between the strata of the porphyritic gneiss, before they were metamorphosed; but there is sufficient analogy between the two cases to render such an explanation possible.

Stratification of the escarpment.—The strata of the Blue Mountains appear to the eye horizontal; but they probably have a similar inclination with the surface of the platform, which slopes from the west towards the escarpment over the Nepean, at an angle of one degree, or of one hundred feet in a mile.[2] The strata of the escarpment dip almost conformably with its steeply inclined face, and with so much regularity, that they appear as if thrown into their present position; but on a more careful examination, they are seen to thicken and to thin out, and in the upper part to be succeeded and almost capped by horizontal beds. These appearances render it probable, that we here see an original escarpment, not formed by the sea having eaten back into the strata, but by the strata having originally extended only thus far. Those who have been in the habit of examining accurate charts of sea-coasts, where sediment is accumulating, will be aware, that the surfaces of the banks thus formed, generally slope from the coast very gently towards a certain line in the offing, beyond which the depth in most cases suddenly becomes great. I may instance the great banks of sediment within the West Indian Archipelago,[3] which terminate in submarine slopes, inclined at angles of between thirty and forty degrees, and sometimes even at more than forty degrees: every one knows how steep such a slope would appear on the land. Banks of this nature, if uplifted, would probably have nearly the same external form as the platform of the Blue Mountains, where it abruptly terminates over the Nepean.

[2] This is stated on the authority of Sir T. Mitchell, in his "Travels," vol. ii, p. 357.

[3] I have described these very curious banks in the Appendix to my volume on the structure of Coral-Reefs. I have ascertained the inclination of the edges of the banks, from information given me by Captain B. Allen, one of the surveyors, and by carefully measuring the horizontal distances between the last sounding on the bank and the first in the deep water. Widely extended banks in all parts of the West Indies have the same general form of surface.

Current-cleavage.—The strata of sandstone in the low coast country, and likewise on the Blue Mountains, are often divided by cross or current laminæ, which dip in different directions, and frequently at an angle of forty-five degrees. Most authors have attributed these cross layers to successive small accumulations on an inclined surface; but from a careful examination in some parts of the New Red Sandstone of England, I believe that such layers generally form parts of a series of curves, like gigantic tidal ripples, the tops of which have since been cut off, either by nearly horizontal layers, or by another set of great ripples, the folds of which do not exactly coincide with those below them. It is well-known to surveyors that mud and sand are disturbed during storms at considerable depths, at least from three hundred to four hundred and fifty feet,[4] so that the nature of the bottom even becomes temporarily changed; the bottom, also, at a depth between sixty and seventy feet, has been observed[5] to be broadly rippled. One may, therefore, be allowed to suspect, from the appearance just mentioned in the New Red Sandstone, that at greater depths, the bed of the ocean is heaped up during gales into great ripple-like furrows and depressions, which are afterwards cut off by the currents during more tranquil weather, and again furrowed during gales.

[4] See Martin White, on "Soundings in the British Channel," pp. 4 and 166.

[5] M. Siau on the "Action of Waves," *Edin. New Phil. Journ.,* vol. xxxi, p. 245.

Valleys in the sandstone platforms.—The grand valleys, by which the Blue Mountains and the other sandstone platforms of this part of Australia are penetrated, and which long offered an insuperable obstacle to the attempts of the most enterprising colonist to reach the interior country, form the most striking feature in the geology of New South Wales. They are of grand dimensions, and are bordered by continuous links of lofty cliffs. It is not easy to conceive a more magnificent spectacle, than is presented to a person walking on the summit-plains, when without any notice he arrives at the brink of one of these cliffs, which are so perpendicular, that he can strike with a stone (as I have tried) the trees growing, at the depth of between one thousand and one thousand five hundred feet below him; on both hands he sees headland beyond headland of the receding line of cliff, and on the opposite side of the valley, often at the distance of several miles, he beholds another line rising up to the same height with that on which he stands, and formed of the same horizontal strata of pale sandstone. The bottoms of these valleys are moderately level, and the fall of the rivers flowing in them, according to Sir T. Mitchell, is gentle. The main valleys often send into the platform great baylike arms, which expand at their upper ends; and on the other hand, the platform often sends promontories into the valley, and even leaves in them great, almost insulated, masses. So continuous are the bounding lines of cliff, that to descend into some of these valleys, it is necessary to go round twenty miles; and into others, the surveyors have only lately penetrated, and the colonists have not yet been able to drive in their cattle. But the most remarkable point of structure in these valleys, is, that although several miles wide in their upper parts, they generally contract towards their mouths to such a degree as to become impassable. The Surveyor-General, Sir T. Mitchell,[6] in vain endeavoured, first on foot and then by crawling between the great fallen fragments of sandstone, to ascend through the gorge by which the river Grose joins the Nepean; yet the valley of the Grose in its upper part, as I saw, forms a magnificent basin some miles in width, and is on all sides surrounded by cliffs, the summits of which are believed to be nowhere less than 3,000 feet above the level of the sea. When cattle are driven into the valley of the Wolgan by a path (which I descended) partly cut by the colonists, they cannot escape; for this valley is in every other part surrounded by perpendicular cliffs, and eight miles lower down, it contracts, from an average width of half a mile, to a mere chasm impassable to man or beast. Sir T. Mitchell[7] states, that the great valley of the Cox river with all its branches contracts, where it unites with the Nepean, into a gorge 2,200 yards wide, and about one thousand feet in depth. Other similar cases might have been added.

[6] "Travels in Australia," vol. i, p. 154.—I must express my obligation to Sir T. Mitchell for several interesting personal communications on the subject of these great valleys of New South Wales.

[7] *Idem*, vol. ii, p. 358.

The first impression, from seeing the correspondence of the horizontal strata, on each side of these valleys and great amphitheatre-like depressions, is that they have been in chief part hollowed out, like other valleys, by aqueous erosion; but when one reflects on the enormous amount of stone, which on this view must have been removed, in most of the above cases through mere gorges or chasms, one is led to ask whether these spaces may not have subsided. But considering the form of the irregularly branching valleys, and of the narrow promontories, projecting into them from the platforms, we are compelled to abandon this notion. To attribute these hollows to alluvial action, would be preposterous; nor does the drainage from the summit-level always fall, as I remarked near the Weatherboard, into the head of these valleys, but into one side of their bay-like recesses. Some of the inhabitants remarked to me, that they never viewed one of these baylike recesses, with the headlands receding on both hands, without being struck with their resemblance to a bold sea-coast. This is certainly the case; moreover, the numerous fine harbours, with their widely branching arms, on the present coast of New South Wales, which are generally connected with the sea by a narrow mouth, from one mile to a quarter of a mile in width, passing through the sandstone coast-cliffs, present a likeness, though on a miniature scale, to the great valleys of the interior. But then immediately occurs the startling difficulty, why has the sea worn out these great, though circumscribed, depressions on a wide platform, and left mere gorges, through which the whole vast amount of triturated matter must have been carried away? The only light I can throw on this enigma, is by showing that banks appear to be forming in some seas of the most irregular forms, and that the sides of such banks are so steep (as before stated) that a comparatively small amount of subsequent erosion would form them into cliffs: that the waves have power to form high and precipitous cliffs, even in landlocked harbours, I have observed in many parts of South America. In the Red Sea, banks with an extremely irregular outline and composed of sediment, are penetrated by the most singularly shaped creeks with narrow mouths: this is likewise the case, though on a larger scale, with the Bahama Banks. Such banks, I have been led to suppose,[8] have been formed by currents heaping sediment on an irregular bottom. That in some cases, the sea, instead of spreading out sediment in a uniform sheet, heaps it round submarine rocks and islands, it is hardly possible to doubt, after having examined the charts of the West Indies. To apply these ideas to the sandstone platforms of New South Wales, I imagine that the strata might have been heaped on an irregular bottom by the action of strong currents, and of the undulations of an open sea; and that the valley-like spaces thus left unfilled might, during a slow elevation of the land, have had their steeply sloping flanks worn into cliffs; the worn-down sandstone being removed, either at the time when the narrow gorges were cut by the retreating sea, or subsequently by alluvial action.

[8] See the “Appendix” to the Part on Coral-Reefs. The fact of the sea heaping up mud round a submarine nucleus, is worthy of the notice of geologists: for outlyers of the same composition with the coast banks are thus formed; and these, if upheaved and worn into cliffs, would naturally be thought to have been once connected together.

Van Diemen’s Land.

The southern part of this island is mainly formed of mountains of greenstone, which often assumes a syenitic character, and contains much hypersthene. These mountains, in their lower half, are generally encased by strata containing numerous small corals and some shells. These shells have been examined by Mr. G. B. Sowerby, and have been described by him: they consist of two species of Producta, and of six of Spirifera; two of these, namely, *P. rugata* and *S. rotundata*, resemble, as far as their imperfect condition allows of comparison, British mountain-limestone shells. Mr. Lonsdale has had the kindness to examine the corals; they consist of six undescribed species, belonging to three genera. Species of these genera occur in the Silurian, Devonian, and Carboniferous strata of Europe. Mr. Lonsdale remarks, that all these fossils have undoubtedly a Palæozoic character, and that probably they correspond in age to a division of the system above the Silurian formations.

The strata containing these remains are singular from the extreme variability of their mineralogical composition. Every intermediate form is present, between flinty-slate, clay-slate passing into grey wacke, pure limestone, sandstone, and porcellanic rock; and some of the beds can only be described as composed of a siliceo-calcareo-clay-slate. The formation, as far as I could judge, is at least a thousand feet in thickness: the upper few hundred feet usually consist of a siliceous sandstone, containing pebbles and no organic remains; the inferior strata, of which a pale flinty slate is perhaps the most abundant, are the most variable; and these chiefly abound with the remains. Between two beds of hard crystalline limestone, near Newtown, a layer of white soft calcareous matter is quarried, and is used for whitewashing houses. From information given to me by Mr. Frankland, the Surveyor-General, it appears that this Palæozoic formation is found in different parts of the whole island; from the same authority, I may add, that on the north-eastern coast and in Bass’ Straits primary rocks extensively occur.

The shores of Storm Bay are skirted, to the height of a few hundred feet, by strata of sandstone, containing pebbles of the formation just described, with its characteristic fossils, and therefore belonging to a subsequent age. These strata of sandstone often pass into shale, and alternate with layers of impure coal; they have in many places been violently disturbed. Near Hobart Town, I observed one dike, nearly a hundred yards in width, on one side of which the strata were tilted at an angle of 60 degrees, and on the other they were in some parts vertical, and had been altered by the effects of the heat. On the west side of Storm Bay, I found these strata capped by streams of basaltic lava with olivine; and close by there was a mass of brecciated scoriæ, containing pebbles of lava, which probably marks the place of an ancient submarine crater. Two of these streams of basalt were separated from each other by a layer of argillaceous wacke, which could be traced passing into partially altered scoriæ. The wacke contained numerous rounded grains of a soft, grass-green mineral, with a waxy lustre, and translucent on its edges: under the blowpipe it instantly blackened, and the points fused into a strongly magnetic, black enamel. In these characters, it resembles those masses of decomposed olivine, described at St. Jago in the Cape de Verde group; and I should have thought that it had thus originated, had I not found a similar substance, in cylindrical threads, within the cells of the vesicular basalt,—a state under which olivine never appears; this substance,[9] I believe, would be classed as bole by mineralogists.

[9] Chlorophæite, described by Dr. MacCulloch ("Western Islands," vol. i, p. 504) as occurring in a basaltic amygdaloid, differs from this substance, in remaining unchanged before the blowpipe, and in blackening from exposure to the air. May we suppose that olivine, in undergoing the remarkable change described at St. Jago, passes through several states?

Travertin with extinct plants.—Behind Hobart Town there is a small quarry of a hard travertin, the lower strata of which abound with distinct impressions of leaves. Mr. Robert Brown has had the kindness to look at my specimens, and he informed me that there are four or five kinds, none of which he recognises as belonging to existing species. The most remarkable leaf is palmate, like that of a fan-palm, and no plant having leaves of this structure has hitherto been discovered in Van Diemen's Land. The other leaves do not resemble the most usual form of the Eucalyptus (of which tribe the existing forests are chiefly composed), nor do they resemble that class of exceptions to the common form of the leaves of the Eucalyptus, which occur in this island. The travertin containing this remnant of a lost vegetation, is of a pale yellow colour, hard, and in parts even crystalline; but not compact, and is everywhere penetrated by minute, tortuous, cylindrical pores. It contains a very few pebbles of quartz, and occasionally layers of chalcedonic nodules, like those of chert in our Greensand. From the pureness of this calcareous rock, it has been searched for in other places, but has never been found. From this circumstance, and from the character of the deposit, it was probably formed by a calcareous spring entering a small pool or narrow creek. The strata have subsequently been tilted and fissured; and the surface has been covered by a singular mass, with which, also, a large fissure has been filled up, formed of balls of trap embedded in a mixture of wacke and a white, earthy, alumino-calcareous substance. Hence it would appear, as if a volcanic eruption had taken place on the borders of the pool, in which the calcareous matter was depositing, and had broken it up and drained it.

Elevation of the land.—Both the eastern and western shores of the bay, in the neighbourhood of Hobart Town, are in most parts covered to the height of thirty feet above the level of high-water mark, with broken shells, mingled with pebbles. The colonists attribute these shells to the aborigines having carried them up for food: undoubtedly, there are many large mounds, as was pointed out to me by Mr. Frankland, which have been thus formed; but I think from the numbers of the shells, from their frequent small size, from the manner in which they are thinly scattered, and from some appearances in the form of the land, that we must attribute the presence of the greater number to a small elevation of the land. On the shore of Ralph Bay (opening into Storm Bay) I observed a continuous beach about fifteen feet above high-water mark, clothed with vegetation, and by digging into it, pebbles encrusted with Serpulæ were found: along the banks, also, of the river Derwent, I found a bed of broken sea-shells above the surface of the river, and at a point where the water is now much too fresh for sea-shells to live; but in both these cases, it is just possible, that before certain spits of sand and banks of mud in Storm Bay were accumulated, the tides might have risen to the height where we now find the shells.[10]

[10] It would appear that some changes are now in progress in

Ralph Bay, for I was assured by an intelligent farmer, that oysters were formerly abundant in it, but that about the year 1834 they had, without any apparent cause, disappeared. In the "Transactions of the Maryland Academy" (vol. i, part i, p. 28) there is an account by Mr. Ducatel of vast beds of oysters and clams having been destroyed by the gradual filling up of the shallow lagoons and channels, on the shores of the southern United States. At Chiloe, in South America, I heard of a similar loss, sustained by the inhabitants, in the disappearance from one part of the coast of an edible species of Ascidia.

Evidence more or less distinct of a change of level between the land and water, has been detected on almost all the land on this side of the globe. Captain Grey, and other travellers, have found in Southern Australia upraised shells, belonging either to the recent, or to a late tertiary period. The French naturalists in Baudin's expedition, found shells similarly circumstanced on the S.W. coast of Australia. The Rev. W. B. Clarke[11] finds proofs of the elevation of the land, to the amount of 400 feet, at the Cape of Good Hope. In the neighbourhood of the Bay of Islands in New Zealand,[12] I observed that the shores were scattered to some height, as at Van Diemen's Land, with sea-shells, which the colonists attribute to the natives. Whatever may have been the origin of these shells, I cannot doubt, after having seen a section of the valley of the Thames River (37 degrees S.), drawn by the Rev. W. Williams, that the land has been there elevated: on the opposite sides of this great valley, three step-like terraces, composed of an enormous accumulation of rounded pebbles, exactly correspond with each other: the escarpment of each terrace is about fifty feet in height. No one after having examined the terraces in the valleys on the western shores of South America, which are strewed with sea-shells, and have been formed during intervals of rest in the slow elevation of the land, could doubt that the New Zealand terraces have been similarly formed. I may add, that Dr. Dieffenbach, in his description of the Chatham Islands[13] (S.W. of New Zealand), states that it is manifest "that the sea has left many places bare which were once covered by its waters."

[11] "Proceedings of the Geological Society," vol. iii, p. 420.

[12] I will here give a catalogue of the rocks which I met with near the Bay of Islands, in New Zealand:—1st, Much basaltic lava, and scoriform rocks, forming distinct craters;—2nd, A castellated hill of horizontal strata of flesh-coloured limestone, showing when fractured distinct crystalline facets: the rain has acted on this rock in a remarkable manner, corroding its surface into a miniature model of an Alpine country: I observed here layers of chert and clay ironstone; and in the bed of a stream, pebbles of clay-slate;—3rd, The shores of the Bay of Islands are formed of a feldspathic rock, of a bluish-grey colour, often much decomposed, with an angular fracture, and crossed by numerous ferruginous seams, but without any distinct stratification or cleavage. Some varieties are highly crystalline, and would at once be pronounced to be trap; others strikingly resembled clay-slate, slightly altered by heat: I was unable to form any decided opinion on this formation.

[13] *Geographical Journal*, vol. xi, pp. 202, 205.

King George's Sound.

This settlement is situated at the south-western angle of the Australian continent: the whole country is granitic, with the constituent minerals sometimes obscurely arranged in straight or curved laminæ. In these cases, the rock would be called by Humboldt, gneiss-granite, and it is remarkable that the form of the bare conical hills, appearing to be composed of great folding layers, strikingly resembles, on a small scale, those composed of gneiss-granite at Rio de Janeiro, and those described by Humboldt at Venezuela. These plutonic rocks are, in many places, intersected by trappean-dikes; in one place, I found ten parallel dikes ranging in an E. and W. line; and not far off another set of eight dikes, composed of a different variety of trap, ranging at right angles to the former ones. I have observed in several primary districts, the occurrence of systems of dikes parallel and close to each other.

Superficial ferruginous beds.—The lower parts of the country are everywhere covered by a bed, following the inequalities of the surface, of a honeycombed sandstone, abounding with oxides of iron. Beds of nearly similar composition are common, I believe, along the whole western coast of Australia, and on many of the East Indian islands. At the Cape of Good Hope, at the base of the mountains formed of granite and capped with sandstone, the ground is everywhere coated either by a fine-grained, rubbly, ochraceous mass, like that at King George’s Sound, or by a coarser sandstone with fragments of quartz, and rendered hard and heavy by an abundance of the hydrate of iron, which presents, when freshly broken, a metallic lustre. Both these varieties have a very irregular texture, including spaces either rounded or angular, full of loose sand: from this cause the surface is always honeycombed. The oxide of iron is most abundant on the edges of the cavities, where alone it affords a metallic fracture. In these formations, as well as in many true sedimentary deposits, it is evident that iron tends to become aggregated, either in the form of a shell, or of a network. The origin of these superficial beds, though sufficiently obscure, seems to be due to alluvial action on detritus abounding with iron.

Superficial calcareous deposit.—A calcareous deposit on the summit of Bald Head, containing branched bodies, supposed by some authors to have been corals, has been celebrated by the descriptions of many distinguished voyagers.[14] It folds round and conceals irregular hummocks of granite, at the height of 600 feet above the level of the sea. It varies much in thickness; where stratified, the beds are often inclined at high angles, even as much as at thirty degrees, and they dip in all directions. These beds are sometimes crossed by oblique and even-sided laminæ. The deposit consists either of a fine, white calcareous powder, in which not a trace of structure can be discovered, or of exceedingly minute, rounded grains, of brown, yellowish, and purplish colours; both varieties being generally, but not always, mixed with small particles of quartz, and being cemented into a more or less perfect stone. The rounded calcareous grains, when heated in a slight degree, instantly lose their colours; in this and in every other respect, closely resembling those minute, equal-sized particles of shells and corals, which at St. Helena have been drifted up the side of the mountains, and have thus been winnowed of all coarser fragments. I cannot doubt that the coloured calcareous particles here have had a similar origin. The impalpable powder has probably been derived from the decay of the rounded particles; this certainly is possible, for on the coast of Peru, I have traced *large unbroken* shells gradually falling into a substance as fine as powdered chalk. Both of the above-mentioned varieties of calcareous sandstone frequently alternate with, and blend into, thin layers of a hard substalagmitic[15] rock, which, even when the stone on each side contains particles of quartz, is entirely free from them: hence we must suppose that these layers, as well as certain vein-like masses, have been formed by rain dissolving the calcareous matter and re-precipitating it, as has happened at St. Helena. Each layer probably marks a fresh surface, when the, now firmly cemented, particles existed as loose sand. These layers are sometimes brecciated and re-cemented, as if they had been broken by the slipping of the sand when soft. I did not find a single fragment of a sea-shell; but bleached shells of the *Helix melo*, an existing land species, abound in all the strata; and I likewise found another Helix, and the case of an Oniscus.

[14] I visited this hill, in company with Captain Fitzroy, and we came to a similar conclusion regarding these branching bodies.

[15] I adopt this term from Lieutenant Nelson’s excellent paper on the Bermuda Islands (“Geolog. Trans.,” vol. v, p. 106), for the hard, compact, cream- or brown-coloured stone, without any crystalline structure, which so often accompanies superficial calcareous accumulations. I have observed such superficial beds, coated with substalagmitic rock, at the Cape of Good Hope, in several parts of Chile, and over wide spaces in La Plata and Patagonia. Some of these beds have been formed from decayed shells, but the origin of the greater number is sufficiently obscure. The causes which determine water to dissolve lime, and then soon to redeposit it, are not, I think, known. The surface of the substalagmitic layers appears always to be corroded by the rain-water. As all the above-mentioned countries have a long dry season, compared with the rainy one, I should have thought that the presence of the substalagmitic was connected with the climate, had not Lieutenant Nelson found this substance forming under sea-water. Disintegrated shell seems to be extremely soluble; of which I found good evidence, in a curious rock at Coquimbo in Chile, which consisted of small, pellucid, empty husks, cemented together. A series of specimens clearly showed that these husks had originally contained small rounded particles of shells, which had been enveloped and cemented together by calcareous matter (as often happens on sea-beaches), and which subsequently had decayed, and been dissolved by water, that must have penetrated through the calcareous husks, without corroding them,—of which processes every stage could be seen.

The branches are absolutely undistinguishable in shape from the broken and upright stumps of a thicket; their roots are often uncovered, and are seen to diverge on all sides; here and there a branch lies prostrate. The branches generally consist of the sandstone, rather firmer than the surrounding matter, with the central parts filled, either with friable, calcareous matter, or with a substalagmitic variety; this central part is also frequently penetrated by linear crevices, sometimes, though rarely, containing a trace of woody matter. These calcareous, branching bodies, appear to have been formed by fine calcareous matter being washed into the casts or cavities, left by the decay of branches and roots of thickets, buried under drifted sand. The whole surface of the hill is now undergoing disintegration, and hence the casts, which are compact and hard, are left projecting. In calcareous sand at the Cape of Good Hope, I found the casts, described by Abel, quite similar to these at Bald Head; but their centres are often filled with black carbonaceous matter not yet removed. It is not surprising, that the woody matter should have been almost entirely removed from the casts on Bald Head; for it is certain, that many centuries must have elapsed since the thickets were buried; at present, owing to the form and height of the narrow promontory, no sand is drifted up, and the whole surface, as I have remarked, is wearing away. We must, therefore, look back to a period when the land stood lower, of which the French naturalists[16] found evidence in upraised shells of recent species, for the drifting on Bald Head of the calcareous and quartzose sand, and the consequent embedment of the vegetable remains. There was only one appearance which at first made me doubt concerning the origin of the cast,—namely, that the finer roots from different stems sometimes became united together into upright plates or veins; but when the manner is borne in mind in which fine roots often fill up cracks in hard earth, and that these roots would decay and leave hollows, as well as the stems, there is no real difficulty in this case. Besides the calcareous branches from the Cape of Good Hope, I have seen casts, of exactly the same forms, from Madeira[17] and from Bermuda; at this latter place, the surrounding calcareous rocks, judging from the specimens collected by Lieutenant Nelson, are likewise similar, as is their subaerial formation. Reflecting on the stratification of the deposit on Bald Head,—on the irregularly alternating layers of substalagmitic rock,—on the uniformly sized, and rounded particles, apparently of sea-shells and corals,—on the abundance of land-shells throughout the mass,—and finally, on the absolute resemblance of the calcareous casts, to the stumps, roots, and branches of that kind of vegetation, which would grow on sand-hillocks, I think there can be no reasonable doubt, notwithstanding the different opinion of some authors, that a true view of their origin has been here given.

[16] See M. Péron's "Voyage," tome i, p. 204.

[17] Dr. J. Macaulay has fully described (*Edinb. New Phil. Journ.*, vol. xxix, p. 350) the casts from Madeira. He considers (differently from Mr. Smith of Jordan Hill) these bodies to be corals, and the calcareous deposit to be of subaqueous origin. His arguments chiefly rest (for his remarks on their structure are vague) on the great quantity of the calcareous matter, and on the casts containing animal matter, as shown by their evolving ammonia. Had Dr. Macaulay seen the enormous masses of rolled particles of shells and corals on the beach of Ascension, and especially on coral-reefs; and had he reflected on the effects of long-continued, gentle winds, in drifting up the finer particles, he would hardly have advanced the argument of quantity, which is seldom trustworthy in geology. If the calcareous matter has originated from disintegrated shells and corals, the presence of animal matter is what might have been expected. Mr. Anderson analysed for Dr. Macaulay part of a cast, and he found it composed of—

Carbonate of lime	73·15
Silica	11·90
Phosphate of lime	8·81
Animal matter	4·25
Sulphate of lime	a trace
	———
	98·11

Calcareous deposits, like these of King George's Sound, are of vast extent on the Australian shores. Dr. Fitton remarks, that "recent calcareous breccia (by which term all these deposits are included) was found during Baudin's voyage, over a space of no less than twenty-five degrees of latitude and an equal extent of longitude, on the southern, western, and north-western coasts."[18] It appears also from M. Peron, with whose observations and opinions on the origin of the calcareous matter and branching casts mine entirely accord, that the deposit is generally much more continuous than near King George's Sound. At Swan River, Archdeacon Scott[19] states that in one part it extends ten miles inland. Captain Wickham, moreover, informs me that during his late survey of the western coast, the bottom of the sea, wherever the vessel anchored, was ascertained, by crowbars being let down, to consist of white calcareous matter. Hence it seems that along this coast, as at Bermuda and at Keeling Atoll, submarine and subaerial deposits are contemporaneously in process of formation, from the disintegration of marine organic bodies. The extent of these deposits, considering their origin, is very striking; and they can be compared in this respect only with the great coral-reefs of the Indian and Pacific Oceans. In other parts of the world, for instance in South America, there are *superficial* calcareous deposits of great extent, in which not a trace of organic structure is discoverable; these observations would lead to the inquiry, whether such deposits may not, also, have been formed from disintegrated shells and corals.

[18] For ample details on this formation consult Dr. Fitton's "Appendix to Captain King's Voyage." Dr. Fitton is inclined to attribute a concretionary origin to the branching bodies: I may remark, that I have seen in beds of sand in La Plata cylindrical stems which no doubt thus originated; but they differed much in appearance from these at Bald Head, and the other places above specified.

[19] "Proceedings of the Geolog. Soc.," vol. i, p. 320.

Cape of Good Hope.

After the accounts given by Barrow, Carmichael, Basil Hall, and W. B. Clarke of the geology of this district, I shall confine myself to a few observations on the junction of the three principal formations. The fundamental rock is granite,[20] overlaid by clay-slate: the latter is generally hard, and glossy from containing minute scales of mica; it alternates with, and passes into, beds of slightly crystalline, feldspathic, slaty rock. This clay-slate is remarkable from being in some places (as on the Lion's Rump) decomposed, even to the depth of twenty feet, into a pale-coloured, sandstone-like rock, which has been mistaken, I believe, by some observers, for a separate formation. I was guided by Dr. Andrew Smith to a fine junction at Green Point between the granite and clay-slate: the latter at the distance of a quarter of a mile from the spot, where the granite appears on the beach (though, probably, the granite is much nearer underground), becomes slightly more compact and crystalline. At a less distance, some of the beds of clay-slate are of a homogeneous texture, and obscurely striped with different zones of colour, whilst others are obscurely spotted. Within a hundred yards of the first vein of granite, the clay-slate consists of several varieties; some compact with a tinge of purple, others glistening with numerous minute scales of mica and imperfectly crystallised feldspar; some obscurely granular, others porphyritic with small, elongated spots of a soft white mineral, which being easily corroded, gives to this variety a vesicular appearance. Close to the granite, the clay-slate is changed into a dark-coloured, laminated rock, having a granular fracture, which is due to imperfect crystals of feldspar, coated by minute, brilliant scales of mica.

[20] In several places I observed in the granite, small dark-coloured balls, composed of minute scales of black mica in a tough basis. In another place, I found crystals of black schorl radiating from a common centre. Dr. Andrew Smith found, in the interior parts of the country, some beautiful specimens of granite, with silvery mica radiating or rather branching, like moss, from central points. At the Geological Society, there are specimens of granite with crystallised feldspar branching and radiating in like manner.

The actual junction between the granitic and clay-slate districts extends over a width of about two hundred yards, and consists of irregular masses and of numerous dikes of granite, entangled and surrounded by the clay-slate: most of the dikes range in a N.W. and S.E. line, parallel to the cleavage of the slate. As we leave the junction, thin beds, and lastly, mere films of the altered clay-slate are seen, quite isolated, as if floating, in the coarsely crystallised granite; but although completely detached, they all retain traces of the uniform N.W. and S.E. cleavage. This fact has been observed in other similar cases, and has been advanced by some eminent geologists,[21] as a great difficulty on the ordinary theory, of granite having been injected whilst liquified; but if we reflect on the probable state of the lower surface of a laminated mass, like clay-slate, after having been violently arched by a body of molten granite, we may conclude that it would be full of fissures parallel to the planes of cleavage; and that these would be filled with granite, so that wherever the fissures were close to each other, mere parting layers or wedges of the slate would depend into the granite. Should, therefore, the whole body of rock afterwards become worn down and denuded, the lower ends of these dependent masses or wedges of slate would be left quite isolated in the granite; yet they would retain their proper lines of cleavage, from having been united, whilst the granite was fluid, with a continuous covering of clay-slate.

[21] See M. Keilhau's "Theory on Granite" translated in the *Edinburgh New Philosophical Journal,* vol.xxiv, p. 402.

Following, in company with Dr. A. Smith, the line of junction between the granite and the slate, as it stretched inland, in a S.E. direction, we came to a place, where the slate was converted into a fine-grained, perfectly characterised gneiss, composed of yellow-brown granular feldspar, of abundant black brilliant mica, and of few and thin laminæ of quartz. From the abundance of the mica in this gneiss, compared with the small quantity and excessively minute scales, in which it exists in the glossy clay-slate, we must conclude, that it has been here formed by the metamorphic action—a circumstance doubted, under nearly similar circumstances, by some authors. The laminæ of the clay-slate are straight; and it was interesting to observe, that as they assumed the character of gneiss, they became undulatory with some of the smaller flexures angular, like the laminæ of many true metamorphic schists.

Sandstone formation.—This formation makes the most imposing feature in the geology of Southern Africa. The strata are in many parts horizontal, and attain a thickness of about two thousand feet. The sandstone varies in character; it contains little earthy matter, but is often stained with iron; some of the beds are very fine-grained and quite white; others are as compact and homogeneous as quartz rock. In some places I observed a breccia of quartz, with the fragments almost dissolved in a siliceous paste. Broad veins of quartz, often including large and perfect crystals, are very numerous; and it is evident in nearly all the strata, that silica has been deposited from solution in remarkable quantity. Many of the varieties of quartzite appeared quite like metamorphic rocks; but from the upper strata being as siliceous as the lower, and from the undisturbed junctions with the granite, which in many places can be examined, I can hardly believe that these sandstone-strata have been exposed to heat.[22] On the lines of junction between these two great formations, I found in several places the granite decayed to the depth of a few inches, and succeeded, either by a thin layer of ferruginous shale, or by four or five inches in thickness of the re-cemented crystals of the granite, on which the great pile of sandstone immediately rested.

[22] The Rev. W. B. Clarke, however, states, to my surprise ("Geolog. Proceedings," vol. iii, p. 422), that the sandstone in some parts is penetrated by granitic dikes: such dikes must belong to an epoch altogether subsequent to that when the molten granite acted on the clay-slate.

Mr. Schomburgk has described[23] a great sandstone formation in Northern Brazil, resting on granite, and resembling to a remarkable degree, in composition and in the external form of the land, this formation of the Cape of Good Hope. The sandstones of the great platforms of Eastern Australia, which also rest on granite, differ in containing more earthy and less siliceous matter. No fossil remains have been discovered in these three vast deposits. Finally, I may add that I did not see any boulders of far-transported rocks at the Cape of Good Hope, or on the eastern and western shores of Australia, or at Van Diemen's Land. In the northern island of New Zealand, I noticed some large blocks of greenstone, but whether their parent rock was far distant, I had no opportunity of determining.

[23] *Geographical Journal,* vol. x, p. 246.

GEOLOGICAL OBSERVATIONS ON SOUTH AMERICA.

CRITICAL INTRODUCTION.

Of the remarkable “trilogy” constituted by Darwin’s writings which deal with the geology of the *Beagle*, the member which has perhaps attracted least attention, up to the present time is that which treats of the geology of South America. The actual writing of this book appears to have occupied Darwin a shorter period than either of the other volumes of the series; his diary records that the work was accomplished within ten months, namely, between July 1844 and April 1845; but the book was not actually issued till late in the year following, the preface bearing the date “September 1846.” Altogether, as Darwin informs us in his “Autobiography,” the geological books “consumed four and a half years’ steady work,” most of the remainder of the ten years that elapsed between the return of the *Beagle*, and the completion of his geological books being, it is sad to relate, “lost through illness!”

Concerning the “Geological Observations on South America,” Darwin wrote to his friend Lyell, as follows:—“My volume will be about 240 pages, dreadfully dull, yet much condensed. I think whenever you have time to look through it, you will think the collection of facts on the elevation of the land and on the formation of terraces pretty good.”

“Much condensed” is the verdict that everyone must endorse, on rising from the perusal of this remarkable book; but by no means “dull.” The three and a half years from April 1832 to September 1835, were spent by Darwin in South America, and were devoted to continuous scientific work; the problems he dealt with were either purely geological or those which constitute the borderland between the geological and biological sciences. It is impossible to read the journal which he kept during this time without being impressed by the conviction that it contains all the germs of thought which afterwards developed into the “Origin of Species.” But it is equally evident that after his return to England, biological speculations gradually began to exercise a more exclusive sway over Darwin’s mind, and tended to dispossess geology, which during the actual period of the voyage certainly engrossed most of his time and attention. The wonderful series of observations made during those three and a half years in South America could scarcely be done justice to, in the 240 pages devoted to their exposition. That he executed the work of preparing the book on South America in somewhat the manner of a task, is shown by many references in his letters. Writing to Sir Joseph Hooker in 1845, he says, “I hope this next summer to finish my South American Geology, then to get out a little Zoology, and *hurrah for my species work!*”

It would seem that the feeling of disappointment, which Darwin so often experienced in comparing a book when completed, with the observations and speculations which had inspired it, was more keenly felt in the case of his volume on South America than any other. To one friend he writes, “I have of late been slaving extra hard, to the great discomfiture of wretched digestive organs, at South America, and thank all the fates, I have done three-fourths of it. Writing plain English grows with me more and more difficult, and never attainable. As for your pretending that you will read anything so dull as my pure geological descriptions, lay not such a flattering unction on my soul, for it is incredible.” To another friend he writes, “You do not know what you threaten when you propose to read it—it is purely geological. I said to my brother, ‘You will of course read it,’ and his answer was, ‘Upon my life, I would sooner even buy it.’”

In spite of these disparaging remarks, however, we are strongly inclined to believe that this book, despised by its author, and neglected by his contemporaries, will in the end be admitted to be one of Darwin’s chief titles to fame. It is, perhaps, an unfortunate circumstance that the great success which he attained in biology by the publication of the “Origin of Species” has, to some extent, overshadowed the fact that Darwin’s claims as a geologist, are of the very highest order. It is not too much to say that, had Darwin not been a geologist, the “Origin of Species” could never have been written by him. But apart from those geological questions, which have an important bearing on biological thought and speculation, such as the proofs of imperfection in the geological record, the relations of the later tertiary faunas to the recent ones in the same areas, and the apparent intermingling of types belonging to distant geological epochs, when we study the palæontology of remote districts,—there are other purely geological problems, upon which the contributions made by Darwin are of the very highest value. I believe that the verdict of the historians of science will be that if Darwin had not taken a foremost place among the biologists of this century, his position as a geologist would have been an almost equally commanding one.

But in the case of Darwin's principal geological work—that relating to the origin of the crystalline schists,—geologists were not at the time prepared to receive his revolutionary teachings. The influence of powerful authority was long exercised, indeed, to stifle his teaching, and only now, when this unfortunate opposition has disappeared, is the true nature and importance of Darwin's purely geological work beginning to be recognised.

The two first chapters of the "Geological Observations on South America," deal with the proofs which exist of great, but frequently interrupted, movements of elevation during very recent geological times. In connection with this subject, Darwin's particular attention was directed to the relations between the great earthquakes of South America—of some of which he had impressive experience—and the permanent changes of elevation which were taking place. He was much struck by the rapidity with which the evidence of such great earth movements is frequently obliterated; and especially with the remarkable way in which the action of rain-water, percolating through deposits on the earth's surface, removes all traces of shells and other calcareous organisms. It was these considerations which were the parents of the generalisation that a palæontological record can only be preserved during those periods in which long-continued slow subsidence is going on. This in turn, led to the still wider and more suggestive conclusion that the geological record as a whole is, and never can be more than, a series of more or less isolated fragments. The recognition of this important fact constitutes the keystone to any theory of evolution which seeks to find a basis in the actual study of the types of life that have formerly inhabited our globe.

In his third chapter, Darwin gives a number of interesting facts, collected during his visits to the plains and valleys of Chili, which bear on the question of the origin of saliferous deposits—the accumulation of salt, gypsum, and nitrate of soda. This is a problem that has excited much discussion among geologists, and which, in spite of many valuable observations, still remains to a great extent very obscure. Among the important considerations insisted upon by Darwin is that relating to the absence of marine shells in beds associated with such deposits. He justly argues that if the strata were formed in shallow waters, and then exposed by upheaval to subaerial action, all shells and other calcareous organisms would be removed by solution.

Following Lyell's method, Darwin proceeds from the study of deposits now being accumulated on the earth's surface, to those which have been formed during the more recent periods of the geological history.

His account of the great Pampean formation, with its wonderful mammalian remains—*Mastodon, Toxodon, Scelidotherium, Macrauchenia, Megatherium, Megalonyx, Mylodon,* and *Glyptodon*—this full of interest. His discovery of the remains of a true *Equus* afforded a remarkable confirmation of the fact—already made out in North America—that species of horse had existed and become extinct in the New World, before their introduction by the Spaniards in the sixteenth century. Fully perceiving the importance of the microscope in studying the nature and origin of such deposits as those of the Pampas, Darwin submitted many of his specimens both to Dr. Carpenter in this country, and to Professor Ehrenberg in Berlin. Many very important notes on the microscopic organisms contained in the formation will be found scattered through the chapter.

Darwin's study of the older tertiary formations, with their abundant shells, and their relics of vegetable life buried under great sheets of basalt, led him to consider carefully the question of climate during these earlier periods. In opposition to prevalent views on this subject, Darwin points out that his observations are opposed to the conclusion that a higher temperature prevailed universally over the globe during early geological periods. He argues that "the causes which gave to the older tertiary productions of the quite temperate zones of Europe a tropical character, *were of a local character and did not affect the whole globe.*" In this, as in many similar instances, we see the beneficial influence of extensive travel in freeing Darwin's mind from prevailing prejudices. It was this widening of experience which rendered him so especially qualified to deal with the great problem of the origin of species, and in doing so to emancipate himself from ideas which were received with unquestioning faith by geologists whose studies had been circumscribed within the limits of Western Europe.

In the Cordilleras of Northern and Central Chili, Darwin, when studying still older formations, clearly recognised that they contain an admixture of the forms of life, which in Europe are distinctive of the Cretaceous and Jurassic periods respectively. He was thus led to conclude that the classification of geological periods, which fairly well expresses the facts that had been discovered in the areas where the science was first studied, is no longer capable of being applied when we come to the study of widely distant regions. This important conclusion led up to the further generalisation that each great geological period has exhibited a geographical distribution of the forms of animal and vegetable life, comparable to that which prevails in the existing fauna and flora. To those who are familiar with the extent to which the doctrine of universal formations has affected geological thought and speculation, both long before and since the time that Darwin wrote, the importance of this new standpoint to which he was able to attain will be sufficiently apparent. Like the idea of the extreme imperfection of the Geological Record, the doctrine of *local* geological formations is found permeating and moulding all the palæontological reasonings of his great work.

In one of Darwin’s letters, written while he was in South America, there is a passage we have already quoted, in which he expresses his inability to decide between the rival claims upon his attention of “the old crystalline group of rocks,” and “the softer fossiliferous beds” respectively. The sixth chapter of the work before us, entitled “Plutonic and Metamorphic Rocks—Cleavage and Foliation,” contains a brief summary of a series of observations and reasonings upon these crystalline rocks, which are, we believe, calculated to effect a revolution in geological science, and—though their value and importance have long been overlooked—are likely to entitle Darwin in the future to a position among geologists, scarcely, if at all, inferior to that which he already occupies among biologists.

Darwin’s studies of the great rock-masses of the Andes convinced him of the close relations between the granitic or Plutonic rocks, and those which were undoubtedly poured forth as lavas. Upon his return, he set to work, with the aid of Professor Miller, to make a careful study of the minerals composing the granites and those which occur in the lavas, and he was able to show that in all essential respects they are identical. He was further able to prove that there is a complete gradation between the highly crystalline or granitic rock-masses, and those containing more or less glassy matter between their crystals, which constitute ordinary lavas. The importance of this conclusion will be realised when we remember that it was then the common creed of geologists—and still continues to be so on the Continent—that all highly crystalline rocks are of great geological antiquity, and that the igneous ejections which have taken place since the beginning of the tertiary periods differ essentially, in their composition, their structure, and their mode of occurrence, from those which have made their appearance at earlier periods of the world’s history.

Very completely have the conclusions of Darwin upon these subjects been justified by recent researches. In England, the United States, and Italy, examples of the gradual passage of rocks of truly granitic structure into ordinary lavas have been described, and the reality of the transition has been demonstrated by the most careful studies with the microscope. Recent researches carried on in South America by Professor Stelzner, have also shown the existence of a class of highly crystalline rocks—the “Andengranites”—which combine in themselves many of the characteristics which were once thought to be distinctive of the so-called Plutonic and volcanic rocks. No one familiar with recent geological literature—even in Germany and France, where the old views concerning the distinction of igneous products of different ages have been most stoutly maintained—can fail to recognise the fact that the principles contended for by Darwin bid fair at no distant period to win universal acceptance among geologists all over the globe.

Still more important are the conclusions at which Darwin arrived with respect to the origin of the schists and gneisses which cover so large an area in South America.

Carefully noting, by the aid of his compass and clinometer, at every point which he visited, the direction and amount of inclination of the parallel divisions in these rocks, he was led to a very important generalisation—namely, that over very wide areas the direction (strike) of the planes of cleavage in slates, and of foliation in schists and gneisses, remained constant, though the amount of their inclination (dip) often varied within wide limits. Further than this it appeared that there was always a close correspondence between the strike of the cleavage and foliation and the direction of the great axes along which elevation had taken place in the district.

In Tierra del Fuego, Darwin found striking evidence that the cleavage intersecting great masses of slate-rocks was quite independent of their original stratification, and could often, indeed, be seen cutting across it at right angles. He was also able to verify Sedgwick’s observation that, in some slates, glossy surfaces on the planes of cleavage arise from the development of new minerals, chlorite, epidote or mica, and that in this way a complete graduation from slates to true schists may be traced.

Darwin further showed that in highly schistose rocks, the folia bend around and encircle any foreign bodies in the mass, and that in some cases they exhibit the most tortuous forms and complicated puckerings. He clearly saw that in all cases the forces by which these striking phenomena must have been produced were persistent over wide areas, and were connected with the great movements by which the rocks had been upheaved and folded.

That the distinct folia of quartz, feldspar, mica, and other minerals composing the metamorphic schists could not have been separately deposited as sediment was strongly insisted upon by Darwin; and in doing so he opposed the view generally prevalent among geologists at that time. He was thus driven to the conclusion that foliation, like cleavage, is not an original, but a superinduced structure in rock-masses, and that it is the result of re-crystallisation, under the controlling influence of great pressure, of the materials of which the rock was composed.

In studying the lavas of Ascension, as we have already seen, Darwin was led to recognise the circumstance that, when igneous rocks are subjected to great differential movements during the period of their consolidation, they acquire a foliated structure, closely analogous to that of the crystalline schists. Like his predecessor in this field of inquiry, Mr. Poulett Scrope, Charles Darwin seems to have been greatly impressed by these facts, and he argued from them that the rocks exhibiting the foliated structure must have been in a state of plasticity, like that of a cooling mass of lava. At that time the suggestive experiments of Tresca, Daubree, and others, showing that solid masses under the influence of enormous pressure become actually plastic, had not been published. Had Darwin been aware of these facts he would have seen that it was not necessary to assume a state of imperfect solidity in rock-masses in order to account for their having yielded to pressure and tension, and, in doing so, acquiring the new characters which distinguish the crystalline schists.

The views put forward by Darwin on the origin of the crystalline schists found an able advocate in Mr. Daniel Sharpe, who in 1852 and 1854 published two papers, dealing with the geology of the Scottish Highlands and of the Alps respectively, in which he showed that the principles arrived at by Darwin when studying the South American rocks afford a complete explanation of the structure of the two districts in question.

But, on the other hand, the conclusions of Darwin and Sharpe were met with the strongest opposition by Sir Roderick Murchison and Dr. A. Geikie, who in 1861 read a paper before the Geological Society “On the Coincidence between Stratification and Foliation in the Crystalline Rocks of the Scottish Highlands,” in which they insisted that their observations in Scotland tended to entirely disprove the conclusions of Darwin that foliation in rocks is a secondary structure, and entirely independent of the original stratification of the rock-masses.

Now it is a most significant circumstance that, no sooner did the officers of the Geological Survey commence the careful and detailed study of the Scottish Highlands than they found themselves compelled to make a formal retraction of the views which had been put forward by Murchison and Geikie in opposition to the conclusions of Darwin. The officers of the Geological Survey have completely abandoned the view that the foliation of the Highland rocks has been determined by their original stratification, and admit that the structure is the result of the profound movements to which the rocks have been subjected. The same conclusions have recently been supported by observations made in many different districts—among which we may especially refer to those of Dr. H. Reusch in Norway, and those of Dr. J. Lehmann in Saxony. At the present time the arguments so clearly stated by Darwin in the work before us, have, after enduring opposition or neglect for a whole generation, begun to "triumph all along the line," and we may look forward confidently to the near future, when his claim to be regarded as one of the greatest of geological discoverers shall be fully vindicated.

JOHN W. JUDD.

Chapter I

ON THE ELEVATION OF THE EASTERN COAST OF SOUTH AMERICA.

> Upraised shells of La Plata.—Bahia Blanca, Sand-dunes and Pumice-pebbles.—Step-formed plains of Patagonia, with upraised Shells.—Terrace-bounded Valley of Santa Cruz, formerly a Sea-strait.—Upraised shells of Tierra del Fuego.—Length and breadth of the elevated area.—Equability of the movements, as shown by the similar heights of the plains.—Slowness of the elevatory process.—Mode of formation of the step-formed plains.—Summary.—Great Shingle Formation of Patagonia; its extent, origin, and distribution.—Formation of sea-cliffs.

In the following Volume, which treats of the geology of South America, and almost exclusively of the parts southward of the Tropic of Capricorn, I have arranged the chapters according to the age of the deposits, occasionally departing from this order, for the sake of geographical simplicity.

The elevation of the land within the recent period, and the modifications of its surface through the action of the sea (to which subjects I paid particular attention) will be first discussed; I will then pass on to the tertiary deposits, and afterwards to the older rocks. Only those districts and sections will be described in detail which appear to me to deserve some particular attention; and I will, at the end of each chapter, give a summary of the results. We will commence with the proofs of the upheaval of the eastern coast of the continent, from the Rio Plata southward; and, in the Second Chapter, follow up the same subject along the shores of Chile and Peru.

On the northern bank of the great estuary of the Rio Plata, near Maldonado, I found at the head of a lake, sometimes brackish but generally containing fresh water, a bed of muddy clay, six feet in thickness, with numerous shells of species still existing in the Plata, namely, the *Azara labiata*, d'Orbigny, fragments of *Mytilus eduliformis*, d'Orbigny, *Paludestrina Isabellei*, d'Orbigny, and the *Solen Caribæus*, Lam., which last was embedded vertically in the position in which it had lived. These shells lie at the height of only two feet above the lake, nor would they have been worth mentioning, except in connection with analogous facts.

At Monte Video, I noticed near the town, and along the base of the mount, beds of a living Mytilus, raised some feet above the surface of the Plata: in a similar bed, at a height from thirteen to sixteen feet, M. Isabelle collected eight species, which,[1] according to M. d'Orbigny, now live at the mouth of the estuary. At Colonia del Sacramiento, further westward, I observed at the height of about fifteen feet above the river, there of quite fresh water, a small bed of the same Mytilus, which lives in brackish water at Monte Video. Near the mouth of Uruguay, and for at least thirty-five miles northward, there are at intervals large sandy tracts, extending several miles from the banks of the river, but not raised much above its level, abounding with small bivalves, which occur in such numbers that at the Agraciado they are sifted and burnt for lime. Those which I examined near the A. S. Juan were much worn: they consisted of *Mactra Isabellei*, d'Orbigny, mingled with few of *Venus sinuosa*, Lam., both inhabiting, as I am informed by M. d'Orbigny, brackish water at the mouth of the Plata, nearly or quite as salt as the open sea. The loose sand, in which these shells are packed, is heaped into low, straight, long lines of dunes, like those left by the sea at the head of many bays. M. d'Orbigny has described[2] an analogous phenomenon on a greater scale, near San Pedro on the river Parana, where he found widely extended beds and hillocks of sand, with vast numbers of the *Azara labiata*, at the height of nearly 100 feet (English) above the surface of that river. The Azara inhabits brackish water, and is not known to be found nearer to San Pedro than Buenos Ayres, distant above a hundred miles in a straight line. Nearer Buenos Ayres, on the road from that place to San Isidro, there are extensive beds, as I am informed by Sir Woodbine Parish,[3] of the *Azara labiata*, lying at about forty feet above the level of the river, and distant between two and three miles from it. These shells are always found on the highest banks in the district: they are embedded in a stratified earthy mass, precisely like that of the great Pampean deposit hereafter to be described. In one collection of these shells, there were some valves of the *Venus sinuosa*, Lam., the same species found with the Mactra on the banks of the Uruguay. South of Buenos Ayres, near Ensenada, there are other beds of the Azara, some of which seem to have been embedded in yellowish, calcareous, semi-crystalline matter; and Sir W. Parish has given me from the banks of the Arroyo del Tristan, situated in this same neighbourhood, at the distance of about a league from the Plata, a specimen of a pale-reddish, calcereo-argillaceous stone (precisely like parts of the Pampean deposit the importance of which fact will be referred to in a succeeding chapter), abounding with shells of an Azara, much worn, but which in general form and appearance closely resemble, and are probably identical with, the *A. labiata.* Besides these shells, cellular, highly crystalline rock, formed of the casts of small bivalves, is found near Ensenada; and likewise beds of sea-shells, which from their appearance appear to have lain on the surface. Sir W. Parish has given me some of these shells, and M. d'Orbigny pronounces them to be:—

1. Buccinanops globulosum, d'Orbigny.
2. Olivancillaria auricularia, d'Orbigny.
3. Venus flexuosa, Lam.
4. Cytheræa (imperfect).
5. Mactra Isabellei, d'Orbigny.
6. Ostrea pulchella, d'Orbigny.

Besides these, Sir W. Parish procured[4] (as named by Mr. G. B. Sowerby) the following shells:—

1. Voluta colocynthis.
2. Voluta angulata.
3. Buccinum (not spec.?).

[1] "Voyage dans l'Amérique Mérid.: Part. Géolog.," p. 21.

[2] *Ibid.*, p. 43.

[3] "Buenos Ayres," etc., by Sir Woodbine Parish, p. 168.

[4] "Buenos Ayres," etc., by Sir W. Parish, p. 168.

All these species (with, perhaps, the exception of the last) are recent, and live on the South American coast. These shell-beds extend from one league to six leagues from the Plata, and must lie many feet above its level. I heard, also, of beds of shells on the Somborombon, and on the Rio Salado, at which latter place, as M. d'Orbigny informs me, the *Mactra Isabellei* and *Venus sinuosa* are found.

During the elevation of the Provinces of La Plata, the waters of the ancient estuary have but little affected (with the exception of the sand-hills on the banks of the Parana and Uruguay) the outline of the land. M. Parchappe,[5] however, has described groups of sand dunes scattered over the wide extent of the Pampas southward of Buenos Ayres, which M. d'Orbigny attributes with much probability to the action of the sea, before the plains were raised above its level.[6]

[5] D'Orbigny's "Voyage Géolog.," p. 44.

[6] Before proceeding to the districts southward of La Plata, it may be worth while just to state, that there is some evidence that the coast of Brazil has participated in a small amount of elevation. Mr. Burchell informs me, that he collected at Santos (lat. 24° S.) oyster-shells, apparently recent, some miles from the shore, and quite above the tidal action. Westward of Rio de Janeiro, Captain Elliot is asserted (see Harlan, "Med. and Phys. Res.," p. 35, and Dr. Meigs, in "Trans. Amer. Phil. Soc."), to have found human bones, encrusted with sea-shells, between fifteen and twenty feet above the level of the sea. Between Rio de Janeiro and Cape Frio I crossed sandy tracts abounding with sea-shells, at a distance of a league from the coast; but whether these tracts have been formed by upheaval, or through the mere accumulation of drift sand, I am not prepared to assert. At Bahia (lat. 13° S.), in some parts near the coast, there are traces of sea-action at the height of about twenty feet above its present level; there are also, in many parts, remnants of beds of sandstone and conglomerate with numerous recent shells, raised a little above the sea-level. I may add, that at the head of Bahia Bay there is a formation, about forty feet in thickness, containing tertiary shells apparently of fresh-water origin, now washed by the sea and encrusted with Balini; this appears to indicate a small amount of subsidence subsequent to its deposition. At Pernambuco (lat. 8° S.), in the alluvial or tertiary

cliffs, surrounding the low land on which the city stands, I looked in vain for organic remains, or other evidence of changes in level.

Southward of the Plata.—The coast as far as Bahia Blanca (in lat. 39° S.) is formed either of a horizontal range of cliffs, or of immense accumulations of sand-dunes. Within Bahia Blanca, a small piece of tableland, about twenty feet above high-water mark, called Punta Alta, is formed of strata of cemented gravel and of red earthy mud, abounding with shells (with others lying loose on the surface), and the bones of extinct mammifers. These shells, twenty in number, together with a Balanus and two corals, are all recent species, still inhabiting the neighbouring seas. They will be enumerated in the Fourth Chapter, when describing the Pampean formation; five of them are identical with the upraised ones from near Buenos Ayres. The northern shore of Bahia Blanca is, in main part, formed of immense sand-dunes, resting on gravel with recent shells, and ranging in lines parallel to the shore. These ranges are separated from each other by flat spaces, composed of stiff impure red clay, in which, at the distance of about two miles from the coast, I found by digging a few minute fragments of sea-shells. The sand-dunes extend several miles inland, and stand on a plain, which slopes up to a height of between one hundred and two hundred feet. Numerous, small, well-rounded pebbles of pumice lie scattered both on the plain and sand-hillocks: at Monte Hermoso, on the flat summit of a cliff, I found many of them at a height of 120 feet (angular measurement) above the level of the sea. These pumice pebbles, no doubt, were originally brought down from the Cordillera by the rivers which cross the continent, in the same way as the river Negro anciently brought down, and still brings down, pumice, and as the river Chupat brings down scoriæ: when once delivered at the mouth of a river, they would naturally have travelled along the coasts, and been cast up during the elevation of the land, at different heights. The origin of the argillaceous flats, which separate the parallel ranges of sand-dunes, seems due to the tides here having a tendency (as I believe they have on most shoal, protected coasts) to throw up a bar parallel to the shore, and at some distance from it; this bar gradually becomes larger, affording a base for the accumulation of sand-dunes, and the shallow space within then becomes silted up with mud. The repetition of this process, without any elevation of the land, would form a level plain traversed by parallel lines of sand-hillocks; during a slow elevation of the land, the hillocks would rest on a gently inclined surface, like that on the northern shore of Bahia Blanca. I did not observe any shells in this neighbourhood at a greater height than twenty feet; and therefore the age of the sea-drifted pebbles of pumice, now standing at the height of 120 feet, must remain uncertain.

The main plain surrounding Bahia Blanca I estimated at from two hundred to three hundred feet; it insensibly rises towards the distant Sierra Ventana. There are in this neighbourhood some other and lower plains, but they do not abut one at the foot of the other, in the manner hereafter to be described, so characteristic of Patagonia. The plain on which the settlement stands is crossed by many low sand-dunes, abounding with the minute shells of the *Paludestrina australis*, d’Orbigny, which now lives in the bay. This low plain is bounded to the south, at the Cabeza del Buey, by the cliff-formed margin of a wide plain of the Pampean formation, which I estimated at sixty feet in height. On the summit of this cliff there is a range of high sand-dunes extending several miles in an east and west line.

Southward of Bahia Blanca, the river Colorado flows between two plains, apparently from thirty to forty feet in height. Of these plains, the southern one slopes up to the foot of the great sandstone plateau of the Rio Negro; and the northern one against an escarpment of the Pampean deposit; so that the Colorado flows in a valley fifty miles in width, between the upper escarpments. I state this, because on the low plain at the foot of the northern escarpment, I crossed an immense accumulation of high sand-dunes, estimated by the Gauchos at no less than eight miles in breadth. These dunes range westward from the coast, which is twenty miles distant, to far inland, in lines parallel to the valley; they are separated from each other by argillaceous flats, precisely like those on the northern shore of Bahia Blanca. At present there is no source whence this immense accumulation of sand could proceed; but if, as I believe, the upper escarpments once formed the shores of an estuary, in that case the sandstone formation of the river Negro would have afforded an inexhaustible supply of sand, which would naturally have accumulated on the northern shore, as on every part of the coast open to the south winds between Bahia Blanca and Buenos Ayres.

At San Blas (40° 40′ S.) a little south of the mouth of the Colorado, M.

d'Orbigny[7] found fourteen species of existing shells (six of them identical with those from Bahia Blanca), embedded in their natural positions. From the zone of depth which these shells are known to inhabit, they must have been uplifted thirty-two feet. He also found, at from fifteen to twenty feet above this bed, the remains of an ancient beach.

[7] "Voyage," etc., p. 54.

Ten miles southward, but 120 miles to the west, at Port S. Antonio, the Officers employed on the Survey assured me that they saw many old sea-shells strewed on the surface of the ground, similar to those found on other parts of the coast of Patagonia. At San Josef, ninety miles south in nearly the same longitude, I found, above the gravel, which caps an old tertiary formation, an irregular bed and hillock of sand, several feet in thickness, abounding with shells of *Patella deaurita, Mytilus Magellanicus,* the latter retaining much of its colour; *Fusus Magellanicus* (and a variety of the same), and a large Balanus (probably *B. Tulipa*), all now found on this coast: I estimated this bed at from eighty to one hundred feet above the level of the sea. To the westward of this bay, there is a plain estimated at between two hundred and three hundred feet in height: this plain seems, from many measurements, to be a continuation of the sandstone platform of the river Negro. The next place southward, where I landed, was at Port Desire, 340 miles distant; but from the intermediate districts I received, through the kindness of the Officers of the Survey, especially from Lieutenant Stokes and Mr. King, many specimens and sketches, quite sufficient to show the general uniformity of the whole line of coast. I may here state, that the whole of Patagonia consists of a tertiary formation, resting on and sometimes surrounding hills of porphyry and quartz: the surface is worn into many wide valleys and into level step-formed plains, rising one above another, all capped by irregular beds of gravel, chiefly composed of porphyritic rocks. This gravel formation will be separately described at the end of the chapter.

In the following diagrams:

Baseline is Level of sea.

Scale is 1/20 of inch to 100 feet vertical.

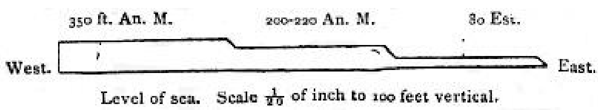
Height is shown in feet thus:

An. M. always stands for angular or trigonometrical measurement.

Ba. M. always stands for barometrical measurement.

Est. always stands for estimation by the Officers of the Survey.

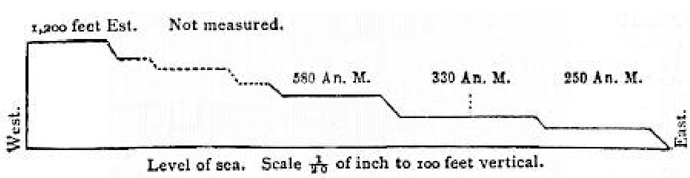
No. 1
Section of step-formed plains south of Nuevo Gulf.



My object in giving the following measurements of the plains, as taken by the Officers of the Survey, is, as will hereafter be seen, to show the remarkable equability of the recent elevatory movements. Round the southern parts of Nuevo Gulf, as far as the River Chupat (seventy miles southward of San Josef), there appear to be several plains, of which the best defined are here represented.

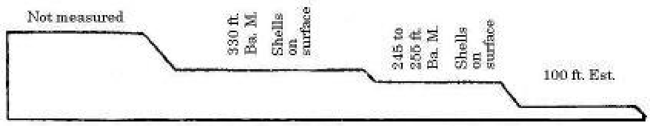
The upper plain is here well defined (called Table Hills); its edge forms a cliff or line of escarpment many miles in length, projecting over a lower plain. The lowest plain corresponds with that at San Josef with the recent shells on its surface. Between this lowest and the uppermost plain, there is probably more than one step-formed terrace: several measurements show the existence of the intermediate one of the height given in diagram No. 1.

No. 2
Section of plains in the Bay of St. George.



Near the north headland of the great Bay of St. George (100 miles south of the Chupat), two well-marked plains of 250 and 330 feet were measured: these are said to sweep round a great part of the Bay. At its south headland, 120 miles distant from the north headland, the 250 feet plain was again measured. In the middle of the bay, a higher plain was found at two neighbouring places (Tilli Roads and C. Marques) to be 580 feet in height. Above this plain, towards the interior, Mr. Stokes informs me that there were several other step-formed plains, the highest of which was estimated at 1,200 feet, and was seen ranging at apparently the same height for 150 miles northward. All these plains have been worn into great valleys and much denuded. The section in diagram No. 3 is illustrative of the general structure of the great Bay of St. George. At the south headland of the Bay of St. George (near C. Three Points) the 250 plain is very extensive. At Port Desire (forty miles southward) I made several measurements with the barometer of a plain, which extends along the north side of the port and along the open coast, and which varies from 245 to 255 feet in height: this plain abuts against the foot of a higher plain of 330 feet, which extends also far northward along the coast, and likewise into the interior. In the distance a higher inland platform was seen, of which I do not know the height. In three separate places, I observed the cliff of the 245-255 feet plain, fringed by a terrace or narrow plain estimated at about one hundred feet in height. These plains are represented in the following section:—

No. 3
Section of plains at Port Desire.

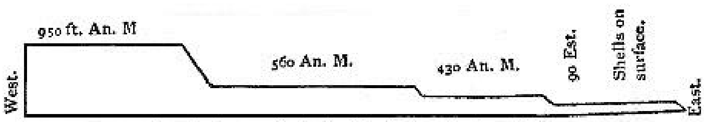


Level of sea. Scale 1/20 of inch to 100 feet vertical.

In many places, even at the distance of three and four miles from the coast, I found on the gravel-capped surface of the 245-255 feet, and of the 330 feet plain, shells of *Mytilus Magellanicus, M. edulis, Patella deaurita*, and another Patella, too much worn to be identified, but apparently similar to one found abundantly adhering to the leaves of the kelp. These species are the commonest now living on this coast. The shells all appeared very old; the blue of the mussels was much faded; and only traces of colour could be perceived in the Patellas, of which the outer surfaces were scaling off. They lay scattered on the smooth surface of the gravel, but abounded most in certain patches, especially at the heads of the smaller valleys: they generally contained sand in their insides; and I presume that they have been washed by alluvial action out of thin sandy layers, traces of which may sometimes be seen covering the gravel. The several plains have very level surfaces; but all are scooped out by numerous broad, winding, flat-bottomed valleys, in which, judging from the bushes, streams never flow. These remarks on the state of the shells, and on the nature of the plains, apply to the following cases, so need not be repeated.

Southward of Port Desire, the plains have been greatly denuded, with only small pieces of tableland marking their former extension. But opposite Bird Island, two considerable step-formed plains were measured, and found respectively to be 350 and 590 feet in height. This latter plain extends along the coast close to Port St. Julian (110 miles south of Port Desire); where we have the following section:—

No. 4
Section of plains at Port St. Julian.



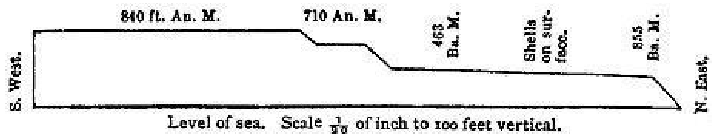
Level of sea. Scale 1/20 of inch to 100 feet vertical.

The lowest plain was estimated at ninety feet: it is remarkable from the usual gravel-bed being deeply worn into hollows, which are filled up with, as well as the general surface covered by, sandy and reddish earthy matter: in one of the hollows thus filled up, the skeleton of the Macrauchenia Patachonica, as will hereafter be described, was embedded. On the surface and in the upper parts of this earthy mass, there were numerous shells of Mytilus Magellanicus and M. edulis, Patella deaurita, and fragments of other species. This plain is tolerably level, but not extensive; it forms a promontory seven or eight miles long, and three or four wide. The upper plains in Diagram 4 were measured by the Officers of the Survey; they were all capped by thick beds of gravel, and were all more or less denuded; the 950 plain consists merely of separate, truncated, gravel-capped hills, two of which, by measurement, were found to differ only three feet. The 430 feet plain extends, apparently with hardly a break, to near the northern entrance of the Rio Santa Cruz (fifty miles to the south); but it was there found to be only 330 feet in height.

On the southern side of the mouth of the Santa Cruz we have Diagram 5, which I am able to give with more detail than in the foregoing cases:—

No. 5

Section of plains at the mouth of the Rio Santa Cruz.



The plain marked 355 feet (as ascertained by the barometer and by angular measurement) is a continuation of the above-mentioned 330 feet plain: it extends in a N.W. direction along the southern shores of the estuary. It is capped by gravel, which in most parts is covered by a thin bed of sandy earth, and is scooped out by many flat-bottomed valleys. It appears to the eye quite level, but in proceeding in a S.S.W. course, towards an escarpment distant about six miles, and likewise ranging across the country in a N.W. line, it was found to rise at first insensibly, and then for the last half-mile, sensibly, close up to the base of the escarpment: at this point it was 463 feet in height, showing a rise of 108 feet in the six miles. On this 355-463 feet plain, I found several shells of *Mytilus Magellanicus* and of a Mytilus, which Mr. Sowerby informs me is yet unnamed, though well-known as recent on this coast; *Patella deaurita*; *Fusus*, I believe, *Magellanicus*, but the specimen has been lost; and at the distance of four miles from the coast, at the height of about four hundred feet, there were fragments of the same Patella and of a Voluta (apparently *V. ancilla*) partially embedded in the superficial sandy earth. All these shells had the same ancient appearance with those from the foregoing localities. As the tides along this part of the coast rise at the Syzygal period forty feet, and therefore form a well-marked beach-line, I particularly looked out for ridges in crossing this plain, which, as we have seen, rises 108 feet in about six miles, but I could not see any traces of such. The next highest plain is 710 feet above the sea; it is very narrow, but level, and is capped with gravel; it abuts to the foot of the 840 feet plain. This summit-plain extends as far as the eye can range, both inland along the southern side of the valley of the Santa Cruz, and southward along the Atlantic.

The Valley of the R. Santa Cruz.—This valley runs in an east and west direction to the Cordillera, a distance of about one hundred and sixty miles. It cuts through the great Patagonian tertiary formation, including, in the upper half of the valley, immense streams of basaltic lava, which as well as the softer beds, are capped by gravel; and this gravel, high up the river, is associated with a vast boulder formation.[8] In ascending the valley, the plain which at the mouth on the southern side is 355 feet high, is seen to trend towards the corresponding plain on the northern side, so that their escarpments appear like the shores of a former estuary, larger than the existing one: the escarpments, also, of the 840 feet summit-plain (with a corresponding northern one, which is met with some way up the valley), appear like the shores of a still larger estuary. Farther up the valley, the sides are bounded throughout its entire length by level, gravel-capped terraces, rising above each other in steps. The width between the upper escarpments is on an average between seven and ten miles; in one spot, however, where cutting through the basaltic lava, it was only one mile and a half. Between the escarpments of the second highest terrace the average width is about four or five miles. The bottom of the valley, at the distance of 110 miles from its mouth, begins sensibly to expand, and soon forms a considerable plain, 440 feet above the level of the sea, through which the river flows in a gut from twenty to forty feet in depth. I here found, at a point 140 miles from the Atlantic, and seventy miles from the nearest creek of the Pacific, at the height of 410 feet, a very old and worn shell of *Patella deaurita.* Lower down the valley, 105 miles from the Atlantic (long. 71° W.), and at an elevation of about 300 feet, I also found, in the bed of the river, two much worn and broken shells of the *Voluta ancilla*, still retaining traces of their colours; and one of the *Patella deaurita.* It appeared that these shells had been washed from the banks into the river; considering the distance from the sea, the desert and absolutely unfrequented character of the country, and the very ancient appearance of the shells (exactly like those found on the plains nearer the coast), there is, I think, no cause to suspect that they could have been brought here by Indians.

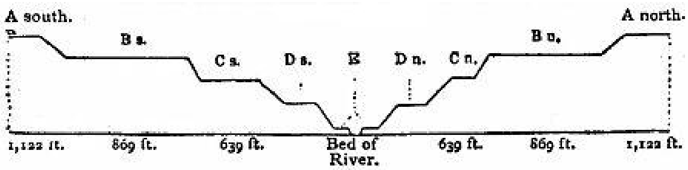
[8] I have described this formation in a paper in the "Geological Transactions," vol. vi, p. 415.

The plain at the head of the valley is tolerably level, but water-worn, and with many sand-dunes on it like those on a sea-coast. At the highest point to which we ascended, it was sixteen miles wide in a north and south line; and forty-five miles in length in an east and west line. It is bordered by the escarpments, one above the other, of two plains, which diverge as they approach the Cordillera, and consequently resemble, at two levels, the shores of great bays facing the mountains; and these mountains are breached in front of the lower plain by a remarkable gap. The valley, therefore, of the Santa Cruz consists of a straight broad cut, about ninety miles in length, bordered by gravel-capped terraces and plains, the escarpments of which at both ends diverge or expand, one over the other, after the manner of the shores of great bays. Bearing in mind this peculiar form of the land—the sand-dunes on the plain at the head of the valley—the gap in the Cordillera, in front of it—the presence in two places of very ancient shells of existing species—and lastly, the circumstance of the 355-453 feet plain, with the numerous marine remains on its surface, sweeping from the Atlantic coast, far up the valley, I think we must admit, that within the recent period, the course of the Santa Cruz formed a sea-strait intersecting the continent. At this period, the southern part of South America consisted of an archipelago of islands 360 miles in a north and south line. We shall presently see, that two other straits also, since closed, then cut through Tierra del Fuego; I may add, that one of them must at that time have expanded at the foot of the Cordillera into a great bay (now Otway Water) like that which formerly covered the 440 feet plain at the head of the Santa Cruz.

I have said that the valley in its whole course is bordered by gravel-capped plains. The section (diagram No. 6), supposed to be drawn in a north and south line across the valley, can scarcely be considered as more than illustrative; for during our hurried ascent it was impossible to measure all the plains at any one place. At a point nearly midway between the Cordillera and the Atlantic, I found the plain (A north) 1,122 feet above the river; all the lower plains on this side were here united into one great broken cliff: at a point sixteen miles lower down the stream, I found by measurement and estimation that B (*n*) was 869 above the river: very near to where A (*n*) was measured, C (*n*) was 639 above the same level: the terrace D (*n*) was nowhere measured: the lowest E (*n*) was in many places about twenty feet above the river. These plains or terraces were best developed where the valley was widest; the whole five, like gigantic steps, occurred together only at a few points. The lower terraces are less continuous than the higher ones, and appear to be entirely lost in the upper third of the valley. Terrace C (*s*), however was traced continuously for a great distance. The terrace B (*n*), at a point fifty-five miles from the mouth of the river, was four miles in width; higher up the valley this terrace (or at least the second highest one, for I could not always trace it continuously) was about eight miles wide. This second plain was generally wider than the lower ones—as indeed follows from the valley from A (*n*) to A (*s*) being generally nearly double the width of from B (*n*) to B (*s*).

No. 6

North and South Section across the terraces bounding the valley of the River Santa Cruz, high up its course.



The height of each terrace above the level of the river, is shown by the number under it. Vertical scale $\frac{1}{20}$ of inch to 100 feet; but terrace E, being only twenty feet above the river, has necessarily been raised. The horizontal distances much contracted; the distance from the edge of A n to A s being on an average from seven to ten miles.

Low down the valley, the summit-plain A (*s*) is continuous with the 840 feet plain on the coast, but it is soon lost or unites with the escarpment of B (*s*). The corresponding plain A (*n*), on the north side of the valley, appears to range continuously from the Cordillera to the head of the present estuary of the Santa Cruz, where it trends northward towards Port St. Julian. Near the Cordillera the summit-plain on both sides of the valley is between 3,200 and 3,300 feet in height; at 100 miles from the Atlantic, it is 1,416 feet, and on the coast 840 feet, all above the sea-beach; so that in a distance of 100 miles the plain rises 576 feet, and much more rapidly near to the Cordillera. The lower terraces B and C also appear to rise as they run up the valley; thus D (*n*), measured at two points twenty-four miles apart, was found to have risen 185 feet. From several reasons I suspect, that this gradual inclination of the plains up the valley, has been chiefly caused by the elevation of the continent in mass, having been the greater the nearer to the Cordillera.

All the terraces are capped with well-rounded gravel, which rests either on the denuded and sometimes furrowed surface of the soft tertiary deposits, or on the basaltic lava. The difference in height between some of the lower steps or terraces seems to be entirely owing to a difference in the thickness of the capping gravel. Furrows and inequalities in the gravel, where such occur, are filled up and smoothed over with sandy earth. The pebbles, especially on the higher plains, are often whitewashed, and even cemented together by a white aluminous substance, and I occasionally found this to be the case with the gravel on the terrace D. I could not perceive any trace of a similar deposition on the pebbles now thrown up by the river, and therefore I do not think that terrace D was river-formed. As the terrace E generally stands about twenty feet above the bed of the river, my first impression was to doubt whether even this lowest one could have been so formed; but it should always be borne in mind, that the horizontal upheaval of a district, by increasing the total descent of the streams, will always tend to increase, first near the sea-coast and then further and further up the valley, their corroding and deepening powers: so that an alluvial plain, formed almost on a level with a stream, will, after an elevation of this kind, in time be cut through, and left standing at a height never again to be reached by the water. With respect to the three upper terraces of the Santa Cruz, I think there can be no doubt, that they were modelled by the sea, when the valley was occupied by a strait, in the same manner (hereafter to be discussed) as the greater step-formed, shell-strewed plains along the coast of Patagonia.

To return to the shores of the Atlantic: the 840 feet plain, at the mouth of the Santa Cruz, is seen extending horizontally far to the south; and I am informed by the Officers of the Survey, that bending round the head of Coy Inlet (sixty-five miles southward), it trends inland. Outliers of apparently the same height are seen forty miles farther south, inland of the river Gallegos; and a plain comes down to Cape Gregory (thirty-five miles southward), in the Strait of Magellan, which was estimated at between eight hundred and one thousand feet in height, and which, rising towards the interior, is capped by the boulder formation. South of the Strait of Magellan, there are large outlying masses of apparently the same great tableland, extending at intervals along the eastern coast of Tierra del Fuego: at two places here, 110 miles a part, this plain was found to be 950 and 970 feet in height.

From Coy Inlet, where the high summit-plain trends inland, a plain estimated at 350 feet in height, extends for forty miles to the river Gallegos. From this point to the Strait of Magellan, and on each side of that Strait, the country has been much denuded and is less level. It consists chiefly of the boulder formation, which rises to a height of between one hundred and fifty and two hundred and fifty feet, and is often capped by beds of gravel. At N.S. Gracia, on the north side of the Inner Narrows of the Strait of Magellan, I found on the summit of a cliff, 160 feet in height, shells of existing Patellæ and Mytili, scattered on the surface and partially embedded in earth. On the eastern coast, also, of Tierra del Fuego, in latitude 53° 20′ south, I found many Mytili on some level land, estimated at 200 feet in height. Anterior to the elevation attested by these shells, it is evident by the present form of the land, and by the distribution of the great erratic boulders[9] on the surface, that two sea-channels connected the Strait of Magellan both with Sebastian Bay and with Otway Water.

[9] “Geolog. Transactions,” vol. vi, p. 419.

Concluding remarks on the recent elevation of the south-eastern coasts of America, and on the action of the sea on the land.—Upraised shells of species, still existing as the commonest kinds in the adjoining sea, occur, as we have seen, at heights of between a few feet and 410 feet, at intervals from latitude 33° 40′ to 53° 20′ south. This is a distance of

1,180 geographical miles—about equal from London to the North Cape of Sweden. As the boulder formation extends with nearly the same height 150 miles south of 53° 20′, the most southern point where I landed and found upraised shells; and as the level Pampas ranges many hundred miles northward of the point, where M. d'Orbigny found at the height of 100 feet beds of the Azara, the space in a north and south line, which has been uplifted within the recent period, must have been much above the 1,180 miles. By the term "recent," I refer only to that period within which the now living mollusca were called into existence; for it will be seen in the Fourth Chapter, that both at Bahia Blanca and P. S. Julian, the mammiferous quadrupeds which co-existed with these shells belong to extinct species. I have said that the upraised shells were found only at intervals on this line of coast, but this in all probability may be attributed to my not having landed at the intermediate points; for wherever I did land, with the exception of the river Negro, shells were found: moreover, the shells are strewed on plains or terraces, which, as we shall immediately see, extend for great distances with a uniform height. I ascended the higher plains only in a few places, owing to the distance at which their escarpments generally range from the coast, so that I am far from knowing that 410 feet is the maximum of elevation of these upraised remains. The shells are those now most abundant in a living state in the adjoining sea.[10] All of them have an ancient appearance; but some, especially the mussels, although lying fully exposed to the weather, retain to a considerable extent their colours: this circumstance appears at first surprising, but it is now known that the colouring principle of the Mytilus is so enduring, that it is preserved when the shell itself is completely disintegrated.[11] Most of the shells are broken; I nowhere found two valves united; the fragments are not rounded, at least in none of the specimens which I brought home.

[10] Captain King, "Voyages of *Adventure* and *Beagle*," vol. i, 1 pp. 6 and 133.

[11] See Mr. Lyell "Proofs of a Gradual Rising in Sweden," in the "Philosoph. Transact.," 1835, p. 1. See also Mr. Smith of Jordan Hill in the *Edin. New Phil. Journal*, vol. xxv, p. 393.

With respect to the breadth of the upraised area in an east and west line, we know from the shells found at the Inner Narrows of the Strait of Magellan, that the entire width of the plain, although there very narrow, has been elevated. It is probable that in this southernmost part of the continent, the movement has extended under the sea far eastward; for at the Falkland Islands, though I could not find any shells, the bones of whales have been noticed by several competent observers, lying on the land at a considerable distance from the sea, and at the height of some hundred feet above it.[12] Moreover, we know that in Tierra del Fuego the boulder formation has been uplifted within the recent period, and a similar formation occurs[13] on the north-western shores (Byron Sound) of these islands. The distance from this point to the Cordillera of Tierra del Fuego, is 360 miles, which we may take as the probable width of the recently upraised area. In the latitude of the R. Santa Cruz, we know from the shells found at the mouth and head, and in the middle of the valley, that the entire width (about 160 miles) of the surface eastward of the Cordillera has been upraised. From the slope of the plains, as shown by the course of the rivers, for several degrees northward of the Santa Cruz, it is probable that the elevation attested by the shells on the coast has likewise extended to the Cordillera. When, however, we look as far northward as the provinces of La Plata, this conclusion would be very hazardous; not only is the distance from Maldonado (where I found upraised shells) to the Cordillera great, namely, 760 miles, but at the head of the estuary of the Plata, a N.N.E. and S.S.W. range of tertiary volcanic rocks has been observed,[14] which may well indicate an axis of elevation quite distinct from that of the Andes. Moreover, in the centre of the Pampas in the chain of Cordova, severe earthquakes have been felt;[15] whereas at Mendoza, at the eastern foot of the Cordillera, only gentle oscillations, transmitted from the shores of the Pacific, have ever been experienced. Hence the elevation of the Pampas may be due to several distinct axes of movement; and we cannot judge, from the upraised shells round the estuary of the Plata, of the breadth of the area uplifted within the recent period.

[12] "Voyages of the *Adventure* and *Beagle*," vol. ii, p. 227. And Bougainville's "Voyage," tome i, p. 112.

[13] I owe this fact to the kindness of Captain Sulivan, R.N., a highly competent observer. I mention it more especially, as in my Paper (p. 427) on the Boulder Formation, I have, after having

examined the northern and middle parts of the eastern island, said that the formation was here wholly absent.

[14] This volcanic formation will be described in Chapter IV. It is not improbable that the height of the upraised shells at the head of the estuary of the Plata, being greater than at Bahia Blanca or at San Blas, may be owing to the upheaval of these latter places having been connected with the distant line of the Cordillera, whilst that of the provinces of La Plata was in connection with the adjoining tertiary volcanic axis.

[15] See Sir W. Parish's work on "La Plata," p. 242. For a notice of an earthquake which drained a lake near Cordova, see also Temple's "Travels in Peru." Sir W. Parish informs me, that a town between Salta and Tucuman (north of Cordova) was formerly utterly overthrown by an earthquake.

Not only has the above specified long range of coast been elevated within the recent period, but I think it may be safely inferred from the similarity in height of the gravel-capped plains at distant points, that there has been a remarkable degree of equability in the elevatory process. I may premise, that when I measured the plains, it was simply to ascertain the heights at which shells occurred; afterwards, comparing these measurements with some of those made during the Survey, I was struck with their uniformity, and accordingly tabulated all those which represented the summit-edges of plains. The extension of the 330 to 355 feet plain is very striking, being found over a space of 500 geographical miles in a north and south line. A table (Table 1) of the measurements is given below. The angular measurements and all the estimations (in feet) are by the Officers of the Survey; the barometrical ones by myself:—

	Feet
Gallegos River to Coy Inlet (partly angular partly estimation)	350
South Side of Santa Cruz (angular and barometric)	355
North Side of Santa Cruz (angular and barometric)	330
Bird Island, plain opposite to (angular)	350
Port Desire, plain extending far along coast (barometric)	330
St. George's Bay, north promontory (angular)	330
Table Land, south of New Bay (angular)	350

A plain, varying from 245 to 255 feet, seems to extend with much uniformity from Port Desire to the north of St. George's Bay, a distance of 170 miles; and some approximate measurements (in feet), also given in the table below, indicate the much greater extension of 780 miles:—

	Feet
Coy Inlet, south of (partly angular and partly estimation)	200 to 300
Port Desire (barometric)	245 to 255
C. Blanco (angular)	250
North Promontory of St. George's Bay (angular)	250
South of New Bay (angular)	200 to 220
North of S. Josef (estimation)	200 to 300
Plain of Rio Negro (angular)	200 to 220
Bahia Blanca (estimation)	200 to 300

The extension, moreover, of the 560 to 580, and of the 80 to 100 feet, plains is remarkable, though somewhat less obvious than in the former cases. Bearing in mind that I have not picked these measurements out of a series, but have used all those which represented the edges of plains, I think it scarcely possible that these coincidences in height should be accidental. We must therefore conclude that the action, whatever it may have been, by which these plains have been modelled into their present forms, has been singularly uniform.

These plains or great terraces, of which three and four often rise like steps one behind the other, are formed by the denudation of the old Patagonian tertiary beds, and by the deposition on their surfaces of a mass of well-rounded gravel, varying, near the coast, from ten to thirty-five feet in thickness, but increasing in thickness towards the interior. The gravel is often capped by a thin irregular bed of sandy earth. The plains slope up, though seldom sensibly to the eye, from the summit edge of one escarpment to the foot of the next highest one. Within a distance of 150 miles, between Santa Cruz to Port Desire, where the plains are particularly well developed, there are at least seven stages or steps, one above the other. On the three lower ones, namely, those of 100 feet, 250 feet, and 350 feet in height, existing littoral shells are abundantly strewed, either on the surface, or partially embedded in the superficial sandy earth. By whatever action these three lower plains have been modelled, so undoubtedly have all the higher ones, up to a height of 950 feet at S. Julian, and of 1,200 feet (by estimation) along St. George's Bay. I think it will not be disputed, considering the presence of the upraised marine shells, that the sea has been the active power during stages of some kind in the elevatory process.

We will now briefly consider this subject: if we look at the existing coast-line, the evidence of the great denuding power of the sea is very distinct; for, from Cape St. Diego, in lat. 54° 30′ to the mouth of the Rio Negro, in lat. 31° (a length of more than eight hundred miles), the shore is formed, with singularly few exceptions, of bold and naked cliffs: in many places the cliffs are high; thus, south of the Santa Cruz, they are between eight and nine hundred feet in height, with their horizontal strata abruptly cut off, showing the immense mass of matter which has been removed. Nearly this whole line of coast consists of a series of greater or lesser curves, the horns of which, and likewise certain straight projecting portions, are formed of hard rocks; hence the concave parts are evidently the effect and the measure of the denuding action on the softer strata. At the foot of all the cliffs, the sea shoals very gradually far outwards; and the bottom, for a space of some miles, everywhere consists of gravel. I carefully examined the bed of the sea off the Santa Cruz, and found that its inclination was exactly the same, both in amount and in its peculiar curvature, with that of the 355 feet plain at this same place. If, therefore, the coast, with the bed of the adjoining sea, were now suddenly elevated one or two hundred feet, an inland line of cliffs, that is an escarpment, would be formed, with a gravel-capped plain at its foot gently sloping to the sea, and having an inclination like that of the existing 355 feet plain. From the denuding tendency of the sea, this newly formed plain would in time be eaten back into a cliff: and repetitions of this elevatory and denuding process would produce a series of gravel-capped sloping terraces, rising one above another, like those fronting the shores of Patagonia.

The chief difficulty (for there are other inconsiderable ones) on this view, is the fact,—as far as I can trust two continuous lines of soundings carefully taken between Santa Cruz and the Falkland Islands, and several scattered observations on this and other coasts,—that the pebbles at the bottom of the sea *quickly* and *regularly* decrease in size with the increasing depth and distance from the shore, whereas in the gravel on the sloping plains, no such decrease in size was perceptible. The following table gives the average result of many soundings off the Santa Cruz:—

Under two miles from the shore, many of the pebbles were of large size,
mingled with some small ones.

Distance in miles from shore	Depth in fathoms	Size of Pebbles
3 to 4	11 to 12	As large as walnuts; mingled in every case with some smaller ones.
6 to 7	17 to 19	As large as hazel-nuts.
10 to 11	23 to 25	From three- to four-tenths of an inch in diameter.
12	30 to 40	Two-tenths of an inch.
22 to 150	45 to 65	One-tenth of an inch, to the finest sand.

I particularly attended to the size of the pebbles on the 355 feet Santa Cruz plain, and I noticed that on the summit-edge of the present sea cliffs many were as large as half a man's head; and in crossing from these cliffs to the foot of the next highest escarpment, a distance of six miles, I could not observe any increase in their size. We shall presently see that the theory of a slow and almost insensible rise of the land, will explain all the facts connected with the gravel-capped terraces, better than the theory of sudden elevations of from one to two hundred feet.

M. d'Orbigny has argued, from the upraised shells at San Blas being embedded in the positions in which they lived, and from the valves of the *Azara labiata* high on the banks of the Parana being united and unrolled, that the elevation of Northern Patagonia and of La Plata must have been sudden; for he thinks, if it had been gradual, these shells would all have been rolled on successive beach-lines. But in *protected* bays, such as in that of Bahia Blanca, wherever the sea is accumulating extensive mud-banks, or where the winds quietly heap up sand-dunes, beds of shells might assuredly be preserved buried in the positions in which they had lived, even whilst the land retained the same level; any, the smallest, amount of elevation would directly aid in their preservation. I saw a multitude of spots in Bahia Blanca where this might have been effected; and at Maldonado it almost certainly has been effected. In speaking of the elevation of the land having been slow, I do not wish to exclude the small starts which accompany earthquakes, as on the coast of Chile; and by such movements beds of shells might easily be uplifted, even in positions exposed to a heavy surf, without undergoing any attrition: for instance, in 1835, a rocky flat off the island of Santa Maria was at one blow upheaved above high-water mark, and was left covered with gaping and putrefying mussel-shells, still attached to the bed on which they had lived. If M. d'Orbigny had been aware of the many long parallel lines of sand-hillocks, with infinitely numerous shells of the Mactra and Venus, at a low level near the Uruguay; if he had seen at Bahia Blanca the immense sand-dunes, with water-worn pebbles of pumice, ranging in parallel lines, one behind the other, up a height of at least 120 feet; if he had seen the sand-dunes, with the countless Paludestrinas, on the low plain near the Fort at this place, and that long line on the edge of the cliff, sixty feet higher up; if he had crossed that long and great belt of parallel sand-dunes, eight miles in width, standing at the height of from forty to fifty feet above the Colorado, where sand could not now collect,—I cannot believe he would have thought that the elevation of this great district had been sudden. Certainly the sand-dunes (especially when abounding with shells), which stand in ranges at so many different levels, must all have required long time for their accumulation; and hence I do not doubt that the last 100 feet of elevation of La Plata and Northern Patagonia has been exceedingly slow.

If we extend this conclusion to Central and Southern Patagonia, the inclination of the successively rising gravel-capped plains can be explained quite as well, as by the more obvious view already given of a few comparatively great and sudden elevations; in either case we must admit long periods of rest, during which the sea ate deeply into the land. Let us suppose the present coast to rise at a nearly equable, slow rate, yet sufficiently quick to prevent the waves quite removing each part as soon as brought up; in this case every portion of the present bed of the sea will successively form a beach-line, and from being exposed to a like action will be similarly affected. It cannot matter to what height the tides rise, even if to forty feet as at Santa Cruz, for they will act with equal force and in like manner on each successive line. Hence there is no difficulty in the fact of the 355 feet plain at Santa Cruz sloping up 108 feet to the foot of the next highest escarpment, and yet having no marks of any one particular beach-line on it; for the whole surface on this view has been a beach. I cannot pretend to follow out the precise action of the tidal-waves during a rise of the land, slow, yet sufficiently quick to prevent or check denudation: but if it be analogous to what takes place on protected parts of the present coast, where gravel is now accumulating in large quantities,[16] an inclined surface, thickly capped by well-rounded pebbles of about the same size, would be ultimately left. On the gravel now accumulating, the waves, aided by the wind, sometimes throw up a thin covering of sand, together with the common coast-shells. Shells thus cast up by gales, would, during an elevatory period, never again be touched by the sea. Hence, on this view of a slow and gradual rising of the land, interrupted by periods of rest and denudation, we can understand the pebbles being of about the same size over the entire width of the step-like plains,—the occasional thin covering of sandy earth,—and the presence of broken, unrolled fragments of those shells, which now live exclusively near the coast.

[16] On the eastern side of Chiloe, which island we shall see in the next chapter is now rising, I observed that all the beaches and extensive tidal-flats were formed of shingle.

Summary of results.—It may be concluded that the coast on this side of the continent, for a space of at least 1,180 miles, has been elevated to a height of 100 feet in La Plata, and of 400 feet in Southern Patagonia, within the period of existing shells, but not of existing mammifers. That in La Plata the elevation has been very slowly effected: that in Patagonia the movement may have been by considerable starts, but much more probably slow and quiet. In either case, there have been long intervening periods of comparative rest,[17] during which the sea corroded deeply, as it is still corroding, into the land. That the periods of denudation and elevation were contemporaneous and equable over great spaces of coast, as shown by the equable heights of the plains; that there have been at least eight periods of denudation, and that the land, up to a height of from 950 to 1,200 feet, has been similarly modelled and affected: that the area elevated, in the southernmost part of the continent, extended in breadth to the Cordillera, and probably seaward to the Falkland Islands; that northward, in La Plata, the breadth is unknown, there having been probably more than one axis of elevation; and finally, that, anterior to the elevation attested by these upraised shells, the land was divided by a Strait where the River Santa Cruz now flows, and that further southward there were other sea-straits, since closed. I may add, that at Santa Cruz, in lat. 50° S., the plains have been uplifted at least 1,400 feet, since the period when gigantic boulders were transported between sixty and seventy miles from their parent rock, on floating icebergs.

[17] I say *comparative* and not *absolute* rest, because the sea acts, as we have seen, with great denuding power on this whole line of coast; and therefore, during an elevation of the land, if excessively slow (and of course during a subsidence of the land), it is quite possible that lines of cliff might be formed.)

Lastly, considering the great upward movements which this long line of coast has undergone, and the proximity of its southern half to the volcanic axis of the Cordillera, it is highly remarkable that in the many fine sections exposed in the Pampean, Patagonian tertiary, and Boulder formations, I nowhere observed the smallest fault or abrupt curvature in the strata.

Gravel Formation of Patagonia.

I will here describe in more detail than has been as yet incidentally done, the nature, origin, and extent of the great shingle covering of Patagonia: but I do not mean to affirm that all of this shingle, especially that on the higher plains, belongs to the recent period. A thin bed of sandy earth, with small pebbles of various porphyries and of quartz, covering a low plain on the north side of the Rio Colorado, is the extreme northern limit of this formation. These little pebbles have probably been derived from the denudation of a more regular bed of gravel, capping the old tertiary sandstone plateau of the Rio Negro. The gravel-bed near the Rio Negro is, on an average, about ten or twelve feet in thickness; and the pebbles are larger than on the northern side of the Colorado, being from one or two inches in diameter, and composed chiefly of rather dark-tinted porphyries. Amongst them I here first noticed a variety often to be referred to, namely, a peculiar gallstone-yellow siliceous porphyry, frequently, but not invariably, containing grains of quartz. The pebbles are embedded in a white, gritty, calcareous matrix, very like mortar, sometimes merely coating with a whitewash the separate stones, and sometimes forming the greater part of the mass. In one place I saw in the gravel concretionary nodules (not rounded) of crystallised gypsum, some as large as a man’s head. I traced this bed for forty-five miles inland, and was assured that it extended far into the interior. As the surface of the calcareo-argillaceous plain of Pampean formation, on the northern side of the wide valley of the Colorado, stands at about the same height with the mortar-like cemented gravel capping the sandstone on the southern side, it is probable, considering the apparent equability of the subterranean movements along this side of America, that this gravel of the Rio Negro and the upper beds of the Pampean formation northward of the Colorado, are of nearly contemporaneous origin, and that the calcareous matter has been derived from the same source.

Southward of the Rio Negro, the cliffs along the great bay of S. Antonio are capped with gravel: at San Josef, I found that the pebbles closely resembled those on the plain of the Rio Negro, but that they were not cemented by calcareous matter. Between San Josef and Port Desire, I was assured by the Officers of the Survey that the whole face of the country is coated with gravel. At Port Desire and over a space of twenty-five miles inland, on the three step-formed plains and in the valleys, I everywhere passed over gravel which, where thickest, was between thirty and forty feet. Here, as in other parts of Patagonia, the gravel, or its sandy covering, was, as we have seen, often strewed with recent marine shells. The sandy covering sometimes fills up furrows in the gravel, as does the gravel in the underlying tertiary formations. The pebbles are frequently whitewashed and even cemented together by a peculiar, white, friable, aluminous, fusible substance, which I believe is decomposed feldspar. At Port Desire, the gravel rested sometimes on the basal formation of porphyry, and sometimes on the upper or the lower denuded tertiary strata. It is remarkable that most of the porphyritic pebbles differ from those varieties of porphyry which occur here abundantly *in situ.* The peculiar gallstone-yellow variety was common, but less numerous than at Port S. Julian, where it formed nearly one-third of the mass of the gravel; the remaining part there consisting of pale grey and greenish porphyries with many crystals of feldspar. At Port S. Julian, I ascended one of the flat-topped hills, the denuded remnant of the highest plain, and found it, at the height of 950 feet, capped with the usual bed of gravel.

Near the mouth of the Santa Cruz, the bed of gravel on the 355 feet plain is from twenty to about thirty-five feet in thickness. The pebbles vary from minute ones to the size of a hen’s egg, and even to that of half a man’s head; they consist of paler varieties of porphyry than those found further northward, and there are fewer of the gallstone-yellow kind; pebbles of compact black clay-slate were here first observed. The gravel, as we have seen, covers the step-formed plains at the mouth, head, and on the sides of the great valley of the Santa Cruz. At a distance of 110 miles from the coast, the plain has risen to the height of 1,416 feet above the sea; and the gravel, with the associated great boulder formation, has attained a thickness of 212 feet. The plain, apparently with its usual gravel covering, slopes up to the foot of the Cordillera to the height of between 3,200 and 3,300 feet. In ascending the valley, the gravel gradually becomes entirely altered in character: high up, we have pebbles of crystalline feldspathic rocks, compact clay-slate, quartzose schists, and pale-coloured porphyries; these rocks, judging both from the gigantic boulders in the surface and from some small pebbles embedded beneath 700 feet in thickness of the old tertiary strata, are the prevailing kinds in this part of the Cordillera; pebbles of basalt from the neighbouring streams of basaltic lava are also numerous; there are few or none of the reddish or of the gallstone-yellow porphyries so common near the coast. Hence the pebbles on the 350 feet plain at the mouth of the Santa Cruz cannot have been derived (with the exception of those of compact clay-slate, which, however, may equally well have come from the south) from the Cordillera in this latitude; but probably, in chief part, from farther north.

Southward of the Santa Cruz, the gravel may be seen continuously capping the great 840 feet plain: at the Rio Gallegos, where this plain is succeeded by a lower one, there is, as I am informed by Captain Sulivan, an irregular covering of gravel from ten to twelve feet in thickness over the whole country. The district on each side of the Strait of Magellan is covered up either with gravel or the boulder formation: it was interesting to observe the marked difference between the perfectly rounded state of the pebbles in the great shingle formation of Patagonia, and the more or less angular fragments in the boulder formation. The pebbles and fragments near the Strait of Magellan nearly all belong to rocks known to occur in Fuegia. I was therefore much surprised in dredging south of the Strait to find, in lat. 54° 10′ south, many pebbles of the gallstone-yellow siliceous porphyry; I procured others from a great depth off Staten Island, and others were brought me from the western extremity of the Falkland Islands.[18] The distribution of the pebbles of this peculiar porphyry, which I venture to affirm is not found *in situ* either in Fuegia, the Falkland Islands, or on the coast of Patagonia, is very remarkable, for they are found over a space of 840 miles in a north and south line, and at the Falklands, 300 miles eastward of the coast of Patagonia. Their occurrence in Fuegia and the Falklands may, however, perhaps be due to the same ice-agency by which the boulders have been there transported.

[18] At my request, Mr. Kent collected for me a bag of pebbles from the beach of White Rock harbour, in the northern part of the sound, between the two Falkland Islands. Out of these well-rounded pebbles, varying in size from a walnut to a hen’s egg, with some larger, thirty-eight evidently belonged to the rocks of these islands; twenty-six were similar to the pebbles of porphyry found on the Patagonian plains, which rocks do not exist *in situ* in the Falklands; one pebble belonged to the peculiar yellow siliceous porphyry; thirty were of doubtful origin.

We have seen that porphyritic pebbles of a small size are first met with on the northern side of the Rio Colorado, the bed becoming well developed near the Rio Negro: from this latter point I have every reason to believe that the gravel extends uninterruptedly over the plains and valleys of Patagonia for at least 630 nautical miles southward to the Rio

Gallegos. From the slope of the plains, from the nature of the pebbles, from their extension at the Rio Negro far into the interior, and at the Santa Cruz close up to the Cordillera, I think it highly probable that the whole breadth of Patagonia is thus covered. If so, the average width of the bed must be about two hundred miles. Near the coast the gravel is generally from ten to thirty feet in thickness; and as in the valley of Santa Cruz it attains, at some distance from the Cordillera, a thickness of 214 feet, we may, I think, safely assume its average thickness over the whole area of 630 by 200 miles, at fifty feet!

The transportal and origin of this vast bed of pebbles is an interesting problem. From the manner in which they cap the step-formed plains, worn by the sea within the period of existing shells, their deposition, at least on the plains up to a height of 400 feet, must have been a recent geological event. From the form of the continent, we may feel sure that they have come from the westward, probably, in chief part from the Cordillera, but, perhaps, partly from unknown rocky ridges in the central districts of Patagonia. That the pebbles have not been transported by rivers, from the interior towards the coast, we may conclude from the fewness and smallness of the streams of Patagonia: moreover, in the case of the one great and rapid river of Santa Cruz, we have good evidence that its transporting power is very trifling. This river is from two to three hundred yards in width, about seventeen feet deep in its middle, and runs with a singular degree of uniformity five knots an hour, with no lakes and scarcely any still reaches: nevertheless, to give one instance of its small transporting power, upon careful examination, pebbles of compact basalt could not be found in the bed of the river at a greater distance than ten miles below the point where the stream rushes over the debris of the great basaltic cliffs forming its shore: fragments of the *cellular* varieties have been washed down twice or thrice as far. That the pebbles in Central and Northern Patagonia have not been transported by ice-agency, as seems to have been the case to a considerable extent farther south, and likewise in the northern hemisphere, we may conclude, from the absence of all angular fragments in the gravel, and from the complete contrast in many other respects between the shingle and neighbouring boulder formation.

Looking to the gravel on any one of the step-formed plains, I cannot doubt, from the several reasons assigned in this chapter, that it has been spread out and leveled by the long-continued action of the sea, probably during the slow rise of the land. The smooth and perfectly rounded condition of the innumerable pebbles alone would prove long-continued action. But how the whole mass of shingle on the coast-plains has been transported from the mountains of the interior, is another and more difficult question. The following considerations, however, show that the sea by its ordinary action has considerable power in distributing pebbles. A table has already been given, showing how very uniformly and gradually[19] the pebbles decrease in size with the gradually seaward increasing depth and distance. A series of this kind irresistibly leads to the conclusion, that the sea has the power of sifting and distributing the loose matter on its bottom. According to Martin White,[20] the bed of the British Channel is disturbed during gales at depths of sixty-three and sixty-seven fathoms, and at thirty fathoms, shingle and fragments of shells are often deposited, afterwards to be carried away again. Groundswells, which are believed to be caused by distant gales, seem especially to affect the bottom: at such times, according to Sir R. Schomburgk,[21] the sea to a great distance round the West Indian Islands, at depths from five to fifteen fathoms, becomes discoloured, and even the anchors of vessels have been moved. There are, however, some difficulties in understanding how the sea can transport pebbles lying at the bottom, for, from experiments instituted on the power of running water, it would appear that the currents of the sea have not sufficient velocity to move stones of even moderate size: moreover, I have repeatedly found in the most exposed situations that the pebbles which lie at the bottom are encrusted with full-grown living corallines, furnished with the most delicate, yet unbroken spines: for instance, in ten fathoms water off the mouth of the Santa Cruz, many pebbles, under half an inch in diameter, were thus coated with Flustracean zoophytes.[22] Hence we must conclude that these pebbles are not often violently disturbed: it should, however, be borne in mind that the growth of corallines is rapid. The view, propounded by Professor Playfair, will, I believe, explain this apparent difficulty,—namely, that from the undulations of the sea *tending* to lift up and down pebbles or other loose bodies at the bottom, such are liable, when thus quite or partially raised, to be moved even by a very small force, a little onwards. We can thus understand how oceanic or tidal currents of no great strength, or that recoil movement of the bottom-water near the land, called by sailors the "undertow" (which I presume must extend out seaward as far as the *breaking* waves impel the surface-water towards the beach), may gain the power during storms of sifting and distributing pebbles even of considerable size, and yet without so violently disturbing them as to injure the encrusting corallines.[23]

[19] I may mention, that at the distance of 150 miles from the Patagonian shore I carefully examined the minute rounded particles in the sand, and found them to be fusible like the porphyries of the great shingle bed. I could even distinguish particles of the gallstone-yellow porphyry. It was interesting to notice how gradually the particles of white quartz increased, as we approached the Falkland Islands, which are thus constituted. In the whole line of soundings between these islands and the coast of Patagonia dead or living organic remains were most rare. On the relations between the depth of water and the nature of the bottom, see Martin White on "Soundings in the Channel," pp. 4, 6, 175; also Captain Beechey's "Voyage to the Pacific," chap. xviii.

[20] "Soundings in the Channel," pp. 4, 166. M. Siau states (*Edin. New Phil. Jour.*, vol. xxxi, p. 246), that he found the sediment, at a depth of 188 metres, arranged in ripples of different degrees of fineness. There are some excellent discussions on this and allied subjects in Sir H. De la Beche's "Theoretical Researches."

[21] *Journal of Royal Geograph. Soc.,* vol. v, p. 25. It appears from Mr. Scott Russell's investigations (see Mr. Murchison's "Anniver. Address Geolog. Soc.," 1843, p. 40), that in waves of translation the motion of the particles of water is nearly as great at the bottom as at the top.

[22] (A pebble, one and a half inch square and half an inch thick, was given me, dredged up from twenty-seven fathoms depth off the western end of the Falkland Islands, where the sea is remarkably stormy, and subject to violent tides. This pebble was encrusted on all sides by a delicate living coralline. I have seen many pebbles from depths between forty and seventy fathoms thus encrusted; one from the latter depth off Cape Horn.

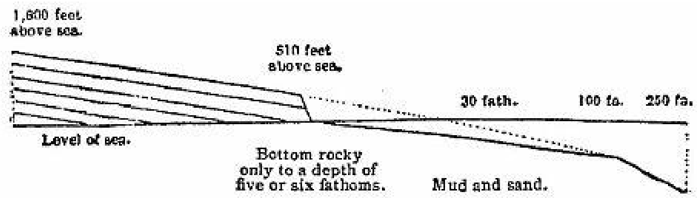
[23] I may take this opportunity of remarking on a singular, but very common character in the form of the bottom, in the creeks which deeply penetrate the western shores of Tierra del Fuego; namely, that they are almost invariably much shallower close to the open sea at their mouths than inland. Thus, Cook, in entering Christmas Sound, first had soundings in thirty-seven fathoms, then in fifty, then in sixty, and a little farther in no bottom with 170 fathoms. The sealers are so familiar with this fact, that they always look out for anchorage near the entrances of the creeks. See, also, on this subject, the "Voyages of the *Adventure* and *Beagle*," vol. i, p. 375 and "Appendix," p. 313. This Shoalness of the sea-channels near their entrances probably results from the quantity of sediment formed by the wear and tear of the outer rocks exposed to the full force of the open sea. I have no doubt that many lakes, for instance in Scotland, which are very deep within, and are separated from the sea apparently only by a tract of detritus, were originally sea-channels with banks of this nature near their mouths, which have since been upheaved.

The sea acts in another and distinct manner in the distribution of pebbles, namely by the waves on the beach. Mr. Palmer,[24] in his excellent memoir on this subject, has shown that vast masses of shingle travel with surprising quickness along lines of coast, according to the direction with which the waves break on the beach and that this is determined by the prevailing direction of the winds. This agency must be powerful in mingling together and disseminating pebbles derived from different sources: we may, perhaps, thus understand the wide distribution of the gallstone-yellow porphyry; and likewise, perhaps, the great difference in the nature of the pebbles at the mouth of the Santa Cruz from those in the same latitude at the head of the valley.

[24] "Philosophical Transactions," 1834, p. 576.

I will not pretend to assign to these several and complicated agencies their shares in the distribution of the Patagonian shingle: but from the several considerations given in this chapter, and I may add, from the frequency of a capping of gravel on tertiary deposits in all parts of the world, as I have myself observed and seen stated in the works of various authors, I cannot doubt that the power of widely dispersing gravel is an ordinary contingent on the action of the sea; and that even in the case of the great Patagonian shingle-bed we have no occasion to call in the aid of debacles. I at one time imagined that perhaps an immense accumulation of shingle had originally been collected at the foot of the Cordillera; and that this accumulation, when upraised above the level of the sea, had been eaten into and partially spread out (as off the present line of coast); and that the newly-spread out bed had in its turn been upraised, eaten into, and re-spread out; and so onwards, until the shingle, which was first accumulated in great thickness at the foot of the Cordillera, had reached in thinner beds its present extension. By whatever means the gravel formation of Patagonia may have been distributed, the vastness of its area, its thickness, its superficial position, its recent origin, and the great degree of similarity in the nature of its pebbles, all appear to me well deserving the attention of geologists, in relation to the origin of the widely-spread beds of conglomerate belonging to past epochs.

No. 7
Section of coast-cliffs and bottom of sea, off the island of St. Helena.



Vertical and horizontal scale, two inches to a nautical mile. The point marked 1,600 feet is at the foot of High Knoll; point marked 510 feet is on the edge of Ladder Hill. The strata consist of basaltic streams.

Formation of Cliffs.—When viewing the sea-worn cliffs of Patagonia, in some parts between eight hundred and nine hundred feet in height, and formed of horizontal tertiary strata, which must once have extended far seaward—or again, when viewing the lofty cliffs round many volcanic islands, in which the gentle inclination of the lava-streams indicates the former extension of the land, a difficulty often occurred to me, namely, how the strata could possibly have been removed by the action of the sea at a considerable depth beneath its surface. The section in diagram No. 7, which represents the general form of the land on the northern and leeward side of St. Helena (taken from Mr. Seale’s large model and various measurements), and of the bottom of the adjoining sea (taken chiefly from Captain Austin’s survey and some old charts), will show the nature of this difficulty.

If, as seems probable, the basaltic streams were originally prolonged with nearly their present inclination, they must, as shown by the dotted line in the section, once have extended at least to a point, now covered by the sea to a depth of nearly thirty fathoms: but I have every reason to believe they extended considerably further, for the inclination of the streams is less near the coast than further inland. It should also be observed, that other sections on the coast of this island would have given far more striking results, but I had not the exact measurements; thus, on the windward side, the cliffs are about two thousand feet in height and the cut-off lava streams very gently inclined, and the bottom of the sea has nearly a similar slope all round the island. How, then, has all the hard basaltic rock, which once extended beneath the surface of the sea, been worn away? According to Captain Austin, the bottom is uneven and rocky only to that very small distance from the beach within which the depth is from five to six fathoms; outside this line, to a depth of about one hundred fathoms, the bottom is smooth, gently inclined, and formed of mud and sand; outside the one hundred fathoms, it plunges suddenly into unfathomable depths, as is so very commonly the case on all coasts where sediment is accumulating. At greater depths than the five or six fathoms, it seems impossible, under existing circumstances, that the sea can both have worn away hard rock, in parts to a thickness of at least 150 feet, and have deposited a smooth bed of fine sediment. Now, if we had any reason to suppose that St. Helena had, during a long period, gone on slowly subsiding, every difficulty would be removed: for looking at the diagram, and imagining a fresh amount of subsidence, we can see that the waves would then act on the coast-cliffs with fresh and unimpaired vigour, whilst the rocky ledge near the beach would be carried down to that depth, at which sand and mud would be deposited on its bare and uneven surface: after the formation near the shore of a new rocky shoal, fresh subsidence would carry it down and allow it to be smoothly covered up. But in the case of the many cliff-bounded islands, for instance in some of the Canary Islands and of Madeira, round which the inclination of the strata shows that the land once extended far into the depths of the sea, where there is no apparent means of hard rock being worn away—are we to suppose that all these islands have slowly subsided? Madeira, I may remark, has, according to Mr. Smith of Jordan Hill, subsided. Are we to extend this conclusion to the high, cliff-bound, horizontally stratified shores of Patagonia, off which, though the water is not deep even at the distance of several miles, yet the smooth bottom of pebbles gradually decreasing in size with the increasing depth, and derived from a foreign source, seem to declare that the sea is now a depositing and not a corroding agent? I am much inclined to suspect, that we shall hereafter find in all such cases, that the land with the adjoining bed of the sea has in truth subsided: the time will, I believe, come, when geologists will consider it as improbable, that the land should have retained the same level during a whole geological period, as that the atmosphere should have remained absolutely calm during an entire season.

Chapter II

ON THE ELEVATION OF THE WESTERN COAST OF SOUTH AMERICA.

Chonos Archipelago.—Chiloe, recent and gradual elevation of, traditions of the inhabitants on this subject.—Concepcion, earthquake and elevation of.—VALPARAISO, great elevation of, upraised shells, earth of marine origin, gradual rise of the land within the historical period.—COQUIMBO, elevation of, in recent times; terraces of marine origin, their inclination, their escarpments not horizontal.—Guasco, gravel terraces of.—Copiapo.—PERU.—Upraised shells of Cobija, Iquique, and Arica.—Lima, shell-beds and sea-beach on San Lorenzo, human remains, fossil earthenware, earthquake debacle, recent subsidence. On the decay of upraised shells.—General summary.

Commencing at the south and proceeding northward, the first place at which I landed, was at Cape Tres Montes, in lat. 46° 35′. Here, on the shores of Christmas Cove, I observed in several places a beach of pebbles with recent shells, about twenty feet above high-water mark. Southward of Tres Montes (between lat. 47° and 48°), Byron[1] remarks, "We thought it very strange, that upon the summits of the highest hills were found beds of shells, a foot or two thick." In the Chonos Archipelago, the island of Lemus (lat. 44° 30′) was, according to M. Coste,[2] suddenly elevated eight feet, during the earthquake of 1829: he adds, "Des roches jadis toujours couvertes par la mer, restant aujourd'hui constamment decouvertes." In other parts of this archipelago, I observed two terraces of gravel, abutting to the foot of each other: at Lowe's Harbour (43° 48′), under a great mass of the boulder formation, about three hundred feet in thickness, I found a layer of sand, with numerous comminuted fragments of sea-shells, having a fresh aspect, but too small to be identified.

[1] "Narrative of the Loss of the *Wager*."

[2] "Comptes Rendus," October 1838, p. 706.

The Island of Chiloe.—The evidence of recent elevation is here more satisfactory. The bay of San Carlos is in most parts bounded by precipitous cliffs from about ten to forty feet in height, their bases being separated from the present line of tidal action by a talus, a few feet in height, covered with vegetation. In one sheltered creek (west of P. Arena), instead of a loose talus, there was a bare sloping bank of tertiary mudstone, perforated, above the line of the highest tides, by numerous shells of a Pholas now common in the harbour. The upper extremities of these shells, standing upright in their holes with grass growing out of them, were abraded about a quarter of an inch, to the same level with the surrounding worn strata. In other parts, I observed (as at Pudeto) a great beach, formed of comminuted shells, twenty feet above the present shore. In other parts again, there were small caves worn into the foot of the low cliffs, and protected from the waves by the talus with its vegetation: one such cave, which I examined, had its mouth about twenty feet, and its bottom, which was filled with sand containing fragments of shells and legs of crabs, from eight to ten feet above high-water mark. From these several facts, and from the appearance of the upraised shells, I inferred that the elevation had been quite recent; and on inquiring from Mr. Williams, the Portmaster, he told me he was convinced that the land had risen, or the sea fallen, four feet within the last four years. During this period, there had been one severe earthquake, but no particular change of level was then observed; from the habits of the people who all keep boats in the protected creeks, it is absolutely impossible that a rise of four feet could have taken place suddenly and been unperceived. Mr. Williams believes that the change has been quite gradual. Without the elevatory movement continues at a quick rate, there can be no doubt that the sea will soon destroy the talus of earth at the foot of the cliffs round the bay, and will then reach its former lateral extension, but not of course its former level: some of the inhabitants assured me that one such talus, with a footpath on it, was even already sensibly decreasing in width. I received several accounts of beds of shells, existing at considerable heights in the inland parts of Chiloe; and to one of these, near Catiman, I was guided by a countryman.

Here, on the south side of the peninsula of Lacuy, there was an immense bed of the *Venus costellata* and of an oyster, lying on the summit-edge of a piece of tableland, 350 feet (by the barometer) above the level of the sea. The shells were closely packed together, embedded in and covered by a very black, damp, peaty mould, two or three feet in thickness, out of which a forest of great trees was growing. Considering the nature and dampness of this peaty soil, it is surprising that the fine ridges on the outside of the Venus are perfectly preserved, though all the shells have a blackened appearance. I did not doubt that the black soil, which when dry, cakes hard, was entirely of terrestrial origin, but on examining it under the microscope, I found many very minute rounded fragments of shells, amongst which I could distinguish bits of Serpulæ and mussels. The *Venus costellata*, and the Ostrea (*O. edulis*, according to Captain King) are now the commonest shells in the adjoining bays. In a bed of shells, a few feet below the 350 feet bed, I found a horn of the little *Cervus humilis*, which now inhabits Chiloe.

The eastern or inland side of Chiloe, with its many adjacent islets, consists of tertiary and boulder deposits, worn into irregular plains capped by gravel. Near Castro, and for ten miles southward, and on the islet of Lemuy, I found the surface of the ground to a height of between twenty and thirty feet above high-water mark, and in several places apparently up to fifty feet, thickly coated by much comminuted shells, chiefly of the *Venus costellata* and *Mytilus Chiloensis*; the species now most abundant on this line of coast. As the inhabitants carry immense numbers of these shells inland, the continuity of the bed at the same height was often the only means of recognising its natural origin. Near Castro, on each side of the creek and rivulet of the Gamboa, three distinct terraces are seen: the lowest was estimated at about one hundred and fifty feet in height, and the highest at about five hundred feet, with the country irregularly rising behind it; obscure traces, also, of these same terraces could be seen along other parts of the coast. There can be no doubt that their three escarpments record pauses in the elevation of the island. I may remark that several promontories have the word Huapi, which signifies in the Indian tongue, island, appended to them, such as Huapilinao, Huapilacuy, Caucahuapi, etc.; and these, according to Indian traditions, once existed as islands. In the same manner the term Pulo in Sumatra is appended[3] to the names of promontories, traditionally said to have been islands; in Sumatra, as in Chiloe, there are upraised recent shells. The Bay of Carelmapu, on the mainland north of Chiloe, according to Agüerros,[4] was in 1643 a good harbour; it is now quite useless, except for boats.

[3] Marsden’s “Sumatra,” p. 31.

[4] “Descripcion Hist. de la Provincia de Chiloé,” p. 78. From the account given by the old Spanish writers, it would appear that several other harbours, between this point and Concepcion, were formerly much deeper than they now are.

Valdivia.—I did not observe here any distinct proofs of recent elevation; but in a bed of very soft sandstone, forming a fringe-like plain, about sixty feet in height, round the hills of mica-slate, there are shells of Mytilus, Crepidula, Solen, Novaculina, and Cytheræa, too imperfect to be specifically recognised. At Imperial, seventy miles north of Valdivia, Agüerros[5] states that there are large beds of shells, at a considerable distance from the coast, which are burnt for lime. The island of Mocha, lying a little north of Imperial, was uplifted two feet,[6] during the earthquake of 1835.

[5] *Ibid.,* p. 25.

[6] “Voyages of *Adventure* and *Beagle*,” vol. ii, p. 415.

Concepcion.—I cannot add anything to the excellent account by Captain Fitzroy[7] of the elevation of the land at this place, which accompanied the earthquake of 1835. I will only recall to the recollection of geologists, that the southern end of the island of St. Mary was uplifted eight feet, the central part nine, and the northern end ten feet; and the whole island more than the surrounding districts. Great beds of mussels, patellæ, and chitons still adhering to the rocks were upraised above high-water mark; and some acres of a rocky flat, which was formerly always covered by the sea, was left standing dry, and exhaled an offensive smell, from the many attached and putrefying shells. It appears from the researches of Captain Fitzroy that both the island of St. Mary and Concepcion (which was uplifted only four or five feet) in the course of some weeks subsided, and lost part of their first elevation. I will only add as a lesson of caution, that round the sandy shores of the great Bay of Concepcion, it was most difficult, owing to the obliterating effects of the great accompanying wave, to recognise any distinct evidence of this considerable upheaval; one spot must be excepted, where there was a detached rock which before the earthquake had always been covered by the sea, but afterwards was left uncovered.

> [7] *Ibid.,* vol. ii, p. 412, *et seq.* In vol. v, p. 601 of the "Geological Transactions" I have given an account of the remarkable volcanic phenomena, which accompanied this earthquake. These phenomena appear to me to prove that the action, by which large tracts of land are uplifted, and by which volcanic eruptions are produced, is in every respect identical.

On the island of Quiriquina (in the Bay of Concepcion), I found, at an estimated height of four hundred feet, extensive layers of shells, mostly comminuted, but some perfectly preserved and closely packed in black vegetable mould; they consisted of Concholepas, Fissurella, Mytilus, Trochus, and Balanus. Some of these layers of shells rested on a thick bed of bright-red, dry, friable earth, capping the surface of the tertiary sandstone, and extending, as I observed whilst sailing along the coast, for 150 miles southward: at Valparaiso, we shall presently see that a similar red earthy mass, though quite like terrestrial mould, is really in chief part of recent marine origin. On the flanks of this island of Quiriquina, at a less height than the 400 feet, there were spaces several feet square, thickly strewed with fragments of similar shells. During a subsequent visit of the *Beagle* to Concepcion, Mr. Kent, the assistant-surgeon, was so kind as to make for me some measurements with the barometer: he found many marine remains along the shores of the whole bay, at a height of about twenty feet; and from the hill of Sentinella behind Talcahuano, at the height of 160 feet, he collected numerous shells, packed together close beneath the surface in black earth, consisting of two species of Mytilus, two of Crepidula, one of Concholepas, of Fissurella, Venus, Mactra, Turbo, Monoceros, and the *Balanus psittacus.* These shells were bleached, and within some of the Balani other Balani were growing, showing that they must have long lain dead in the sea. The above species I compared with living ones from the bay, and found them identical; but having since lost the specimens, I cannot give their names: this is of little importance, as Mr. Broderip has examined a similar collection, made during Captain Beechey's expedition, and ascertained that they consisted of ten recent species, associated with fragments of Echini, crabs, and Flustræ; some of these remains were estimated by Lieutenant Belcher to lie at the height of nearly a thousand feet above the level of the sea.[8] In some places round the bay, Mr. Kent observed that there were beds formed exclusively of the *Mytilus Chiloensis*: this species now lives in parts never uncovered by the tides. At considerable heights, Mr. Kent found only a few shells; but from the summit of one hill, 625 feet high, he brought me specimens of the Concholepas, *Mytilus Chiloensis*, and a Turbo. These shells were softer and more brittle than those from the height of 164 feet; and these latter had obviously a much more ancient appearance than the same species from the height of only twenty feet.

> [8] "Zoology of Captain Beechey's Voyage," p. 162.

Coast north of Concepcion.—The first point examined was at the mouth of the Rapel (160 miles north of Concepcion and sixty miles south of Valparaiso), where I observed a few shells at the height of 100 feet, and some barnacles adhering to the rocks three or four feet above the highest tides: M. Gay[9] found here recent shells at the distance of two leagues from the shore. Inland there are some wide, gravel-capped plains, intersected by many broad, flat-bottomed valleys (now carrying insignificant streamlets), with their sides cut into successive wall-like escarpments, rising one above another, and in many places, according to M. Gay, worn into caves. The one cave (C. del Obispo) which I examined, resembled those formed on many sea-coasts, with its bottom filled with shingle. These inland plains, instead of sloping towards the coast, are inclined in an opposite direction towards the Cordillera, like the successively rising terraces on the inland or eastern side of Chiloe: some points of granite, which project through the plains near the coast, no doubt once formed a chain of outlying islands, on the inland shores of which the plains were accumulated. At Bucalemu, a few miles northward of the Rapel, I observed at the foot, and on the summit-edge of a plain, ten miles from the coast, many recent shells, mostly comminuted, but some perfect. There were, also, many at the bottom of the great valley of the Maypu. At San Antonio, shells are said to be collected and burnt for lime. At the bottom of a great ravine (Quebrada Onda, on the road to

Casa Blanca), at the distance of several miles from the coast, I noticed a considerable bed, composed exclusively of *Mesodesma donaciforme*, Desh., lying on a bed of muddy sand: this shell now lives associated together in great numbers, on tidal-flats on the coast of Chile.

[9] “Annales des Scienc. Nat.,” Avril 1833.

Valparaiso.

During two successive years I carefully examined, part of the time in company with Mr. Alison, into all the facts connected with the recent elevation of this neighbourhood. In very many parts a beach of broken shells, about fourteen or fifteen feet above high-water mark, may be observed; and at this level the coast-rocks, where precipitous, are corroded in a band. At one spot, Mr. Alison, by removing some birds’ dung, found at this same level barnacles adhering to the rocks. For several miles southward of the bay, almost every flat little headland, between the heights of 60 and 230 feet (measured by the barometer), is smoothly coated by a thick mass of comminuted shells, of the same species, and apparently in the same proportional numbers with those existing in the adjoining sea. The Concholepas is much the most abundant, and the best preserved shell; but I extracted perfectly preserved specimens of the *Fissurella biradiata*, a Trochus and Balanus (both well-known, but according to Mr. Sowerby yet unnamed) and parts of the *Mytilus Chiloensis.* Most of these shells, as well as an encrusting Nullipora, partially retain their colour; but they are brittle, and often stained red from the underlying brecciated mass of primary rocks; some are packed together, either in black or reddish moulds; some lie loose on the bare rocky surfaces. The total number of these shells is immense; they are less numerous, though still far from rare, up a height of 1,000 feet above the sea. On the summit of a hill, measured 557 feet, there was a small horizontal band of comminuted shells, of which *many* consisted (and likewise from lesser heights) of very young and small specimens of the still living Concholepas, Trochus, Patellæ, Crepidulæ, and of *Mytilus Magellanicus* (?):[10] several of these shells were under a quarter of an inch in their greatest diameter. My attention was called to this circumstance by a native fisherman, whom I took to look at these shell-beds; and he ridiculed the notion of such small shells having been brought up for food; nor could some of the species have adhered when alive to other larger shells. On another hill, some miles distant, and 648 feet high, I found shells of the Concholepas and Trochus, perfect, though very old, with fragments of *Mytilus Chiloensis*, all embedded in reddish-brown mould: I also found these same species, with fragments of an Echinus and of *Balanus psittacus*, on a hill 1,000 feet high. Above this height, shells became very rare, though on a hill 1,300 feet high,[11] I collected the Concholepas, Trochus, Fissurella, and a Patella. At these greater heights the shells are almost invariably embedded in mould, and sometimes are exposed only by tearing up bushes. These shells obviously had a very much more ancient appearance than those from the lesser heights; the apices of the Trochi were often worn down; the little holes made by burrowing animals were greatly enlarged; and the Concholepas was often perforated quite through, owing to the inner plates of shell having scaled off.

[10] Mr. Cuming informs me that he does not think this species identical with, though closely resembling, the true *M. Magellanicus* of the southern and eastern coast of South America; it lives abundantly on the coast of Chile.

[11] Measured by the barometer: the highest point in the range behind Valparaiso I found to be 1,626 feet above the level of the sea.

Many of these shells, as I have said, were packed in, and were quite filled with, blackish or reddish-brown earth, resting on the granitic detritus. I did not doubt until lately that this mould was of purely terrestrial origin, when with a microscope examining some of it from the inside of a Concholepas from the height of about one hundred feet, I found that it was in considerable part composed of minute fragments of the spines, mouth-bones, and shells of Echini, and of minute fragments, of chiefly very young Patellæ, Mytili, and other species. I found similar microscopical fragments in earth filling up the central orifices of some large Fissurellæ. This earth when crushed emits a sickly smell, precisely like that from garden-mould mixed with guano. The earth accidentally preserved within the shells, from the greater heights, has the same general appearance, but it is a little redder; it emits the same smell when rubbed, but I was unable to detect with certainty any marine remains in it. This earth resembles in general appearance, as before remarked, that capping the rocks of Quiriquina in the Bay of Concepcion, on which beds of sea-shells lay. I have, also, shown that the black, peaty soil, in which the shells at the height of 350 feet at Chiloe were packed, contained many minute fragments of marine animals. These facts appear to me interesting, as they show that soils, which would naturally be considered of purely terrestrial nature, may owe their origin in chief part to the sea.

Being well aware from what I have seen at Chiloe and in Tierra del Fuego, that vast quantities of shells are carried, during successive ages, far inland, where the inhabitants chiefly subsist on these productions, I am bound to state that at greater heights than 557 feet, where the number of very young and small shells proved that they had not been carried up for food, the only evidence of the shells having been naturally left by the sea, consists in their invariable and uniform appearance of extreme antiquity—in the distance of some of the places from the coast, in others being inaccessible from the nearest part of the beach, and in the absence of fresh water for men to drink—in the shells *not lying in heaps*,—and, lastly, in the close similarity of the soil in which they are embedded, to that which lower down can be unequivocally shown to be in great part formed from the debris of the sea animals.[12]

[12] In the "Proceedings of the Geolog. Soc.," vol. ii, p. 446, I have given a brief account of the upraised shells on the coast of Chile, and have there stated that the proofs of elevation are not satisfactory above the height of 230 feet. I had at that time unfortunately overlooked a separate page written during my second visit to Valparaiso, describing the shells now in my possession from the 557 feet hill; I had not then unpacked my collections, and had not reconsidered the obvious appearance of greater antiquity of the shells from the greater heights, nor had I at that time discovered the marine origin of the earth in which many of the shells are packed. Considering these facts, I do not now feel a shadow of doubt that the shells, at the height of 1,300 feet, have been upraised by natural causes into their present position.

With respect to the position in which the shells lie, I was repeatedly struck here, at Concepcion, and at other places, with the frequency of their occurrence on the summits and edges either of separate hills, or of little flat headlands often terminating precipitously over the sea. The several above-enumerated species of mollusca, which are found strewed on the surface of the land from a few feet above the level of the sea up to the height of 1,300 feet, all now live either on the beach, or at only a few fathoms' depth: Mr. Edmondston, in a letter to Professor E. Forbes, states that in dredging in the Bay of Valparaiso, he found the common species of Concholepas, Fissurella, Trochus, Monoceros, Chitons, etc., living in abundance from the beach to a depth of seven fathoms; and dead shells occurred only a few fathoms deeper. The common *Turritella cingulata* was dredged up living at even from ten to fifteen fathoms; but this is a species which I did not find here amongst the upraised shells. Considering this fact of the species being all littoral or sub-littoral, considering their occurrence at various heights, their vast numbers, and their generally comminuted state, there can be little doubt that they were left on successive beach-lines during a gradual elevation of the land. The presence, however, of so many whole and perfectly preserved shells appears at first a difficulty on this view, considering that the coast is exposed to the full force of an open ocean: but we may suppose, either that these shells were thrown during gales on flat ledges of rock just above the level of high-water mark, and that during the elevation of the land they are never again touched by the waves, or, that during earthquakes, such as those of 1822, 1835, and 1837, rocky reefs covered with marine-animals were it one blow uplifted above the future reach of the sea. This latter explanation is, perhaps, the most probable one with respect to the beds at Concepcion entirely composed of the *Mytilus Chiloensis*, a species which lives below the lowest tides; and likewise with respect to the great beds occurring both north and south of Valparaiso, of the *Mesodesma donaciforme*,—a shell which, as I am informed by Mr. Cuming, inhabits sandbanks at the level of the lowest tides. But even in the case of shells having the habits of this Mytilus and Mesodesma, beds of them, wherever the sea gently throws up sand or mud, and thus protects its own accumulations, might be upraised by the slowest movement, and yet remain undisturbed by the waves of each new beach-line.

It is worthy of remark, that nowhere near Valparaiso above the height of twenty feet, or rarely of fifty feet, I saw any lines of erosion on the solid rocks, or any beds of pebbles; this, I believe, may be accounted for by the disintegrating tendency of most of the rocks in this neighbourhood. Nor is the land here modelled into terraces: Mr. Alison, however, informs me, that on both sides of one narrow ravine, at the height of 300 feet above the sea, he found a succession of rather indistinct step-formed beaches, composed of broken shells, which together covered a space of about eighty feet vertical.

I can add nothing to the accounts already published of the elevation of the land at Valparaiso,[13] which accompanied the earthquake of 1822: but I heard it confidently asserted, that a sentinel on duty, immediately after the shock, saw a part of a fort, which previously was not within the line of his vision, and this would indicate that the uplifting was not horizontal: it would even appear from some facts collected by Mr. Alison, that only the eastern half of the bay was then elevated. Through the kindness of this same gentleman, I am able to give an interesting account of the changes of level, which have supervened here within historical periods: about the year 1680 a long sea-wall (or Prefil) was built, of which only a few fragments now remain; up to the year 1817, the sea often broke over it, and washed the houses on the opposite side of the road (where the prison now stands); and even in 1819, Mr. J. Martin remembers walking at the foot of this wall, and being often obliged to climb over it to escape the waves. There now stands (1834) on the seaward side of this wall, and between it and the beach, in one part a single row of houses, and in another part two rows with a street between them. This great extension of the beach in so short a time cannot be attributed simply to the accumulation of detritus; for a resident engineer measured for me the height between the lowest part of the wall visible, and the present beach-line at spring-tides, and the difference was eleven feet six inches. The church of S. Augustin is believed to have been built in 1614, and there is a tradition that the sea formerly flowed very near it; by levelling, its foundations were found to stand nineteen feet six inches above the highest beach-line; so that we see in a period of 220 years, the elevation cannot have been as much as nineteen feet six inches. From the facts given with respect to the sea-wall, and from the testimony of the elder inhabitants, it appears certain that the change in level began to be manifest about the year 1817. The only sudden elevation of which there is any record occurred in 1822, and this seems to have been less than three feet. Since that year, I was assured by several competent observers, that part of an old wreck, which is firmly embedded near the beach, has sensibly emerged; hence here, as at Chiloe, a slow rise of the land appears to be now in progress. It seems highly probable that the rocks which are corroded in a band at the height of fourteen feet above the sea were acted on during the period, when by tradition the base of S. Augustin church, now nineteen feet six inches above the highest water-mark, was occasionally washed by the waves.

[13] Dr. Meyen ("Reise um Erde," Th. I, s. 221) found in 1831 seaweed and other bodies still adhering to some rocks which during the shock of 1822 were lifted above the sea.

Valparaiso to Coquimbo.—For the first seventy-five miles north of Valparaiso I followed the coast-road, and throughout this space I observed innumerable masses of upraised shells. About Quintero there are immense accumulations (worked for lime) of the *Mesodesma donaciforme*, packed in sandy earth; they abound chiefly about fifteen feet above high-water, but shells are here found, according to Mr. Miers,[14] to a height of 500 feet, and at a distance of three leagues from the coast: I here noticed barnacles adhering to the rocks three or four feet above the highest tides. In the neighbourhood of Plazilla and Catapilco, at heights of between two hundred and three hundred feet, the number of comminuted shells, with some perfect ones, especially of the Mesodesma, packed in layers, was truly immense: the land at Plazilla had evidently existed as a bay, with abrupt rocky masses rising out of it, precisely like the islets in the broken bays now indenting this coast. On both sides of the rivers Ligua, Longotomo, Guachen, and Quilimari, there are plains of gravel about two hundred feet in height, in many parts absolutely covered with shells. Close to Conchalee, a gravel-plain is fronted by a lower and similar plain about sixty feet in height, and this again is separated from the beach by a wide tract of low land: the surfaces of all three plains or terraces were strewed with vast numbers of the Concholepas, Mesodesma, an existing Venus, and other still existing littoral shells. The two upper terraces closely resemble in miniature the plains of Patagonia; and like them are furrowed by dry, flat-bottomed, winding valleys. Northward of this place I turned inward; and therefore found no more shells: but the valleys of Chuapa, Illapel, and Limari, are bounded by gravel-capped plains, often including a lower terrace within. These plains send bay-like arms between and into the surrounding hills; and they are continuously united with other extensive gravel-capped plains, separating the coast mountain-ranges from the Cordillera.

> [14] "Travels in Chile," vol. i, pp. 395, 458. I received several similar accounts from the inhabitants, and was assured that there are many shells on the plain of Casa Blanca, between Valparaiso and Santiago, at the height of 800 feet.

Coquimbo.

A narrow fringe-like plain, gently inclined towards the sea, here extends for eleven miles along the coast, with arms stretching up between the coast-mountains, and likewise up the valley of Coquimbo: at its southern extremity it is directly connected with the plain of Limari, out of which hills abruptly rise like islets, and other hills project like headlands on a coast. The surface of the fringe-like plain appears level, but differs insensibly in height, and greatly in composition, in different parts.

At the mouth of the valley of Coquimbo, the surface consists wholly of gravel, and stands from 300 to 350 feet above the level of the sea, being about one hundred feet higher than in other parts. In these other and lower parts the superficial beds consist of calcareous matter, and rest on ancient tertiary deposits hereafter to be described. The uppermost calcareous layer is cream-coloured, compact, smooth-fractured, sub-stalactiform, and contains some sand, earthy matter, and recent shells. It lies on, and sends wedge-like veins into,[15] a much more friable, calcareous, tuff-like variety; and both rest on a mass about twenty feet in thickness, formed of fragments of recent shells, with a few whole ones, and with small pebbles firmly cemented together. This latter rock is called by the inhabitants *losa*, and is used for building: in many parts it is divided into strata, which dip at an angle of ten degrees seaward, and appear as if they had originally been heaped in successive layers (as may be seen on coral-reefs) on a steep beach. This stone is remarkable from being in parts entirely formed of empty, pellucid capsules or cells of calcareous matter, of the size of small seeds: a series of specimens unequivocally showed that all these capsules once contained minute rounded fragments of shells which have since been gradually dissolved by water percolating through the mass.[16]

> [15] In many respects this upper hard, and the underlying more friable, varieties, resemble the great superficial beds at King George's Sound in Australia, which I have described in my "Geological Observations on Volcanic Islands." There could be little doubt that the upper layers there have been hardened by the action of rain on the friable, calcareous matter, and that the whole mass has originated in the decay of minutely comminuted sea-shells and corals.

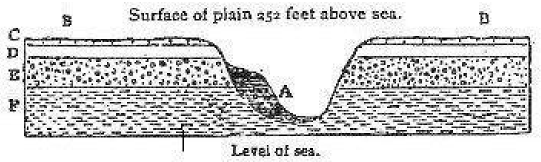
> [16] I have incidentally described this rock in the above work on Volcanic Islands.

The shells embedded in the calcareous beds forming the surface of this fringe-like plain, at the height of from 200 to 250 feet above the sea, consist of:—

1. Venus opaca.
2. Mulinia Byronensis.
3. Pecten purpuratus.
4. Mesodesma donaciforme.
5. Turritella cingulata.
6. Monoceros costatum.
7. Concholepas Peruviana.
8. Trochus (common Valparaiso species).
9. Calyptræa Byronensis.

Although these species are all recent, and are all found in the neighbouring sea, yet I was particularly struck with the difference in the proportional numbers of the several species, and of those now cast up on the present beach. I found only one specimen of the Concholepas, and the Pecten was very rare, though both these shells are now the commonest kinds, with the exception, perhaps, of the *Calyptræa radians*, of which I did not find one in the calcareous beds. I will not pretend to determine how far this difference in the proportional numbers depends on the age of the deposit, and how far on the difference in nature between the present sandy beaches and the calcareous bottom, on which the embedded shells must have lived.

No. 8
Section of plain of Coquimbo.



A. Stratified sand, with recent shells in same proportions as on the beach, half filling up a ravine.
B. Surface of plain, with scattered shells in nearly same proportions as on the beach.
C. Upper calcareous bed, } with recent shells, but not in same proportions as on the beach.
D. Lower calcareous sandy bed (Losa), }
E. Upper ferrugino-sandy old tertiary stratum, } with all, or nearly all, extinct shells.
F. Lower old tertiary stratum, }

On the bare surface of the calcareous plain, or in a thin covering of sand, there were lying, at a height from 200 to 252 feet, many recent shells, which had a much fresher appearance than the embedded ones: fragments of the Concholepas, and of the common Mytilus, still retaining a tinge of its colour, were numerous, and altogether there was manifestly a closer approach in proportional numbers to those now lying on the beach. In a mass of stratified, slightly agglutinated sand, which in some places covers up the lower half of the seaward escarpment of the plain, the included shells appeared to be in exactly the same proportional numbers with those on the beach. On one side of a steep-sided ravine, cutting through the plain behind Herradura Bay, I observed a narrow strip of stratified sand, containing similar shells in similar proportional numbers; a section of the ravine is represented in Diagram 8, which serves also to show the general composition of the plain. I mention this case of the ravine chiefly because without the evidence of the marine shells in the sand, any one would have supposed that it had been hollowed out by simple alluvial action.

The escarpment of the fringe-like plain, which stretches for eleven miles along the coast, is in some parts fronted by two or three narrow, step-formed terraces, one of which at Herradura Bay expands into a small plain. Its surface was there formed of gravel, cemented together by calcareous matter; and out of it I extracted the following recent shells, which are in a more perfect condition than those from the upper plain:—

1. Calyptræa radians.
2. Turritella cingulata.
3. Oliva Peruviana.
4. Murex labiosus, var.
5. Nassa (identical with a living species).
6. Solen Dombeiana.
7. Pecten purpuratus.
8. Venus Chilensis.
9. Amphidesma rugulosum. The small irregular wrinkles of the posterior part of this shell are rather stronger than in the recent specimens of this species from Coquimbo. (G. B. Sowerby.)
10. Balanus (identical with living species).

On the syenitic ridge, which forms the southern boundary of Herradura Bay and Plain, I found the Concholepas and *Turritella cingulata* (mostly in fragments), at the height of 242 feet above the sea. I could not have told that these shells had not formerly been brought up by man, if I had not found one very small mass of them cemented together in a friable calcareous tuff. I mention this fact more particularly, because I carefully looked, in many apparently favourable spots, at lesser heights on the side of this ridge, and could not find even the smallest fragment of a shell. This is only one instance out of many, proving that the absence of sea-shells on the surface, though in many respects inexplicable, is an argument of very little weight in opposition to other evidence on the recent elevation of the land. The highest point in this neighbourhood at which I found upraised shells of existing species was on an inland calcareous plain, at the height of 252 feet above the sea.

It would appear from Mr. Caldcleugh's researches,[17] that a rise has taken place here within the last century and a half; and as no sudden change of level has been observed during the not very severe earthquakes, which have occasionally occurred here, the rising has probably been slow, like that now, or quite lately, in progress at Chiloe and at Valparaiso: there are three well-known rocks, called the Pelicans, which in 1710, according to Feuillèe, were *à fleur d'eau*, but now are said to stand twelve feet above low-water mark: the spring-tides rise here only five feet. There is another rock, now nine feet above high-water mark, which in the time of Frezier and Feuillèe rose only five or six feet out of water. Mr. Caldcleugh, I may add, also shows (and I received similar accounts) that there has been a considerable decrease in the soundings during the last twelve years in the Bays of Coquimbo, Concepcion, Valparaiso, and Guasco; but as in these cases it is nearly impossible to distinguish between the accumulation of sediment and the upheavement of the bottom, I have not entered into any details.

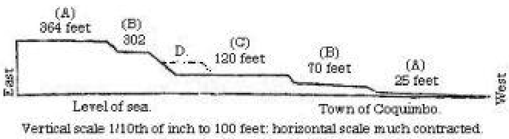
[17] "Proceedings of the Geological Society," vol. ii, p. 446.

Valley of Coquimbo.—The narrow coast-plain sends, as before stated, an arm, or more correctly a fringe, on both sides, but chiefly on the southern side, several miles up the valley. These fringes are worn into steps or terraces, which present a most remarkable appearance, and have been compared (though not very correctly) by Captain Basil Hall, to the parallel roads of Glen Roy in Scotland: their origin has been ably discussed by Mr. Lyell.[18] The first section which I will give (Figure 9), is not drawn across the valley, but in an east and west line at its mouth, where the step-formed terraces debouch and present their very gently inclined surfaces towards the Pacific.

[18] "Principles of Geology" (1st edit.), vol. iii, p. 131.

No. 9

East and west section through the terraces at Coquimbo, where they debouch from the valley, and front the sea.



The bottom plain (A) is about a mile in width, and rises quite insensibly from the beach to a height of twenty-five feet at the foot of the next plain; it is sandy, and abundantly strewed with shells.

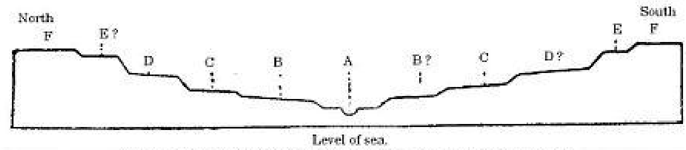
Plain or terrace B is of small extent, and is almost concealed by the houses of the town, as is likewise the escarpment of terrace C. On both sides of a ravine, two miles south of the town, there are two little terraces, one above the other, evidently corresponding with B and C; and on them marine remains of the species already enumerated were plentiful. Terrace E is very narrow, but quite distinct and level; a little southward of the town there were traces of a terrace D intermediate between E and C. Terrace F is part of the fringe-like plain, which stretches for the eleven miles along the coast; it is here composed of shingle, and is 100 feet higher than where composed of calcareous matter. This greater height is obviously due to the quantity of shingle, which at some former period has been brought down the great valley of Coquimbo.

Considering the many shells strewed over the terraces A, B, and C, and a few miles southward on the calcareous plain, which is continuously united with the upper step-like plain F, there cannot, I apprehend, be any doubt, that these six terraces have been formed by the action of the sea; and that their five escarpments mark so many periods of comparative rest in the elevatory movement, during which the sea wore into the land. The elevation between these periods may have been sudden and on *an average* not more than seventy-two feet each time, or it may have been gradual and insensibly slow. From the shells on the three lower terraces, and on the upper one, and I may add on the three gravel-capped terraces at Conchalee, being all littoral and sub-littoral species, and from the analogical facts given at Valparaiso, and lastly from the evidence of a slow rising lately or still in progress here, it appears to me far more probable that the movement has been slow. The existence of these successive escarpments, or old cliff-lines, is in another respect highly instructive, for they show periods of comparative rest in the elevatory movement, and of denudation, which would never even have been suspected from a close examination of many miles of coast southward of Coquimbo.

We come now to the terraces on the opposite sides of the east and west valley of Coquimbo: the section in figure No. 10 is taken in a north and south line across the valley at a point about three miles from the sea. The valley measured from the edges of the escarpments of the upper plain FF is about a mile in width; but from the bases of the bounding mountains it is from three to four miles wide. The terraces marked with an interrogative do not exist on that side of the valley, but are introduced merely to render the diagram more intelligible.

No. 10

North and south section across the valley of Coquimbo.



Vertical scale 1/10th of inch to 100 feet: horizontal scale much contracted.

Terraces marked with ? do not occur on that side of the valley, and are introduced only to make the diagram more intelligible. A river and bottom-plain of valley C, E, and F, on the south side of valley, are respectively, 197, 377, and 420 feet above the level of the sea.

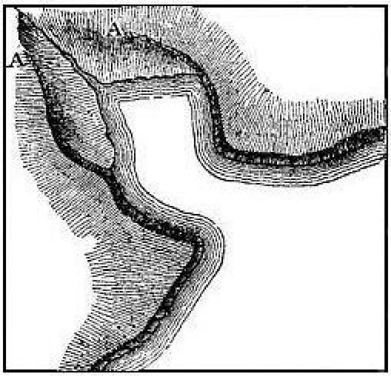
AA. The bottom of the valley, believed to be 100 feet above the sea: it is continuously united with the lowest plain A of figure No. 9.
B. This terrace higher up the valley expands considerably; seaward it is soon lost, its escarpment being united with that of C: it is not developed at all on the south side of the valley.
C. This terrace, like the last, is considerably expanded higher up the valley. These two terraces apparently correspond with B and C of figure No. 9.
D is not well developed in the line of this section; but seaward it expands into a plain: it is not present on the south side of the valley; but it is met with, as stated under the former section, a little south of the town.
E is well developed on the south side, but absent on the north side of the valley: though not continuously united with E of figure No. 9, it apparently corresponds with it.
F. This is the surface-plain, and is continuously united with that which stretches like a fringe along the coast. In ascending the valley it gradually becomes narrower, and is at last, at the distance of about ten miles from the sea, reduced to a row of flat-topped patches on the sides of the mountains. None of the lower terraces extend so far up the valley.

These five terraces are formed of shingle and sand; three of them, as marked by Captain B. Hall (namely, B, C, and F), are much more conspicuous than the others. From the marine remains copiously strewed at the mouth of the valley on the lower terraces, and southward of the town on the upper one, they are, as before remarked, undoubtedly of marine origin; but within the valley, and this fact well deserves notice, at a distance of from only a mile and a half to three or four miles from the sea, I could not find even a fragment of a shell.

On the inclination of the terraces of Coquimbo, and on the upper and basal edges of their escarpments not being horizontal.—The surfaces of these terraces slope in a slight degree, as shown by the two last sections taken conjointly, both towards the centre of the valley, and seawards towards its mouth. This double or diagonal inclination, which is not the same in the several terraces, is, as we shall immediately see, of simple explanation. There are, however, some other points which at first appear by no means obvious,—namely, first, that each terrace, taken in its whole breadth from the summit-edge of one escarpment to the base of that above it, and followed up the valley, is not horizontal; nor have the several terraces, when followed up the valley, all the same inclination; thus I found the terraces C, E, and F, measured at a point about two miles from the mouth of the valley, stood severally between fifty-six to seventy-seven feet higher than at the mouth. Again, if we look to any one line of cliff or escarpment, neither its summit-edge nor its base is horizontal. On the theory of the terraces having been formed during a slow and equable rise of the land, with as many intervals of rest as there are escarpments, it appears at first very surprising that horizontal lines of some kind should not have been left on the land.

The direction of the diagonal inclination in the different terraces being different,—in some being directed more towards the middle of the valley, in others more towards its mouth,—naturally follows on the view of each terrace, being an accumulation of successive beach-lines round bays, which must have been of different forms and sizes when the land stood at different levels: for if we look to the actual beach of a narrow creek, its slope is directed towards the middle; whereas, in an open bay, or slight concavity on a coast, the slope is towards the mouth, that is, almost directly seaward; hence as a bay alters in form and size, so will the direction of the inclination of its successive beaches become changed.

No. 11



If it were possible to trace any one of the many beach-lines, composing each sloping terrace, it would of course be horizontal; but the only lines of demarcation are the summit and basal edges of the escarpments. Now the summit-edge of one of these escarpments marks the furthest line or point to which the sea has cut into a mass of gravel sloping seaward; and as the sea will generally have greater power at the mouth than at the protected head of the bay, so will the escarpment at the mouth be cut deeper into the land, and its summit-edge be higher; consequently it will not be horizontal. With respect to the basal or lower edges of the escarpments, from picturing in one's mind ancient bays *entirely* surrounded at successive periods by cliff-formed shores, one's first impression is that they at least necessarily must be horizontal, if the elevation has been horizontal. But here is a fallacy: for after the sea has, during a cessation of the elevation, worn cliffs all round the shores of a bay, when the movement recommences, and especially if it recommences slowly, it might well happen that, at the exposed mouth of the bay, the waves might continue for some time wearing into the land, whilst in the protected and upper parts successive beach-lines might be accumulating in a sloping surface or terrace at the foot of the cliffs which had been lately reached: hence, supposing the whole line of escarpment to be finally uplifted above the reach of the sea, its basal line or foot near the mouth will run at a lower level than in the upper and protected parts of the bay; consequently this basal line will not be horizontal. And it has already been shown that the summit-edges of each escarpment will generally be higher near the mouth (from the seaward sloping land being there most exposed and cut into) than near the head of the bay; therefore the total height of the escarpments will be greatest near the mouth; and further up the old bay or valley they will on both sides generally thin out and die away: I have observed this thinning out of the successive escarpment at other places besides Coquimbo; and for a long time I was quite unable to understand its meaning. The rude diagram in Figure 11 will perhaps render what I mean more intelligible; it represents a bay in a district which has begun slowly rising. Before the movement commenced, it is supposed that the waves had been enabled to eat into the land and form cliffs, as far up, but with gradually diminishing power, as the points AA: after the movement had commenced and gone on for a little time, the sea is supposed still to have retained the power, at the exposed mouth of the bay, of cutting down and into the land as it slowly emerged; but in the upper parts of the bay it is supposed soon to have lost this power, owing to the more protected situation and to the quantity of detritus brought down by the river; consequently low land was there accumulated. As this low land was formed during a slow elevatory movement, its surface will gently slope upwards from the beach on all sides. Now, let us imagine the bay, not to make the diagram more complicated, suddenly converted into a valley: the basal line of the cliffs will of course be horizontal, as far as the beach is now seen extending in the diagram; but in the upper part of the valley, this line will be higher, the level of the district having been raised whilst the low land was accumulating at the foot of the inland cliffs. If, instead of the bay in the diagram being suddenly converted into a valley, we suppose with much more probability it to be upraised slowly, then the waves in the upper parts of the bay will continue very gradually to fail to reach the cliffs, which are now in the diagram represented as washed by the sea, and which, consequently, will be left standing higher and higher above its level; whilst at the still exposed mouth, it might well happen that the waves might be enabled to cut deeper and deeper, both down and into the cliffs, as the land slowly rose.

The greater or lesser destroying power of the waves at the mouths of successive bays, comparatively with this same power in their upper and protected parts, will vary as the bays become changed in form and size, and therefore at different levels, at their mouths and heads, more or less of the surfaces between the escarpments (that is, the accumulated beach-lines or terraces) will be left undestroyed: from what has gone before we can see that, according as the elevatory movements after each cessation recommence more or less slowly, according to the amount of detritus delivered by the river at the heads of the successive bays, and according to the degree of protection afforded by their altered forms, so will a greater or less extent of terrace be accumulated in the upper part, to which there will be no surface at a corresponding level at the mouth: hence we can perceive why no one terrace, taken in its whole breadth and followed up the valley, is horizontal, though each separate beach-line must have been so; and why the inclination of the several terraces, both transversely, and longitudinally up the valley, is not alike.

I have entered into this case in some detail, for I was long perplexed (and others have felt the same difficulty) in understanding how, on the idea of an equable elevation with the sea at intervals eating into the land, it came that neither the terraces nor the upper nor lower edges of the escarpments were horizontal. Along lines of coast, even of great lengths, such as that of Patagonia, if they are nearly uniformly exposed, the corroding power of the waves will be checked and conquered by the elevatory movement, as often as it recommences, at about the same period; and hence the terraces, or accumulated beach-lines, will commence being formed at nearly the same levels: at each succeeding period of rest, they will, also, be eaten into at nearly the same rate, and consequently there will be a much closer coincidence in their levels and inclinations, than in the terraces and escarpments formed round bays with their different parts very differently exposed to the action of the sea. It is only where the waves are enabled, after a long lapse of time, slowly to corrode hard rocks, or to throw up, owing to the supply of sediment being small and to the surface being steeply inclined, a narrow beach or mound, that we can expect, as at Glen Roy in Scotland,[19] a distinct line marking an old sea-level, and which will be strictly horizontal, if the subsequent elevatory movements have been so: for in these cases no discernible effects will be produced, except during the long intervening periods of rest; whereas in the case of step-formed coasts, such as those described in this and the preceding chapter, the terraces themselves are accumulated during the slow elevatory process, the accumulation commencing sooner in protected than in exposed situations, and sooner where there is copious supply of detritus than where there is little; on the other hand, the steps or escarpments are formed during the stationary periods, and are more deeply cut down and into the coast-land in exposed than in protected situations;—the cutting action, moreover, being prolonged in the most exposed parts, both during the beginning and ending, if slow, of the upward movement.

[19] “Philosophical Transactions,” 1839, p. 39.

Although in the foregoing discussion I have assumed the elevation to have been horizontal, it may be suspected, from the considerable seaward slope of the terraces, both up the valley of S. Cruz and up that of Coquimbo, that the rising has been greater inland than nearer the coast. There is reason to believe,[20] from the effects produced on the water-course of a mill during the earthquake of 1822 in Chile, that the upheaval one mile inland was nearly double, namely, between five and seven feet, to what it was on the Pacific. We know, also, from the admirable researches of M. Bravais,[21] that in Scandinavia the ancient sea-beaches gently slope from the interior mountain-ranges towards the coast, and that they are not parallel one to the other showing that the proportional difference in the amount of elevation on the coast and in the interior, varied at different periods.

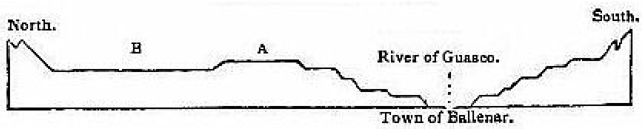
[20] Mr. Place in the *Quarterly Journal of Science,* 1824, vol. xvii, p. 42.

[21] “Voyages de la Comm. du Nord,” etc., also “Comptes Rendus,” Oct. 1842.

Coquimbo to Guasco.—In this distance of ninety miles, I found in almost every part marine shells up to a height of apparently from two hundred to three hundred feet. The desert plain near Choros is thus covered; it is bounded by the escarpment of a higher plain, consisting of pale-coloured, earthy, calcareous stone, like that of Coquimbo, with the same recent shells embedded in it. In the valley of Chaneral, a similar bed occurs in which, differently from that of Coquimbo, I observed many shells of the Concholepas: near Guasco the same calcareous bed is likewise met with.

In the valley of Guasco, the step-formed terraces of gravel are displaced in a more striking manner than at any other point. I followed the valley for thirty-seven miles (as reckoned by the inhabitants) from the coast to Ballenar; in nearly the whole of this distance, five grand terraces, running at corresponding heights on both sides of the broad valley, are more conspicuous than the three best-developed ones at Coquimbo. They give to the landscape the most singular and formal aspect; and when the clouds hung low, hiding the neighbouring mountains, the valley resembled in the most striking manner that of Santa Cruz. The whole thickness of these terraces or plains seems composed of gravel, rather firmly aggregated together, with occasional parting seams of clay: the pebbles on the upper plain are often whitewashed with an aluminous substance, as in Patagonia. Near the coast I observed many sea-shells on the lower plains. At Freyrina (twelve miles up the valley), there are six terraces beside the bottom-surface of the valley: the two lower ones are here only from two hundred to three hundred yards in width, but higher up the valley they expand into plains; the third terrace is generally narrow; the fourth I saw only in one place, but there it was distinct for the length of a mile; the fifth is very broad; the sixth is the summit-plain, which expands inland into a great basin. Not having a barometer with me, I did not ascertain the height of these plains, but they appeared considerably higher than those at Coquimbo. Their width varies much, sometimes being very broad, and sometimes contracting into mere fringes of separate flat-topped projections, and then quite disappearing: at the one spot, where the fourth terrace was visible, the whole six terraces were cut off for a short space by one single bold escarpment. Near Ballenar (thirty-seven miles from the mouth of the river), the valley between the summit-edges of the highest escarpments is several miles in width, and the five terraces on both sides are broadly developed: the highest cannot be less than six hundred feet above the bed of the river, which itself must, I conceive, be some hundred feet above the sea.

No. 12
North and south section across the valley of Guasco, and of a plain north of it.



On the northern side of the valley the summit-plain of gravel (A) has two escarpments, one facing the valley, and the other a great basin-like plain (B), which stretches for several leagues northward. This narrow plain (A) with the double escarpment, evidently once formed a spit or promontory of gravel, projecting into and dividing two great bays, and subsequently was worn on both sides into steep cliffs. Whether the several escarpments in this valley were formed during the same stationary periods with those of Coquimbo, I will not pretend to conjecture; but if so the intervening and subsequent elevatory movements must have been here much more energetic, for these plains certainly stand at a much higher level than do those of Coquimbo.

Copiapo.—From Guasco to Copiapo, I followed the road near the foot of the Cordillera, and therefore saw no upraised remains. At the mouth, however, of the valley of Copiapo there is a plain, estimated by Meyen[22] between fifty and seventy feet in height, of which the upper part consists chiefly of gravel, abounding with recent shells, chiefly of the Concholepas, *Venus Dombeyi*, and *Calyptræa trochiformis.* A little inland, on a plain estimated by myself at nearly three hundred feet, the upper stratum was formed of broken shells and sand cemented by white calcareous matter, and abounding with embedded recent shells, of which the *Mulinia Byronensis* and *Pecten purpuratus* were the most numerous. The lower plain stretches for some miles southward, and for an unknown distance northward, but not far up the valley; its seaward face, according to Meyen, is worn into caves above the level of the present beach. The valley of Copiapo is much less steeply inclined and less direct in its course than any other valley which I saw in Chile; and its bottom does not generally consist of gravel: there are no step-formed terraces in it, except at one spot near the mouth of the great lateral valley of the Despoblado where there are only two, one above the other: lower down the valley, in one place I observed that the solid rock had been cut into the shape of a beach, and was smoothed over with shingle.

[22] "Reise um die Erde," Th. I, s. 372, *et seq.*

Northward of Copiapo, in lat. 26° S., the old voyager Wafer[23] found immense numbers of sea-shells some miles from the coast. At Cobija (lat. 22° 34′) M. d'Orbigny observed beds of gravel and broken shells, containing ten species of recent shells; he also found, on projecting points of porphyry, at a height of 300 feet, shells of Concholepas, Chiton, Calyptræa, Fissurella, and Patella, still attached to the spots on which they had lived. M. d'Orbigny argues from this fact, that the elevation must have been great and sudden:[24] to me it appears far more probable that the movement was gradual, with small starts as during the earthquakes of 1822 and 1835, by which whole beds of shells attached to the rocks were lifted above the subsequent reach of the waves. M. d'Orbigny also found rolled pebbles extending up the mountain to a height of at least six hundred feet. At Iquique (lat. 20° 12′ S.), in a great accumulation of sand, at a height estimated between one hundred and fifty and two hundred feet, I observed many large sea-shells which I thought could not have been blown up by the wind to that height. Mr. J. H. Blake has lately[25] described these shells: he states that "inland toward the mountains they form a compact uniform bed, scarcely a trace of the original shells being discernible; but as we approach the shore, the forms become gradually more distinct till we meet with the living shells on the coast." This interesting observation, showing by the gradual decay of the shells how slowly and gradually the coast must have been uplifted, we shall presently see fully confirmed at Lima. At Arica (lat. 18° 28′), M. d'Orbigny[26] found a great range of sand-dunes, fourteen leagues in length, stretching towards Tacna, including recent shells and bones of Cetacea, and reaching up to a height of 300 feet above the sea. Lieutenant Freyer has given some more precise facts: he states[27] that the Morro of Arica is about four hundred feet high; it is worn into obscure terraces, on the bare rock of which he found Balini and Milleporæ adhering. At the height of between twenty and thirty feet the shells and corals were in a quite fresh state, but at fifty feet they were much abraded; there were, however, traces of organic remains at greater heights. On the road from Tacna to Arequipa, between Loquimbo and Moquegua, Mr. M. Hamilton[28] found numerous recent sea shells in sand, at a considerable distance from the sea.

[23] Burnett's "Collection of Voyages," vol. iv, p. 193.

[24] "Voyage, Part Géolog.," p. 94. M. d'Orbigny (p. 98), in summing up, says: "S'il est certain (as he believes) que tous les terrains en pente, compris entre la mer et les montagnes sont l'ancien rivage de la mer, on doit supposer, pour l'ensemble, un exhaussement que ce ne serait pas moindre de deux cent mètres; il faudrait supposer encore que ce soulèvement n'a point été graduel; . . . mais qu'il résulterait d'une seule et même cause fortuite," etc. Now, on this view, when the sea was forming the beach at the foot of the mountains, many shells of Concholepas, Chiton, Calyptræa, Fissurella, and Patella (which are known to live close to the beach), were attached to rocks at a depth of 300 feet, and at a depth of 600 feet several of these same shells were accumulating in great numbers in horizontal beds. From what I have myself seen in dredging, I believe this to be improbable in the highest degree, if not impossible; and I think everyone who has read Professor E. Forbes's excellent researches on the subject, will without hesitation agree in this conclusion.

[25] *Silliman's Amer. Journ. of Science,* vol. xliv, p. 2.

[26] "Voyage," etc., p. 101.

[27] In a letter to Mr. Lyell, "Geolog. Proc.," vol. ii, p. 179.

[28] *Edin. New Phil. Journ.,* vol. xxx, p. 155.

Lima.

Northward of Arica, I know nothing of the coast for about a space of five degrees of latitude; but near Callao, the port of Lima, there is abundant and very curious evidence of the elevation of the land. The island of San Lorenzo is upwards of one thousand feet high; the basset edges of the strata composing the lower part are worn into three obscure, narrow, sloping steps or ledges, which can be seen only when standing on them: they probably resemble those described by Lieutenant Freyer at Arica. The surface of the lower ledge, which extends from a low cliff overhanging the sea to the foot of the next upper escarpment, is covered by an enormous accumulation of recent shells.[29] The bed is level, and in some parts more than two feet in thickness; I traced it over a space of one mile in length, and heard of it in other places: the uppermost part is eighty-five feet by the barometer above high-water mark. The shells are packed together, but not stratified: they are mingled with earth and stones, and are generally covered by a few inches of detritus; they rest on a mass of nearly angular fragments of the underlying sandstone, sometimes cemented together by common salt. I collected eighteen species of shells of all ages and sizes. Several of the univalves had evidently long lain dead at the bottom of the sea, for their *insides* were incrusted with Balani and Serpulæ. All, according to Mr. G.B. Sowerby, are recent species: they consist of:—

1. Mytilus Magellanicus: same as that found at Valparaiso, and there stated to be probably distinct from the true *M. Magellanicus* of the east coast.
2. Venus costellata, Sowerby "Zoological Proceedings."
3. Pecten purpuratus, Lam.
4. Chama, probably echinulata, Brod.
5. Calyptræa Byronensis, Gray.
6. Calyptræa radians (Trochus, Lam.)
7. Fissurella affinis, Gray.
8. Fissurella biradiata, Trembly.
9. Purpura chocolatta, Duclos.
10. Purpura Peruviana, Gray.
11. Purpura labiata, Gray.
12. Purpura buxea (Murex, Brod.).
13. Concholepas Peruviana.
14. Nassa, related to reticulata.
15. Triton rudis, Brod.
16. Trochus, not yet described, but well-known and very common.
17. and 18. Balanus, two species, both common on the coast.

[29] M. Chevalier, in the "Voyage of the *Bonite*," observed these shells; but his specimens were lost.—"L'Institut," 1838, p. 151.

These upraised shells appear to be nearly in the same proportional numbers—with the exception of the Crepidulæ being more numerous—with those on the existing beach. The state of preservation of the different species differed much; but most of them were much corroded, brittle, and bleached: the upper and lower surfaces of the Concholepas had generally quite scaled off: some of the Trochi and Fissurellæ still partially retain their colours. It is remarkable that these shells, taken all together, have fully as ancient an appearance, although the extremely arid climate appears highly favourable for their preservation, as those from 1,300 feet at Valparaiso, and certainly a more ancient appearance than those from five to six hundred feet from Valparaiso and Concepcion; at which places I have seen grass and other vegetables actually growing out of the shells. Many of the univalves here at San Lorenzo were filled with, and united together by, pure salt, probably left by the evaporation of the sea-spray, as the land slowly emerged.[30] On the highest parts of the ledge, small fragments of the shells were mingled with, and evidently in process of reduction into, a yellowish-white, soft, calcareous powder, tasting strongly of salt, and in some places as fine as prepared medicinal chalk.

[30] The underlying sandstone contains true layers of salt; so that the salt may possibly have come from the beds in the higher parts of the island; but I think more probably from the sea-spray. It is generally asserted that rain never falls on the coast of Peru; but this is not quite accurate; for, on several days, during our visit, the so-called Peruvian dew fell in sufficient quantity to make the streets muddy, and it would certainly have washed so deliquescent a substance as salt into the soil. I state this because M. d'Orbigny, in discussing an analogous subject, supposes that I had forgotten that it never rains on this whole line of coast. See Ulloa's "Voyage" (vol. ii, Eng. Trans., p. 67) for an account of the muddy streets of Lima, and on the continuance of the mists during the whole winter. Rain, also, falls at rare intervals even in the driest districts, as, for instance, during forty days, in 1726, at Chocope (7° 46′);

this rain entirely ruined ("Ulloa," etc., p. 18) the mud houses of the inhabitants.

Fossil-remains of human art.—In the midst of these shells on San Lorenzo, I found light corallines, the horny ovule-cases of Mollusca, roots of seaweed,[31] bones of birds, the heads of Indian corn and other vegetable matter, a piece of woven rushes, and another of nearly decayed *cotton* string. I extracted these remains by digging a hole, on a level spot; and they had all indisputably been embedded with the shells. I compared the plaited rush, the *cotton* string, and Indian corn, at the house of an antiquary, with similar objects, taken from the Huacas or burial-grounds of the ancient Peruvians, and they were undistinguishable; it should be observed that the Peruvians used string only of cotton. The small quantity of sand or gravel with the shells, the absence of large stones, the width and thickness of the bed, and the time requisite for a ledge to be cut into the sandstone, all show that these remains were not thrown high up by an earthquake-wave: on the other hand, these facts, together with the number of dead shells, and of floating objects, both marine and terrestrial, both natural and human, render it almost certain that they were accumulated on a true beach, since upraised eighty-five feet, and upraised this much since *Indian man inhabited Peru.* The elevation may have been, either by several small sudden starts, or quite gradual; in this latter case the unrolled shells having been thrown up during gales beyond the reach of the waves which afterwards broke on the slowly emerging land. I have made these remarks, chiefly because I was at first surprised at the complete difference in nature, between this broad, smooth, upraised bed of shells, and the present shingle-beach at the foot of the low sandstone-cliffs; but a beach formed, when the sea is cutting into the land, as is shown now to be the case by the low bare sandstone-cliffs, ought not to be compared with a beach accumulated on a gently inclined rocky surface, at a period when the sea (probably owing to the elevatory movement in process) was not able to eat into the land. With respect to the mass of nearly angular, salt-cemented fragments of sandstone, which lie under the shells, and which are so unlike the materials of an ordinary sea-beach; I think it probable after having seen the remarkable effects[32] of the earthquake of 1835, in absolutely shattering as if by gunpowder the *surface* of the primary rocks near Concepcion, that a smooth bare surface of stone was left by the sea covered by the shelly mass, and that afterwards when upraised, it was superficially shattered by the severe shocks so often experienced here.

[31] Mr. Smith of Jordan Hill found pieces of seaweed in an upraised pleistocene deposit in Scotland. See his admirable Paper in the *Edin. New Phil. Journal,* vol. xxv, p. 384.

[32] I have described this in my "Journal of Researches," p. 303, 2nd edit.

The very low land surrounding the town of Callao, is to the south joined by an obscure escarpment to a higher plain (south of Bella Vista), which stretches along the coast for a length of about eight miles. This plain appears to the eye quite level; but the sea-cliffs show that its height varies (as far as I could estimate) from seventy to one hundred and twenty feet. It is composed of thin, sometimes waving, beds of clay, often of bright red and yellow colours, of layers of impure sand, and in one part with a great stratified mass of granitic pebbles. These beds are capped by a remarkable mass, varying from two to six feet in thickness, of reddish loam or mud, containing many scattered and broken fragments of recent marine shells, sometimes though rarely single large round pebble, more frequently short irregular layers of fine gravel, and very many pieces of red coarse earthenware, which from their curvatures must once have formed parts of large vessels. The earthenware is of Indian manufacture; and I found exactly similar pieces accidentally included within the bricks, of which the neighbouring ancient Peruvian burial-mounds are built. These fragments abounded in such numbers in certain spots, that it appeared as if waggon-loads of earthenware had been smashed to pieces. The broken sea-shells and pottery are strewed both on the surface, and throughout the whole thickness of this upper loamy mass. I found them wherever I examined the cliffs, for a space of between two and three miles, and for half a mile inland; and there can be little doubt that this same bed extends with a smooth surface several miles further over the entire plain. Besides the little included irregular layers of small pebbles, there are occasionally very obscure traces of stratification.

At one of the highest parts of the cliff, estimated 120 feet above the sea, where a little ravine came down, there were two sections, at right angles to each other, of the floor of a shed or building. In both sections or faces, two rows, one over the other, of large round stones could be distinctly seen; they were packed close together on an artificial layer of sand two inches thick, which had been placed on the natural clay-beds; the round stones were covered by three feet in thickness of the loam with broken sea-shells and pottery. Hence, before this widely spread-out bed of loam was deposited, it is certain that the plain was inhabited; and it is probable, from the broken vessels being so much more abundant in certain spots than in others, and from the underlying clay being fitted for their manufacture, that the kilns stood here.

The smoothness and wide extent of the plain, the bulk of matter deposited, and the obscure traces of stratification seem to indicate that the loam was deposited under water; on the other hand, the presence of sea-shells, their broken state, the pebbles of various sizes, and the artificial floor of round stones, almost prove that it must have originated in a rush of water from the sea over the land. The height of the plain, namely, 120 feet, renders it improbable that an earthquake-wave, vast as some have here been, could have broken over the surface at its present level; but when the land stood eighty-five feet lower, at the period when the shells were thrown up on the ledge at S. Lorenzo, and when as we know man inhabited this district, such an event might well have occurred; and if we may further suppose, that the plain was at that time converted into a temporary lake, as actually occurred, during the earthquakes of 1713 and 1746, in the case of the low land round Callao owing to its being encircled by a high shingle-beach, all the appearances above described will be perfectly explained. I must add, that at a lower level near the point where the present low land round Callao joins the higher plain, there are appearances of two distinct deposits both apparently formed by debacles: in the upper one, a horse's tooth and a dog's jaw were embedded; so that both must have been formed after the settlement of the Spaniards: according to Acosta, the earthquake-wave of 1586 rose eighty-four feet.

The inhabitants of Callao do not believe, as far as I could ascertain, that any change in level is now in progress. The great fragments of brickwork, which it is asserted can be seen at the bottom of the sea, and which have been adduced as a proof of a late subsidence, are, as I am informed by Mr. Gill, a resident engineer, loose fragments; this is probable, for I found on the beach, and not near the remains of any building, masses of brickwork, three and four feet square, which had been washed into their present places, and smoothed over with shingle during the earthquake of 1746. The spit of land, on which the ruins of *Old* Callao stand, is so extremely low and narrow, that it is improbable in the highest degree that a town should have been founded on it in its present state; and I have lately heard[33] that M. Tschudi has come to the conclusion, from a comparison of old with modern charts, that the coast both south and north of Callao has subsided. I have shown that the island of San Lorenzo has been upraised eighty-five feet since the Peruvians inhabited this country; and whatever may have been the amount of recent subsidence, by so much more must the elevation have exceeded the eighty-five feet. In several places[34] in this neighbourhood, marks of sea-action have been observed: Ulloa gives a detailed account of such appearances at a point five leagues northward of Callao: Mr. Cruikshank found near Lima successive lines of sea-cliffs, with rounded blocks at their bases, at a height of 700 feet above the present level of the sea.

[33] I am indebted for this fact to Dr. E. Dieffenbach. I may add that there is a tradition, that the islands of San Lorenzo and Fronton were once joined, and that the channel between San Lorenzo and the mainland, now above two miles in width, was so narrow that cattle used to swim over.

[34] "Observaciones sobre el Clima del Lima" par Dr. H. Unanùe, p. 4.—Ulloa's "Voyage," vol. ii, Eng. Trans., p. 97.—For Mr. Cruikshank's observations, see Mr. Lyell's "Principles of Geology" (1st edition) vol. iii, p. 130.

On the decay of upraised sea-shells.—I have stated that many of the shells on the lower inclined ledge or terrace of San Lorenzo are corroded in a peculiar manner, and that they have a much more ancient appearance than the same species at considerably greater heights on the coast of Chile. I have, also, stated that these shells in the upper part of the ledge, at the height of eighty-five feet above the sea, are falling, and in some parts are quite changed into a fine, soft, saline, calcareous powder. The finest part of this powder has been analysed for me, at the request of Sir H. De la Beche, by the kindness of Mr. Trenham Reeks of the Museum of Economic Geology; it consists of carbonate of lime in abundance, of sulphate and muriate of lime, and of muriate and sulphate of soda. The carbonate of lime is obviously derived from the shells; and common salt is so abundant in parts of the bed, that, as before remarked, the univalves are often filled with it. The sulphate of lime may have been derived, as has probably the common salt, from the evaporation of the sea-spray, during the emergence of the land; for sulphate of lime is now copiously deposited from the spray on the shores of Ascension.[35] The other saline bodies may perhaps have been partially thus derived, but chiefly, as I conclude from the following facts, through a different means.

[35] See "Volcanic Islands," etc., by the Author.

On most parts of the second ledge or old sea-beach, at a height of 170 feet, there is a layer of white powder of variable thickness, as much in some parts as two inches, lying on the angular, salt-cemented fragments of sandstone and under about four inches of earth, which powder, from its close resemblance in nature to the upper and most decayed parts of the shelly mass, I can hardly doubt originally existed as a bed of shells, now much collapsed and quite disintegrated. I could not discover with the microscope a trace of organic structure in it; but its chemical constituents, according to Mr. Reeks, are the same as in the powder extracted from amongst the decaying shells on the lower ledge, with the marked exception that the carbonate of lime is present in only very small quantity. On the third and highest ledge, I observed some of this powder in a similar position, and likewise occasionally in small patches at considerably greater heights near the summit of the island. At Iquique, where the whole face of the country is covered by a highly saliferous alluvium, and where the climate is extremely dry, we have seen that, according to Mr. Blake, the shells which are perfect near the beach become, in ascending, gradually less and less perfect, until scarcely a trace of their original structure can be discovered. It is known that carbonate of lime and common salt left in a mass together,[36] and slightly moistened, partially decompose each other: now we have at San Lorenzo and at Iquique, in the shells and salt packed together, and occasionally moistened by the so-called Peruvian dew, the proper elements for this action. We can thus understand the peculiar corroded appearance of the shells on San Lorenzo, and the great decrease of quantity in the carbonate of lime in the powder on the upper ledge. There is, however, a great difficulty on this view, for the resultant salts should be carbonate of soda and muriate of lime; the latter is present, but not the carbonate of soda. Hence I am led to the perhaps unauthorised conjecture (which I shall hereafter have to refer to) that the carbonate of soda, by some unexplained means, becomes converted into a sulphate. If the above remarks be just, we are led to the very unexpected conclusion, that a dry climate, by leaving the salt from the sea-spray undissolved, is much less favourable to the preservation of upraised shells than a humid climate. However this may be, it is interesting to know the manner in which masses of shells, gradually upraised above the sea-level, decay and finally disappear.

[36] I am informed by Dr. Kane, through Mr. Reeks, that a manufactory was established on this principle in France, but failed from the small quantity of carbonate of soda produced. Sprengel (*Gardeners' Chron.,* 1845, p. 157) states, that salt and carbonate of lime are liable to mutual decomposition in the soil. Sir H. De la Beche informs me, that calcareous rocks washed by the spray of the sea, are often corroded in a peculiar manner; see also on this latter subject *Gardeners' Chron.,* p. 675, 1844.

Summary on the recent elevation of the west coast of South America.—We have seen that upraised marine remains occur at intervals, and in some parts almost continuously, from lat. 45° 35′ to 12° S., along the shores of the Pacific. This is a distance, in a north and south line, of 2,075 geographical miles. From Byron's observations, the elevation has no doubt extended sixty miles further south; and from the similarity in the form of the country near Lima, it has probably extended many leagues further north.[37] Along this great line of coast, besides the organic remains, there are in very many parts, marks of erosion, caves, ancient beaches, sand-dunes, and successive terraces of gravel, all above the present level of the sea. From the steepness of the land on this side of the continent, shells have rarely been found at greater distances inland than from two to three leagues; but the marks of sea-action are evident farther from the coast; for instance, in the valley of Guasco, at a distance of between thirty and forty miles. Judging from the upraised shells alone, the elevation in Chiloe has been 350 feet, at Concepcion certainly 625 feet; and by estimation 1,000 feet; at Valparaiso 1,300 feet; at Coquimbo 252 feet; northward of this place, sea-shells have not, I believe, been found above 300 feet; and at Lima they were falling into decay (hastened probably by the salt) at 85 feet. Not only has this amount of elevation taken place within the period of existing Mollusca and Cirripedes; but their proportional numbers in the neighbouring sea have in most cases remained the same. Near Lima, however, a small change in this respect between the living and the upraised was observed: at Coquimbo this was more evident, all the shells being existing species, but with those embedded in the uppermost calcareous plain not approximating so closely in proportional numbers, as do those that lie loose on its surface at the height of 252 feet, and still less closely than those which are strewed on the lower plains, which latter are identical in proportional numbers with those now cast up on the beach. From this circumstance, and from not finding, upon careful examination, near Coquimbo any shells at a greater height than 252 feet, I believe that the recent elevation there has been much less than at Valparaiso, where it has been 1,300 feet, and I may add, than at Concepcion. This considerable inequality in the amount of elevation at Coquimbo and Valparaiso, places only 200 miles apart, is not improbable, considering, first, the difference in the force and number of the shocks now yearly affecting different parts of this coast; and, secondly, the fact of single areas, such as that of the province of Concepcion, having been uplifted very unequally during the same earthquake. It would, in most cases, be very hazardous to infer an inequality of elevation, from shells being found on the surface or in superficial beds at different heights; for we do not know on what their rate of decay depends; and at Coquimbo one instance out of many has been given, of a promontory, which, from the occurrence of one very small collection of lime-cemented shells, has indisputably been elevated 242 feet, and yet on which, not even a fragment of shell could be found on careful examination between this height and the beach, although many sites appeared very favourable for the preservation of organic remains: the absence, also, of shells on the gravel-terraces a short distance up the valley of Coquimbo, though abundant on the corresponding terraces at its mouth, should be borne in mind.

[37] I may take this opportunity of stating that in a MS. in the Geological Society by Mr. Weaver, it is stated that beds of oysters and other recent shells are found thirty feet above the level of the sea, in many parts of Tampico, in the Gulf of Mexico.

There are other epochs, besides that of the existence of recent Mollusca, by which to judge of the changes of level on this coast. At Lima, as we have just seen, the elevation has been at least eighty-five feet, within the Indo-human period; and since the arrival of the Spaniards in 1530, there has apparently been a sinking of the surface. At Valparaiso, in the course of 220 years, the rise must have been less than nineteen feet; but it has been as much as from ten to eleven feet in the seventeen years subsequently to 1817, and of this rise only a part can be attributed to the earthquake of 1822, the remainder having been insensible and apparently still, in 1834, in progress. At Chiloe the elevation has been gradual, and about four feet during four years. At Coquimbo, also, it has been gradual, and in the course of 150 years has amounted to several feet. The sudden small upheavals, accompanied by earthquakes, as in 1822 at Valparaiso, in 1835 at Concepcion, and in 1837 in the Chonos Archipelago, are familiar to most geologists, but the gradual rising of the coast of Chile has been hardly noticed; it is, however, very important, as connecting together these two orders of events.

The rise of Lima, having been eighty-five feet within the period of man, is the more surprising if we refer to the eastern coast of the continent, for at Port S. Julian, in Patagonia, there is good evidence (as we shall hereafter see) that when the land stood ninety feet lower, the Macrauchenia, a mammiferous beast, was alive; and at Bahia Blanca, when it stood only a few feet lower than it now does, many gigantic quadrupeds ranged over the adjoining country. But the coast of Patagonia is some way distant from the Cordillera, and the movement at Bahia Blanca is perhaps noways connected with this great range, but rather with the tertiary volcanic rocks of Banda Oriental, and therefore the elevation at these places may have been infinitely slower than on the coast of Peru. All such speculations, however, must be vague, for as we know with certainty that the elevation of the whole coast of Patagonia has been interrupted by many and long pauses, who will pretend to say that, in such cases, many and long periods of subsidence may not also have been intercalated?

In many parts of the coast of Chile and Peru there are marks of the action of the sea at successive heights on the land, showing that the elevation has been interrupted by periods of comparative rest in the upward movement, and of denudation in the action of the sea. These are plainest at Chiloe, where, in a height of about five hundred feet, there are three escarpments,—at Coquimbo, where in a height of 364 feet, there are five,—at Guasco, where there are six, of which five may perhaps correspond with those at Coquimbo, but if so, the subsequent and intervening elevatory movements have been here much more energetic,—at Lima, where, in a height of about 250 feet there are three terraces, and others, as it is asserted, at considerably greater heights. The almost entire absence of ancient marks of sea-action at defined levels along considerable spaces of coast, as near Valparaiso and Concepcion, is highly instructive, for as it is improbable that the elevation at these places alone should have been continuous, we must attribute the absence of such marks to the nature and form of the coast-rocks. Seeing over how many hundred miles of the coast of Patagonia, and on how many places on the shores of the Pacific, the elevatory process has been interrupted by periods of comparative rest, we may conclude, conjointly with the evidence drawn from other quarters of the world, that the elevation of the land is generally an intermittent action. From the quantity of matter removed in the formation of the escarpments, especially of those of Patagonia, it appears that the periods of rest in the movement, and of denudation of the land, have generally been very long. In Patagonia, we have seen that the elevation has been equable, and the periods of denudation synchronous over very wide spaces of coast; on the shores of the Pacific, owing to the terraces chiefly occurring in the valleys, we have not equal means of judging on this point; and the very different heights of the upraised shells at Coquimbo, Valparaiso, and Concepcion seem directly opposed to such a conclusion.

Whether on this side of the continent the elevation, between the periods of comparative rest when the escarpments were formed, has been by small sudden starts, such as those accompanying recent earthquakes, or, as is most probable, by such starts conjointly with a gradual upward movement, or by great and sudden upheavals, I have no direct evidence. But as on the eastern coast, I was led to think, from the analogy of the last hundred feet of elevation in La Plata, and from the nearly equal size of the pebbles over the entire width of the terraces, and from the upraised shells being all littoral species, that the elevation had been gradual; so do I on this western coast, from the analogy of the movements now in progress, and from the vast numbers of shells now living exclusively on or close to the beach, which are strewed over the whole surface of the land up to very considerable heights, conclude, that the movement here also has been slow and gradual, aided probably by small occasional starts. We know at least that at Coquimbo, where five escarpments occur in a height of 364 feet, the successive elevations, if they have been sudden, cannot have been very great. It has, I think, been shown that the occasional preservation of shells, unrolled and unbroken, is not improbable even during a quite gradual rising of the land; and their preservation, if the movement has been aided by small starts, is quite conformable with what actually takes place during recent earthquakes.

Judging from the present action of the sea, along the shores of the Pacific, on the deposits of its own accumulation, the present time seems in most places to be one of comparative rest in the elevatory movement, and of denudation of the land. Undoubtedly this is the case along the whole great length of Patagonia. At Chiloe, however, we have seen that a narrow sloping fringe, covered with vegetation, separates the present sea-beach from a line of low cliffs, which the waves lately reached; here, then, the land is gaining in breadth and height, and the present period is not one of rest in the elevation and of contingent denudation; but if the rising be not prolonged at a quick rate, there is every probability that the sea will soon regain its former horizontal limits. I observed similar low sloping fringes on several parts of the coast, both northward of Valparaiso and near Coquimbo; but at this latter place, from the change in form which the coast has undergone since the old escarpments were worn, it may be doubted whether the sea, acting for any length of time at its present level, would eat into the land; for it now rather tends to throw up great masses of sand. It is from facts such as these that I have generally used the term *comparative rest*, as applied to the elevation of the land; the rest or cessation in the movement being comparative both with what has preceded it and followed it, and with the sea’s power of corrosion at each spot and at each level. Near Lima, the cliff-formed shores of San Lorenzo, and on the mainland south of Callao, show that the sea is gaining on the land; and as we have here some evidence that its surface has lately subsided or is still sinking, the periods of comparative rest in the elevation and of contingent denudation, may probably in many cases include periods of subsidence. It is only, as was shown in detail when discussing the terraces of Coquimbo, when the sea with difficulty and after a long lapse of time has either corroded a narrow ledge into solid rock, or has heaped up on a steep surface a *narrow* mound of detritus, that we can confidently assert that the land at that level and at that period long remained absolutely stationary. In the case of terraces formed of gravel or sand, although the elevation may have been strictly horizontal, it may well happen that no one level beach-line may be traceable, and that neither the terraces themselves nor the summit nor basal edges of their escarpments may be horizontal.

Finally, comparing the extent of the elevated area, as deduced from the upraised recent organic remains, on the two sides of the continent, we have seen that on the Atlantic, shells have been found at intervals from Eastern Tierra del Fuego for 1,180 miles northward, and on the Pacific for a space of 2,075 miles. For a length of 775 miles, they occur in the same latitudes on both sides of the continent. Without taking this circumstance into consideration, it is probable from the reasons assigned in the last chapter, that the entire breadth of the continent in Central Patagonia has been uplifted in mass; but from other reasons there given, it would be hazardous to extend this conclusion to La Plata. From the continent being narrow in the southern-most parts of Patagonia, and from the shells found at the Inner Narrows of the Strait of Magellan, and likewise far up the valley of the Santa Cruz, it is probable that the southern part of the western coast, which was not visited by me, has been elevated within the period of recent Mollusca: if so, the shores of the Pacific have been continuously, recently, and in a geological sense synchronously upraised, from Lima for a length of 2,480 nautical miles southward,—a distance equal to that from the Red Sea to the North Cape of Scandinavia!

Chapter III

ON THE PLAINS AND VALLEYS OF CHILE:—SALIFEROUS SUPERFICIAL DEPOSITS.

Basin-like plains of Chile; their drainage, their marine origin.—Marks of sea-action on the eastern flanks of the Cordillera.—Sloping terrace-like fringes of stratified shingle within the valleys of the Cordillera; their marine origin.—Boulders in the valley of Cachapual.—Horizontal elevation of the Cordillera.—Formation of valleys.—Boulders moved by earthquake-waves.—Saline superficial deposits.—Bed of nitrate of soda at Iquique.—Saline incrustations.—Salt-lakes of La Plata and Patagonia; purity of the salt; its origin.

The space between the Cordillera and the coast of Chile is on a rude average from eighty to above one hundred miles in width; it is formed, either of an almost continuous mass of mountains, or more commonly of several nearly parallel ranges, separated by plains; in the more southern parts of this province the mountains are quite subordinate to the plains; in the northern part the mountains predominate.

The basin-like plains at the foot of the Cordillera are in several respects remarkable; that on which the capital of Chile stands is fifteen miles in width, in an east and west line, and of much greater length in a north and south line; it stands 1,750 feet above the sea; its surface appears smooth, but really falls and rises in wide gentle undulations, the hollows corresponding with the main valleys of the Cordillera: the striking manner in which it abruptly comes up to the foot of this great range has been remarked by every author[1] since the time of Molina. Near the Cordillera it is composed of a stratified mass of pebbles of all sizes, occasionally including rounded boulders: near its western boundary, it consists of reddish sandy clay, containing some pebbles and numerous fragments of pumice, and sometimes passes into pure sand or into volcanic ashes. At Podaguel, on this western side of the plain, beds of sand are capped by a calcareous tuff, the uppermost layers being generally hard and substalagmitic, and the lower ones white and friable, both together precisely resembling the beds at Coquimbo, which contain recent marine shells. Abrupt, but rounded, hummocks of rock rise out of this plain: those of Sta. Lucia and S. Cristoval are formed of greenstone-porphyry almost entirely denuded of its original covering of porphyritic claystone breccia; on their summits, many fragments of rock (some of them kinds not found in situ) are coated and united together by a white, friable, calcareous tuff, like that found at Podaguel. When this matter was deposited on the summit of S. Cristoval, the water must have stood 946 feet[2] above the surface of the surrounding plain.

[1] This plain is partially separated into two basins by a range of hills; the southern half, according to Meyen ("Reise um Erde," Th. i, s. 274), falls in height, by an abrupt step, of between fifteen and twenty feet.

[2] Or 2,690 feet above the sea, as measured barometrically by Mr. Eck. This tuff appears to the eye nearly pure; but when placed in acid it leaves a considerable residue of sand and broken crystals, apparently of feldspar. Dr. Meyen ("Reise," Th. i, s. 269) says he found a similar substance on the neighbouring hill of Dominico (and I found it also on the Cerro Blanco), and he attributes it to the weathering of the stone. In some places which I examined, its bulk put this view of its origin quite out of the question; and I should much doubt whether the decomposition of a porphyry would, in any case, leave a crust chiefly composed of carbonate of lime. The white crust, which is commonly seen on weathered feldspathic rocks, does not appear to contain any free carbonate of lime.

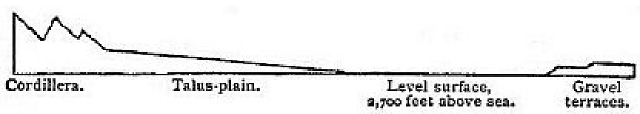
To the south this basin-like plain contracts, and rising scarcely perceptibly with a smooth surface, passes through a remarkable level gap in the mountains, forming a true land-strait, and called the Angostura. It then immediately expands into a second basin-formed plain: this again to the south contracts into another land-strait, and expands into a third basin, which, however, falls suddenly in level about forty feet. This third basin, to the south, likewise contracts into a strait, and then again opens into the great plain of San Fernando, stretching so far south that the snowy peaks of the distant Cordillera are seen rising above its horizon as above the sea. These plains, near the Cordillera, are generally formed of a thick stratified mass of shingle;[3] in other parts, of a red sandy clay, often with an admixture of pumiceous matter. Although these basins are connected together like a necklace, in a north and south line, by smooth land-straits, the streams which drain them do not all flow north and south, but mostly westward, through breaches worn in the bounding mountains; and in the case of the second basin, or that of Rancagua, there are two distinct breaches. Each basin, moreover, is not drained singly; thus, to give the most striking instance, but not the only one, in proceeding southward over the plain of Rancagua, we first find the water flowing northward to and through the northern land-strait; then, without crossing any marked ridge or watershed, we see it flowing south-westward towards the northern one of the two breaches in the western mountainous boundary; and lastly, again without any ridge, it flows towards the southern breach in these same mountains. Hence the surface of this one basin-like plain, appearing to the eye so level, has been modelled with great nicety, so that the drainage, without any conspicuous watersheds, is directed towards three openings in the encircling mountains.[4] The streams flowing from the southern basin-like plains, after passing through the breaches to the west, unite and form the river Rapel, which enters the Pacific near Navidad. I followed the southernmost branch of this river, and found that the basin or plain of San Fernando is continuously and smoothly united with those plains, which were described in the Second Chapter, as being worn near the coast into successive cave-eaten escarpments, and still nearer to the coast, as being strewed with upraised recent marine remains. I might have given descriptions of numerous other plains of the same general form, some at the foot of the Cordillera, some near the coast, and some halfway between these points. I will allude only to one other, namely, the plain of Uspallata, lying on the eastern or opposite side of the Cordillera, between that great range and the parallel lower range of Uspallata. According to Miers, its surface is 6,000 feet above the level of the sea: it is from ten to fifteen miles in width, and is said to extend with an unbroken surface for 180 miles northwards: it is drained by two rivers passing through breaches in the mountains to the east. On the banks of the River Mendoza it is seen to be composed of a great accumulation of stratified shingle, estimated at 400 feet in thickness. In general appearance, and in numerous points of structure, this plain closely resembles those of Chile.

[3] The plain of San Fernando has, according to MM. Meyen and Gay “Reise,” etc., Th. i, ss. 295 and 298, near the Cordillera, an upper step-formed plain of clay, on the surface of which they found numerous blocks of rocks, from two to three feet long, either lying single or piled in heaps, but all arranged in nearly straight lines.

[4] It appears from Captain Herbert’s account of the Diluvium of the Himalaya, (“Gleanings of Science,” Calcutta, vol. ii, p. 164), that precisely similar remarks apply to the drainage of the plains or valleys between those great mountains.

The origin and manner of formation of the thick beds of gravel, sandy clay, volcanic detritus, and calcareous tuff, composing these basin-like plains, is very important; because, as we shall presently show, they send arms or fringes far up the main valleys of the Cordillera. Many of the inhabitants believe that these plains were once occupied by lakes, suddenly drained; but I conceive that the number of the separate breaches at nearly the same level in the mountains surrounding them quite precludes this idea. Had not such distinguished naturalists as MM. Meyen and Gay stated their belief that these deposits were left by great debacles rushing down from the Cordillera, I should not have noticed a view, which appears to me from many reasons improbable in the highest degree—namely, from the vast accumulation of *well-rounded pebbles*—their frequent stratification with layers of sand—the overlying beds of calcareous tuff—this same substance coating and uniting the fragments of rock on the hummocks in the plain of Santiago—and lastly even from the worn, rounded, and much denuded state of these hummocks, and of the headlands which project from the surrounding mountains. On the other hand, these several circumstances, as well as the continuous union of the basins at the foot of the Cordillera, with the great plain of the Rio Rapel which still retains the marks of sea-action at various levels, and their general similarity in form and composition with the many plains near the coast, which are either similarly marked or are strewed with upraised marine remains, fully convince me that the mountains bounding these basin-plains were breached, their islet-like projecting rocks worn, and the loose stratified detritus forming their now level surfaces deposited, by the sea, as the land slowly emerged. It is hardly possible to state too strongly the perfect resemblance in outline between these basin-like, long, and narrow plains of Chile (especially when in the early morning the mists hanging low represented water), and the creeks and fiords now intersecting the southern and western shores of the continent. We can on this view of the sea, when the land stood lower, having long and tranquilly occupied the spaces between the mountain-ranges, understand how the boundaries of the separate basins were breached in more than one place; for we see that this is the general character of the inland bays and channels of Tierra del Fuego; we there, also, see in the sawing action of the tides, which flow with great force in the cross channels, a power sufficient to keep the breaches open as the land emerged. We can further see that the waves would naturally leave the smooth bottom of each great bay or channel, as it became slowly converted into land, gently inclined to as many points as there were mouths, through which the sea finally retreated, thus forming so many watersheds, without any marked ridges, on a nearly level surface. The absence of marine remains in these high inland plains cannot be properly adduced as an objection to their marine origin: for we may conclude, from shells not being found in the great shingle beds of Patagonia, though copiously strewed on their surfaces, and from many other analogous facts, that such deposits are eminently unfavourable for the embedment of such remains; and with respect to shells not being found strewed on the surface of these basin-like plains, it was shown in the last chapter that remains thus exposed in time decay and disappear.

No. 13
Section of the plain at the eastern foot of the Chilian Cordillera.

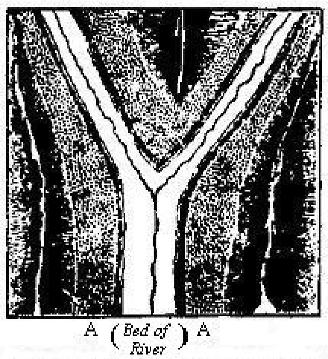


I observed some appearances on the plains at the eastern and opposite foot of the Cordillera which are worth notice, as showing that the sea there long acted at nearly the same level as on the basin-plains of Chile. The mountains on this eastern side are exceedingly abrupt; they rise out of a smooth, talus-like, very gentle, slope, from five to ten miles in width (as represented in Figure 13), entirely composed of perfectly rounded pebbles, often white-washed with an aluminous substance like decomposed feldspar. This sloping plain or talus blends into a perfectly flat space a few miles in width, composed of reddish impure clay, with small calcareous concretions as in the Pampean deposit,—of fine white sand with small pebbles in layers,—and of the above-mentioned white aluminous earth, all interstratified together. This flat space runs as far as Mendoza, thirty miles northward, and stands probably at about the same height, namely, 2,700 feet (Pentland and Miers) above the sea. To the east it is bounded by an escarpment, eighty feet in height, running for many miles north and south, and composed of perfectly round pebbles, and loose, white-washed, or embedded in the aluminous earth: behind this escarpment there is a second and similar one of gravel. Northward of Mendoza, these escarpments become broken and quite obliterated; and it does not appear that they ever enclosed a lake-like area: I conclude, therefore, that they were formed by the sea, when it reached the foot of the Cordillera, like the similar escarpments occurring at so many points on the coasts of Chile and Patagonia.

The talus-like plain slopes up with a smooth surface into the great dry valleys of the Cordillera. On each hand of the Portillo valley, the mountains are formed of red granite, mica-slate, and basalt, which all have suffered a truly astonishing amount of denudation; the gravel in the valley, as well as on the talus-like plain in front of it, is composed of these rocks; but at the mouth of the valley, in the middle (height probably about three thousand five hundred feet above the sea), a few small isolated hillocks of several varieties of porphyry project, round which, on all sides, smooth and often white-washed pebbles of these same porphyries, to the exclusion of all others, extend to a circumscribed distance. Now, it is difficult to conceive any other agency, except the quiet and long-continued action of the sea on these hillocks, which could have rounded and whitewashed the fragments of porphyry, and caused them to radiate from such small and quite insignificant centres, in the midst of that vast stream of stones which has descended from the main Cordillera.

Sloping terraces of gravel in the valleys of the Cordillera.—All the main valleys on both flanks of the Chilean Cordillera have formerly had, or still have, their bottoms filled up to a considerable thickness by a mass of rudely stratified shingle. In Central Chile the greater part of this mass has been removed by the torrents; cliff-bounded fringes, more or less continuous, being left at corresponding heights on both sides of the valleys. These fringes, or as they may be called terraces, have a smooth surface, and as the valleys rise, they gently rise with them: hence they are easily irrigated, and afford great facilities for the construction of the roads. From their uniformity, they give a remarkable character to the scenery of these grand, wild, broken valleys. In width, the fringes vary much, sometimes being only broad enough for the roads, and sometimes expanding into narrow plains. Their surfaces, besides gently rising up the valley, are slightly inclined towards its centre in such a manner as to show that the whole bottom must once have been filled up with a smooth and slightly concave mass, as still are the dry unfurrowed valleys of Northern Chile. Where two valleys unite into one, these terraces are particularly well exhibited, as is represented in Figure 14. The thickness of the gravel forming these fringes, on a rude average, may be said to vary from thirty to sixty or eighty feet; but near the mouths of the valleys it was in several places from two to three hundred feet. The amount of matter removed by the torrents has been immense; yet in the lower parts of the valleys the terraces have seldom been entirely worn away on either side, nor has the solid underlying rock been reached: higher up the valleys, the terraces have frequently been removed on one or the other side, and sometimes on both sides; but in this latter case they reappear after a short interval on the line, which they would have held had they been unbroken. Where the solid rock has been reached, it has been cut into deep and narrow gorges. Still higher up the valleys, the terraces gradually become more and more broken, narrower, and less thick, until, at a height of from seven to nine thousand feet, they become lost, and blended with the piles of fallen detritus.

No. 14



Ground plan of a bifurcating valley in the Cordillera, bordered by smooth, sloping gravel-fringes (A A A), worn along the course of the river into cliffs.

I carefully examined in many places the state of the gravel, and almost everywhere found the pebbles equally and perfectly rounded, occasionally with great blocks of rock, and generally distinctly stratified, often with parting seams of sand. The pebbles were sometimes coated with a white aluminous, and less frequently with a calcareous, crust. At great heights up the valleys the pebbles become less rounded; and as the terraces become obliterated, the whole mass passes into the nature of ordinary detritus. I was repeatedly struck with the great difference between this detritus high up the valleys, and the gravel of the terraces low down, namely, in the greater number of the quite angular fragments in the detritus,—in the unequal degree to which the other fragments have been rounded,—in the quantity of associated earth,—in the absence of stratification,—and in the irregularity of the upper surfaces. This difference was likewise well shown at points low down the valleys, where precipitous ravines, cutting through mountains of highly coloured rock, have thrown down wide, fan-shaped accumulations of detritus on the terraces: in such cases, the line of separation between the detritus and the terrace could be pointed out to within an inch or two; the detritus consisting entirely of angular and only partially rounded fragments of the adjoining coloured rocks; the stratified shingle (as I ascertained by close inspection, especially in one case, in the valley of the River Mendoza) containing only a small proportion of these fragments, and those few well rounded.

I particularly attended to the appearance of the terraces where the valleys made abrupt and considerable bends, but I could perceive no difference in their structure: they followed the bends with their usual nearly equable inclination. I observed, also, in several valleys, that wherever large blocks of any rock became numerous, either on the surface of the terrace or embedded in it, this rock soon appeared higher up *in situ*: thus I have noticed blocks of porphyry, of andesitic syenite, of porphyry and of syenite, alternately becoming numerous, and in each case succeeded by mountains thus constituted. There is, however, one remarkable exception to this rule; for along the valley of the Cachapual, M. Gay found numerous large blocks of white granite, which does not occur in the neighbourhood. I observed these blocks, as well as others of andesitic syenite (not occurring here *in situ*), near the baths of Cauquenes at a height of between two and three hundred feet above the river, and therefore quite above the terrace or fringe which borders that river; some miles up the valleys there were other blocks at about the same height. I also noticed, at a less height, just above the terrace, blocks of porphyries (apparently not found in the immediately impending mountains), arranged in rude lines, as on a sea-beach. All these blocks were rounded, and though large, not gigantic, like the true erratic boulders of Patagonia and Fuegia. M. Gay[5] states that the granite does not occur in situ within a distance of twenty leagues; I suspect, for several reasons, that it will ultimately be found at a much less distance, though certainly not in the immediate neighbourhood. The boulders found by MM. Meyen and Gay on the upper plain of San Fernando (mentioned in a previous note) probably belong to this same class of phenomena.

[5] "Annales des Science Nat." (I. séries, tome 28). M. Gay, as I was informed, penetrated the Cordillera by the great oblique valley of Los Cupressos, and not by the most direct line.

These fringes of stratified gravel occur along all the great valleys of the Cordillera, as well as along their main branches; they are strikingly developed in the valleys of the Maypu, Mendoza, Aconcagua, Cachapual, and according to Meyen,[6] in the Tinguirica. XIn the valleys, however, of Northern Chile, and in some on the eastern flank of the Cordillera, as in the Portillo Valley, where streams have never flowed, or are quite insignificant in volume, the presence of a mass of stratified gravel can be inferred only from the smooth slightly concave form of the bottom. One naturally seeks for some explanation of so general and striking a phenomenon; that the matter forming the fringes along the valleys, or still filling up their entire beds, has not fallen from the adjoining mountains like common detritus, is evident from the complete contrast in every respect between the gravel and the piles of detritus, whether seen high up the valleys on their sides, or low down in front of the more precipitous ravines; that the matter has not been deposited by debacles, even if we could believe in debacles having rushed down *every* valley, and all their branches, eastward and westward from the central pinnacles of the Cordillera, we must admit from the following reasons,—from the distinct stratification of the mass,—its smooth upper surface,—the well-rounded and sometimes encrusted state of the pebbles, so different from the loose debris on the mountains,—and especially from the terraces preserving their uniform inclination round the most abrupt bends. To suppose that as the land now stands, the rivers deposited the shingle along the course of every valley, and all their main branches, appears to me preposterous, seeing that these same rivers not only are now removing and have removed much of this deposit, but are everywhere tending to cut deep and narrow gorges in the hard underlying rocks.

[6] "Reise," etc., Th. I, s. 302.

I have stated that these fringes of gravel, the origin of which are inexplicable on the notion of debacles or of ordinary alluvial action, are directly continuous with the similarly-composed basin-like plains at the foot of the Cordillera, which, from the several reasons before assigned, I cannot doubt were modelled by the agency of the sea. Now if we suppose that the sea formerly occupied the valleys of the Chilean Cordillera, in precisely the same manner as it now does in the more southern parts of the continent, where deep winding creeks penetrate into the very heart of, and in the case of Obstruction Sound quite through, this great range; and if we suppose that the mountains were upraised in the same slow manner as the eastern and western coasts have been upraised within the recent period, then the origin and formation of these sloping, terrace-like fringes of gravel can be simply explained. For every part of the bottom of each valley will, on this view, have long stood at the head of a sea creek, into which the then existing torrents will have delivered fragments of rocks, where, by the action of the tides, they will have been rolled, sometimes encrusted, rudely stratified, and the whole surface levelled by the blending together of the successive beach lines.[7] As the land rose, the torrents in every valley will have tended to have removed the matter which just before had been arrested on, or near, the beach-lines; the torrents, also, having continued to gain in force by the continued elevation increasing their total descent from their sources to the sea. This slow rising of the Cordillera, which explains so well the otherwise inexplicable origin and structure of the terraces, judging from all known analogies, will probably have been interrupted by many periods of rest; but we ought not to expect to find any evidence of these periods in the structure of the gravel-terraces: for, as the waves at the heads of deep creeks have little erosive power, so the only effect of the sea having long remained at the same level will be that the upper parts of the creeks will have become filled up at such periods to the level of the water with gravel and sand; and that afterwards the rivers will have thrown down on the filled-up parts a talus of similar matter, of which the inclination (as at the head of a partially filled-up lake) will have been determined by the supply of detritus, and the force of the stream.[8] Hence, after the final conversion of the creeks into valleys, almost the only difference in the terraces at those points at which the sea stood long, will be a somewhat more gentle inclination, with river-worn instead of sea-worn detritus on the surface.

[7] Sloping terraces of precisely similar structure have been described by me ("Philosoph. Transactions," 1839, p. 58) in the valleys of Lochaber in Scotland, where, at higher levels, the parallel roads of Glen Roy show the marks of the long and quiet residence of the sea. I have no doubt that these sloping terraces would have been present in the valleys of most of the European ranges, had not every trace of them, and all wrecks of sea-action, been swept away by the glaciers which have since occupied them. I have shown that this is the case with the mountains (*London and Edin. Phil. Journal,* vol. xxi, p. 187) of North Wales.

[8] I have attempted to explain this process in a more detailed manner, in a letter to Mr. Maclaren, published in the *Edinburgh New Phil. Journal,* vol. xxxv, p. 288.

I know of only one difficulty on the foregoing view, namely, the far-transported blocks of rock high on the sides of the valley of the Cachapual: I will not attempt any explanation of this phenomenon, but I may state my belief that a mountain-ridge near the Baths of Cauquenes has been upraised long subsequently to all the other ranges in the neighbourhood, and that when this was effected the whole face of the country must have been greatly altered. In the course of ages, moreover, in this and other valleys, events may have occurred like, but even on a grander scale than, that described by Molina,[9] when a slip during the earthquake of 1762 banked up for ten days the great River Lontue, which then bursting its barrier "inundated the whole country," and doubtless transported many great fragments of rock. Finally, notwithstanding this one case of difficulty, I cannot entertain any doubt, that these terrace-like fringes, which are continuously united with the basin-shaped plains at the foot of the Cordillera, have been formed by the arrestment of river-borne detritus at successive levels, in the same manner as we see now taking place at the heads of all those many, deep, winding fiords intersecting the southern coasts. To my mind, this has been one of the most important conclusions to which my observations on the geology of South America have led me; for we thus learn that one of the grandest and most symmetrical mountain-chains in the world, with its several parallel lines,[10] has been together uplifted in mass between seven and nine thousand feet, in the same gradual manner as have the eastern and western coasts within the recent period.

[9] "Compendio de la Hist.," etc., tome i, p. 30. M. Brongniart, in his report on M. Gay's labours ("Annales des Sciences" 1833), considers that the boulders in the Cachapual belong to the same class with the erratic boulders of Europe. As the blocks which I saw are not gigantic, and especially as they are not angular, and as they have not been transported fairly across low spaces or wide valleys, I am unwilling to class them with those which, both in the northern and southern hemisphere ("Geolog. Transac.," vol. vi, p. 415), have been transported by ice. It is to be hoped that when M. Gay's long-continued and admirable labours in Chile are published, more light will be thrown on this subject. However, the boulders may have been primarily transported; the final position of those of porphyry, which have been described as arranged at the foot of the mountain in rude lines, I cannot doubt, has been due to the action of waves on a beach. The valley of the Cachapual, in the part where the boulders occur, bursts through the high ridge of Cauquenes, which runs parallel to, but at some distance from, the

Cordillera. This ridge has been subjected to excessive violence; trachytic lava has burst from it, and hot springs yet flow at its base. Seeing the enormous amount of denudation of solid rock in the upper and much broader parts of this valley where it enters the Cordillera, and seeing to what extent the ridge of Cauquenes now protects the great range, I could not help believing (as alluded to in the text) that this ridge with its trachytic eruptions had been thrown up at a much later period than the Cordillera. If this has been the case, the boulders, after having been transported to a low level by the torrents (which exhibit in every valley proofs of their power of moving great fragments), may have been raised up to their present height, with the land on which they rested.

[10] I do not wish to affirm that all the lines have been uplifted quite equally; slight differences in the elevation would leave no perceptible effect on the terraces. It may, however, be inferred, perhaps with one exception, that since the period when the sea occupied these valleys, the several ranges have not been dislocated by *great* and *abrupt* faults or upheavals; for if such had occurred, the terraces of gravel at these points would not have been continuous. The one exception is at the lower end of a plain in the Valle del Yeso (a branch of the Maypu), where, at a great height, the terraces and valley appear to have been broken through by a line of upheaval, of which the evidence is plain in the adjoining mountains; this dislocation, perhaps, occurred *after the elevation* of this part of the valley above the level of the sea. The valley here is almost blocked up by a pile about one thousand feet in thickness, formed, as far as I could judge, from three sides, entirely, or at least in chief part, of gravel and detritus. On the south side, the river has cut quite through this mass; on the northern side, and on the very summit, deep ravines, parallel to the line of the valley, are worn, as if the drainage from the valley above had passed by these two lines before following its present course.

Formation of Valleys.

The bulk of solid rock which has been removed in the lower parts of the valleys of the Cordillera has been enormous. It is only by reflecting on such cases as that of the gravel beds of Patagonia, covering so many thousand square leagues of surface, and which, if heaped into a ridge, would form a mountain-range almost equal to the Cordillera, that the amount of denudation becomes credible. The valleys within this range often follow anticlinal but rarely synclinal lines; that is, the strata on the two sides more often dip from the line of valley than towards it. On the flanks of the range, the valleys most frequently run neither along anticlinal nor synclinal axes, but along lines of flexure or faults: that is, the strata on both sides dip in the same direction, but with different, though often only slightly different, inclinations. As most of the nearly parallel ridges which together form the Cordillera run approximately north and south, the east and west valleys cross them in zig-zag lines, bursting through the points where the strata have been least inclined. No doubt the greater part of the denudation was affected at the periods when tidal-creeks occupied the valleys, and when the outer flanks of the mountains were exposed to the full force of an open ocean. I have already alluded to the power of the tidal action in the channels connecting great bays; and I may here mention that one of the surveying vessels in a channel of this kind, though under sail, was whirled round and round by the force of the current. We shall hereafter see, that of the two main ridges forming the Chilean Cordillera, the eastern and loftiest one owes the greater part of its *angular* upheaval to a period subsequent to the elevation of the western ridge; and it is likewise probable that many of the other parallel ridges have been angularly upheaved at different periods; consequently many parts of the surfaces of these mountains must formerly have been exposed to the full force of the waves, which, if the Cordillera were now sunk into the sea, would be protected by parallel chains of islands. The torrents in the valleys certainly have great power in wearing the rocks; as could be told by the dull rattling sound of the many fragments night and day hurrying downwards; and as was attested by the vast size of certain fragments, which I was assured had been carried onwards during floods; yet we have seen in the lower parts of the valleys, that the torrents have seldom removed all the sea-checked shingle forming the terraces, and have had time since the last elevation in mass only to cut in the underlying rocks, gorges, deep and narrow, but quite insignificant in dimensions compared with the entire width and depth of the valleys.

Along the shores of the Pacific, I never ceased during my many and long excursions to feel astonished at seeing every valley, ravine, and even little inequality of surface, both in the hard granitic and soft tertiary districts, retaining the exact outline, which they had when the sea left their surfaces coated with organic remains. When these remains shall have decayed, there will be scarcely any difference in appearance between this line of coast-land and most other countries, which we are accustomed to believe have assumed their present features chiefly through the agency of the weather and fresh-water streams. In the old granitic districts, no doubt it would be rash to attribute all the modifications of outline exclusively to the sea-action; for who can say how often this lately submerged coast may not previously have existed as land, worn by running streams and washed by rain? This source of doubt, however, does not apply to the districts superficially formed of the modern tertiary deposits. The valleys worn by the sea, through the softer formations, both on the Atlantic and Pacific sides of the continent, are generally broad, winding, and flat-bottomed: the only district of this nature now penetrated by arms of the sea, is the island of Chiloe.

Finally, the conclusion at which I have arrived, with respect to the relative powers of rain and sea water on the land, is, that the latter is far the most efficient agent, and that its chief tendency is to widen the valleys; whilst torrents and rivers tend to deepen them, and to remove the wreck of the sea's destroying action. As the waves have more power, the more open and exposed the space may be, so will they always tend to widen more and more the mouths of valleys compared with their upper parts: hence, doubtless, it is, that most valleys expand at their mouths,—that part, at which the rivers flowing in them, generally have the least wearing power.

When reflecting on the action of the sea on the land at former levels, the effect of the great waves, which generally accompany earthquakes, must not be overlooked: few years pass without a severe earthquake occurring on some part of the west coast of South America; and the waves thus caused have great power. At Concepcion, after the shock of 1835, I saw large slabs of sandstone, one of which was six feet long, three in breadth, and two in thickness, thrown high up on the beach; and from the nature of the marine animals still adhering to it, it must have been torn up from a considerable depth. On the other hand, at Callao, the recoil-wave of the earthquake of 1746 carried great masses of brickwork, between three and four feet square, some way out seaward. During the course of ages, the effect thus produced at each successive level, cannot have been small; and in some of the tertiary deposits on this line of coast, I observed great boulders of granite and other neighbouring rocks, embedded in fine sedimentary layers, the transportal of which, except by the means of earthquake-waves, always appeared to me inexplicable.

Superficial Saline Deposits.

This subject may be here conveniently treated of: I will begin with the most interesting case, namely, the superficial saline beds near Iquique in Peru. The porphyritic mountains on the coast rise abruptly to a height of between one thousand nine hundred and three thousand feet: between their summits and an inland plain, on which the celebrated deposit of nitrate of soda lies, there is a high undulatory district, covered by a remarkable superficial saliferous crust, chiefly composed of common salt, either in white, hard, opaque nodules, or mingled with sand, in this latter case forming a compact sandstone. This saliferous superficial crust extends from the edge of the coast-escarpment, over the whole face of the country; but never attains, as I am assured by Mr. Bollaert (long resident here) any great thickness. Although a very slight shower falls only at intervals of many years, yet small funnel-shaped cavities show that the salt has been in some parts dissolved.[11] In several places I saw large patches of sand, quite moist, owing to the quantity of muriate of lime (as ascertained by Mr. T. Reeks) contained in them. From the compact salt-cemented sand being either red, purplish, or yellow, according to the colour of the rocky strata on which it rested, I imagined that this[12] substance had probably been derived through common alluvial action from the layers of salt which occur interstratified in the surrounding mountains: but from the interesting details given by M. d'Orbigny, and from finding on a fresh examination of this agglomerated sand, that it is not irregularly cemented, but consists of thin layers of sand of different tints of colour, alternating with excessively fine parallel layers of salt, I conclude that it is not of alluvial origin. M. d'Orbigny[13] observed analogous saline beds extending from Cobija for five degrees of latitude northward, and at heights varying from six hundred to nine hundred feet: from finding recent sea-shells strewed on these saliferous beds, and under them, great well-rounded blocks, exactly like those on the existing beach, he believes that the salt, which is invariably superficial, has been left by the evaporation of the sea-water. This same conclusion must, I now believe, be extended to the superficial saliferous beds of Iquique, though they stand about three thousand feet above the level of the sea.

[11] It is singular how slowly, according to the observations of M. Cordier on the salt-mountain of Cardona in Spain ("Ann. des Mines, Transl. of Geolog. Mem." by De la Beche, p. 60), salt is dissolved, where the amount of rain is supposed to be as much as 31·4 of an inch in the year. It is calculated that only five feet in thickness is dissolved in the course of a century.

[12] "Journal of Researches," p. 444, first edit.

[13] "Voyage," etc., p. 102. M. d'Orbigny found this deposit intersected, in many places, by deep ravines, in which there was no salt. Streams must once, though historically unknown, have flowed in them; and M. d'Orbigny argues from the presence of undissolved salt over the whole surrounding country, that the streams must have arisen from rain or snow having fallen, not in the adjoining country, but on the now arid Cordillera. I may remark, that from having observed ruins of Indian buildings in absolutely sterile parts of the Chilian Cordillera ("Journal," 2nd edit., p. 357), I am led to believe that the climate, at a time when Indian man inhabited this part of the continent, was in some slight degree more humid than it is at present.

Associated with the salt in the superficial beds, there are numerous, thin, horizontal layers of impure, dirty-white, friable, gypseous and calcareous tuffs. The gypseous beds are very remarkable, from abounding with, so as sometimes to be almost composed of, irregular concretions, from the size of an egg to that of a man's head, of very hard, compact, heavy gypsum, in the form of anhydrite. This gypsum contains some foreign particles of stone; it is stained, judging from its action with borax, with iron, and it exhales a strong aluminous odour. The surfaces of the concretions are marked by sharp, radiating, or bifurcating ridges, as if they had been (but not really) corroded: internally they are penetrated by branching veins (like those of calcareous spar in the septaria of the London clay) of pure white anhydrite. These veins might naturally have been thought to have been formed by subsequent infiltration, had not each little embedded fragment of rock been likewise edged in a very remarkable manner by a narrow border of the same white anhydrite: this shows that the veins must have been formed by a process of segregation, and not of infiltration. Some of the little included and *cracked* fragments of foreign rock are penetrated by the anhydrite, and portions have evidently been thus mechanically displaced: at St. Helena, I observed that calcareous matter, deposited by rain water, also had the power to separate small fragments of rock from the larger masses.[14] I believe the superficial gypseous deposit is widely extended: I received specimens of it from Pisagua, forty miles north of Iquique, and likewise from Arica, where it coats a layer of pure salt. M. d'Orbigny[15] found at Cobija a bed of clay, lying above a mass of upraised recent shells, which was saturated with sulphate of soda, and included thin layers of fibrous gypsum. These widely extended, superficial, beds of salt and gypsum, appear to me an interesting geological phenomenon, which could be presented only under a very dry climate.

[14] "Volcanic Islands," etc., p. 87.

[15] "Voyage Géolog.," etc., p. 95.

The plain or basin, on the borders of which the famous bed of nitrate of soda lies, is situated at the distance of about thirty miles from the sea, being separated from it by the saliferous district just described. It stands at a height of 3,300 feet; its surface is level, and some leagues in width; it extends forty miles northward, and has a total length (as I was informed by Mr. Belford Wilson, the Consul-General at Lima) of 420 miles. In a well near the works, thirty-six yards in depth, sand, earth, and a little gravel were found: in another well, near Almonte, fifty yards deep, the whole consisted, according to Mr. Blake,[16] of clay, including a layer of sand two feet thick, which rested on fine gravel, and this on coarse gravel, with large rounded fragments of rock. In many parts of this now utterly desert plain, rushes and large prostrate trees in a hardened state, apparently Mimosas, are found buried, at a depth from three to six feet; according to Mr. Blake, they have all fallen to the south-west. The bed of nitrate of soda is said to extend for forty to fifty leagues along the western margin of the plain, but is not found in its central parts: it is from two to three feet in thickness, and is so hard that it is generally blasted with gunpowder; it slopes gently upwards from the edge of the plain to between ten and thirty feet above its level. It rests on sand in which, it is said, vegetable remains and broken shells have been found; shells have also been found, according to Mr. Blake, both on and in the nitrate of soda. It is covered by a superficial mass of sand, containing nodules of common salt, and, as I was assured by a miner, much soft gypseous matter, precisely like that in the superficial crust already described: certainly this crust, with its characteristic concretions of anhydrite, comes close down to the edge of the plain.

[16] See an admirable paper "Geolog. and Miscell. Notices of Tarapaca," in *Silliman's American Journal*, vol. xliv, p. 1.

The nitrate of soda varies in purity in different parts, and often contains nodules of common salt. According to Mr. Blake, the proportion of nitrate of soda varies from 20 to 75 per cent. An analysis by Mr. A. Hayes, of an average specimen, gave:—

Nitrate of Soda	64·98
Sulphate of Soda	3·00
Chloride of Soda	28·69
Iodic Salts	0·63
Shells and Marl	2·60
	———
	99.90

The "mother-water" at some of the refineries is very rich in iodic salts, and is supposed[17] to contain much muriate of lime. In an unrefined specimen brought home by myself, Mr. T. Reeks has ascertained that the muriate of lime is very abundant. With respect to the origin of this saline mass, from the manner in which the gently inclined, compact bed follows for so many miles the sinuous margin of the plain, there can be no doubt that it was deposited from a sheet of water: from the fragments of embedded shells, from the abundant iodic salts, from the superficial saliferous crust occurring at a higher level and being probably of marine origin, and from the plain resembling in form those of Chile and that of Uspallata, there can be little doubt that this sheet of water was, at least originally, connected with the sea.[18]

[17] *Literary Gazette*, 1841, p. 475.

[18] (From an official document, shown me by Mr. Belford Wilson, it appears that the first export of nitrate of soda to Europe was in July 1830, on French account, in a British ship:—

Entire export in	Quintals
1830	17,300
1831	40,885
1832	51,400
1833	91,335
1834	149,538

The Spanish quintal nearly equals 100 English pounds.

Thin, superficial, saline incrustations.—These saline incrustations are common in many parts of America: Humboldt met with them on the tableland of Mexico, and the Jesuit Falkner and other authors[19] state that they occur at intervals over the vast plains extending from the mouth of the Plata to Rioja and Catamarca. Hence it is that during droughts, most of the streams in the Pampas are saline. I nowhere met with these incrustations so abundantly as near Bahia Blanca: square miles of the mud-flats, which near that place are raised only a few feet above the sea, just enough to protect them from being overflowed, appear, after dry weather, whiter than the ground after the thickest hoar-frost. After rain the salts disappear, and every puddle of water becomes highly saline; as the surface dries, the capillary action draws the moisture up pieces of broken earth, dead sticks, and tufts of grass, where the salt effloresces. The incrustation, where thickest, does not exceed a quarter of an inch. M. Parchappe[20] has analysed it; and finds that the specimens collected at the extreme head of the low plain, near the River Manuello, consist of 93 per cent of sulphate of soda, and 7 of common salt; whilst the specimens taken close to the coast contain only 63 per cent of the sulphate, and 37 of the muriate of soda. This remarkable fact, together with our knowledge that the whole of this low muddy plain has been covered by the sea within the recent period, must lead to the suspicion that the common salt, by some unknown process, becomes in time changed into the sulphate. Friable, calcareous matter is here abundant, and the case of the apparent double decomposition of the shells and salt on San Lorenzo, should not be forgotten.

[19] Azara ("Travels," vol. i, p. 55) considers that the Parana is the eastern boundary of the saliferous region; but I heard of "salitrales" in the Province of Entre Rios.

[20] M. d'Orbigny's "Voyage," etc., Part. Hist., tome i, p. 664.

The saline incrustations, near Bahia Blanca, are not confined to, though most abundant on, the low muddy flats; for I noticed some on a calcareous plain between thirty and forty feet above the sea, and even a little occurs in still higher valleys. Low alluvial tracts in the valleys of the Rivers Negro and Colorado are also encrusted, and in the latter valley such spaces appeared to be occasionally overflowed by the river. I observed saline incrustations in some of the valleys of Southern Patagonia. At Port Desire a low, flat, muddy valley was thickly incrusted by salts, which on analysis by Mr. T. Reeks, are found to consist of a mixture of sulphate and muriate of soda, with carbonate of lime and earthy matter. On the western side of the continent, the southern coasts are much too humid for this phenomenon; but in Northern Chile I again met with similar incrustations. On the hardened mud, in parts of the broad, flat-bottomed valley of Copiapo, the saline matter encrusts the ground to the thickness of some inches: specimens, sent by Mr. Bingley to Apothecaries' Hall for analysis, were said to consist of carbonate and sulphate of soda. Much sulphate of soda is found in the desert of Atacama. In all parts of South America, the saline incrustations occur most frequently on low damp surfaces of mud, where the climate is rather dry; and these low surfaces have, in almost every case, been upraised above the level of the sea, within the recent period.

Salt-lakes of Patagonia and La Plata.—Salinas, or natural salt-lakes, occur in various formations on the eastern side of the continent,—in the argillaceo-calcareous deposit of the Pampas, in the sandstone of the Rio Negro, where they are very numerous, in the pumiceous and other beds of the Patagonian tertiary formation, and in small primary districts in the midst of this latter formation. Port S. Julian is the most southerly point (lat. 49° to 50°) at which salinas are known to occur.[21] The depressions, in which these salt-lakes lie, are from a few feet to sixty metres, as asserted by M. d'Orbigny,[22] below the surface of the surrounding plains; and, according to this same author, near the Rio Negro they all trend, either in the N.E. and S.W. or in E. and W. lines, coincident with the general slope of the plain. These depressions in the plain generally have one side lower than the others, but there are no outlets for drainage. Under a less dry climate, an outlet would soon have been formed, and the salt washed away. The salinas occur at different elevations above the sea; they are often several leagues in diameter; they are generally very shallow, but there is a deep one in a quartz-rock formation near C. Blanco. In the wet season, the whole, or a part, of the salt is dissolved, being redeposited during the succeeding dry season. At this period the appearance of the snow-white expanse of salt crystallised in great cubes, is very striking. In a large salina, northward of the Rio Negro, the salt at the bottom, during the whole year, is between two and three feet in thickness.

[21] According to Azara ("Travels," vol. i, p. 56) there are salt-lakes as far north as Chaco (lat. 25°), on the banks of the Vermejo. The salt-lakes of Siberia appear (Pallas's "Travels," English Trans., vol. i, p. 284) to occur in very similar depressions to those of Patagonia.

[22] "Voyage Géolog.," p. 63.

The salt rests almost always on a thick bed of black muddy sand, which is fetid, probably from the decay of the burrowing worms inhabiting it.[23] In a salina, situated about fifteen miles above the town of El Carmen on the Rio Negro, and three or four miles from the banks of that river, I observed that this black mud rested on gravel with a calcareous matrix, similar to that spread over the whole surrounding plains: at Port S. Julian the mud, also, rested on the gravel: hence the depressions must have been formed anteriorly to, or contemporaneously with, the spreading out of the gravel. I was informed that one small salina occurs in an alluvial plain within the valley of the Rio Negro, and therefore its origin must be subsequent to the excavation of that valley. When I visited the salina, fifteen miles above the town, the salt was beginning to crystallise, and on the muddy bottom there were lying many crystals, generally placed crossways of sulphate of soda (as ascertained by Mr. Reeks), and embedded in the mud, numerous crystals of sulphate of lime, from one to three inches in length: M. d'Orbigny[24] states that some of these crystals are acicular and more than even nine inches in length; others are macled and of great purity: those I found all contained some sand in their centres. As the black and fetid sand overlies the gravel, and that overlies the regular tertiary strata, I think there can be no doubt that these remarkable crystals of sulphate of lime have been deposited from the waters of the lake. The inhabitants call the crystals of selenite, the *padre del sal*, and those of the sulphate of soda, the *madre del sal*; they assured me that both are found under the same circumstances in several of the neighbouring salinas; and that the sulphate of soda is annually dissolved, and is always crystallised before the common salt on the muddy bottom.[25] The association of gypsum and salt in this case, as well as in the superficial deposits of Iquique, appears to me interesting, considering how generally these substances are associated in the older stratified formations.

[23] Professor Ehrenberg examined some of this muddy sand, but was unable to find in it any infusoria.

[24] "Voyage Géolog.," p. 64.

[25] This is what might have been expected; for M. Ballard asserts (*Acad. des Sciences*, Oct. 7, 1844, that sulphate of soda is precipitated from solution more readily from water containing muriate of soda in excess, than from pure water.

Mr. Reeks has analysed for me some of the salt from the salina near the Rio Negro; he finds it composed entirely of chloride of sodium, with the exception of 0·26 of sulphate of lime and of 0·22 of earthy matter: there are no traces of iodic salts. Some salt from the salina Chiquitos, in the Pampean formation, is equally pure. It is a singular fact, that the salt from these salinas does not serve so well for preserving meat, as sea-salt from the Cape de Verde Islands; and a merchant at Buenos Ayres told me that he considered it as 50 per cent less valuable. The purity of the Patagonian salt, or absence from it of those other saline bodies found in all sea-water, is the only assignable cause for this inferiority; a conclusion which is supported by the fact lately ascertained,[26] that those salts answer best for preserving cheese which contain most of the deliquescent chlorides.[27]

[26] *Hort. and Agricult. Gazette*, 1845, p. 93.

[27] It would probably well answer for the merchants of Buenos Ayres (considering the great consumption there of salt for preserving meat) to import the deliquescent chlorides to mix with the salt from the salinas: I may call attention to the fact, that at Iquique, a large quantity of muriate of lime, left in the *mother-water* during the refinement of the nitrate of soda, is annually thrown away.

With respect to the origin of the salt in the salinas, the foregoing analysis seems opposed to the view entertained by M. d'Orbigny and others, and which seems so probable considering the recent elevation of this line of coast, namely, that it is due to the evaporation of sea-water and to the drainage from the surrounding strata impregnated with sea-salt. I was informed (I know not whether accurately) that on the northern side of the salina on the Rio Negro, there is a small brine spring which flows at all times of the year: if this be so, the salt in this case at least, probably is of subterranean origin. It at first appears very singular that fresh water can often be procured in wells,[28] and is sometimes found in small lakes, quite close to these salinas. I am not aware that this fact bears particularly on the origin of the salt; but perhaps it is rather opposed to the view of the salt having been washed out of the surrounding superficial strata, but not to its having been the residue of sea-water, left in depressions as the land was slowly elevated.

[28] Sir W. Parish states ("Buenos Ayres," etc., pp. 122 and 170) that this is the case near the great salinas westward of the S. Ventana. I have seen similar statements in an ancient MS. Journal lately published by S. Angelis. At Iquique, where the surface is so thickly encrusted with saline matter, I tasted water only slightly brackish, procured in a well thirty-six yards deep; but here one feels less surprise at its presence, as pure water might percolate under ground from the not very distant Cordillera.

Chapter IV

ON THE FORMATIONS OF THE PAMPAS.

Mineralogical constitution.—Microscopical structure.—Buenos Ayres, shells embedded in tosca-rock.—Buenos Ayres to the Colorado.—San Ventana.—Bahia Blanca; M. Hermoso, bones and infusoria of; P. Alta, shells, bones, and infusoria of; co-existence of the recent shells and extinct mammifers.—Buenos Ayres to Santa Fé.—Skeletons of Mastodon.—Infusoria.—Inferior marine tertiary strata, their age.—Horse’s tooth. BANDA ORIENTAL.—Superficial Pampean formation.—Inferior tertiary strata, variation of, connected with volcanic action; Macrauchenia Patachonica at San Julian in Patagonia, age of, subsequent to living mollusca and to the erratic block period. SUMMARY.—Area of Pampean formation.—Theories of origin.—Source of sediment.—Estuary origin.—Contemporaneous with existing mollusca.—Relations to underlying tertiary strata.—Ancient deposit of estuary origin.—Elevation and successive deposition of the Pampean formation.—Number and state of the remains of mammifers; their habitation, food, extinction, and range.—Conclusion.—Localities in Pampas at which mammiferous remains have been found.

The Pampean formation is highly interesting from its vast extent, its disputed origin, and from the number of extinct gigantic mammifers embedded in it. It has upon the whole a very uniform character: consisting of a more or less dull reddish, slightly indurated, argillaceous earth or mud, often, but not always, including in horizontal lines concretions of marl, and frequently passing into a compact marly rock. The mud, wherever I examined it, even close to the concretions, did not contain any carbonate of lime. The concretions are generally nodular, sometimes rough externally, sometimes stalactiformed; they are of a compact structure, but often penetrated (as well as the mud) by hair-like serpentine cavities, and occasionally with irregular fissures in their centres, lined with minute crystals of carbonate of lime; they are of white, brown, or pale pinkish tints, often marked by black dendritic manganese or iron; they are either darker or lighter tinted than the surrounding mass; they contain much carbonate of lime, but exhale a strong aluminous odour, and leave, when dissolved in acids, a large but varying residue, of which the greater part consists of sand. These concretions often unite into irregular strata; and over very large tracts of country, the entire mass consists of a hard, but generally cavernous marly rock: some of the varieties might be called calcareous tuffs.

Dr. Carpenter has kindly examined under the microscope, sliced and polished specimens of these concretions, and of the solid marl-rock, collected in various places between the Colorado and Santa Fe Bajada. In the greater number, Dr. Carpenter finds that the whole substance presents a tolerably uniform amorphous character, but with traces of incipient crystalline metamorphosis; in other specimens he finds microscopically minute rounded concretions of an amorphous substance (resembling in size those in oolitic rocks, but not having a concentric structure), united by a cement which is often crystalline. In some, Dr. Carpenter can perceive distinct traces of shells, corals, Polythalamia, and rarely of spongoid bodies. For the sake of comparison, I sent Dr. Carpenter specimens of the calcareous rock, formed chiefly of fragments of recent shells, from Coquimbo in Chile: in one of these specimens, Dr. Carpenter finds, besides the larger fragments, microscopical particles of shells, and a varying quantity of opaque amorphous matter; in another specimen from the same bed, he finds the whole composed of the amorphous matter, with layers showing indications of an incipient crystalline metamorphosis: hence these latter specimens, both in external appearance and in microscopical structure, closely resemble those of the Pampas. Dr. Carpenter informs me that it is well known that chemical precipitation throws down carbonate of lime in the opaque amorphous state; and he is inclined to believe that the long-continued attrition of a calcareous body in a state of crystalline or semi-crystalline aggregation (as, for instance, in the ordinary shells of Mollusca, which, when sliced, are transparent) may yield the same result. From the intimate relations between all the Coquimbo specimens, I can hardly doubt that the amorphous carbonate of lime in them has resulted from the attrition and decay of the larger fragments of shell: whether the amorphous matter in the marly rocks of the Pampas has likewise thus originated, it would be hazardous to conjecture.

For convenience' sake, I will call the marly rock by the name given to it by the inhabitants, namely, Tosca-rock; and the reddish argillaceous earth, Pampean mud. This latter substance, I may mention, has been examined for me by Professor Ehrenberg, and the result of his examination will be given under the proper localities.

I will commence my descriptions at a central spot, namely, at Buenos Ayres, and thence proceed first southward to the extreme limit of the deposit, and afterwards northward. The plain on which Buenos Ayres stands is from thirty to forty feet in height. The Pampean mud is here of a rather pale colour, and includes small nearly white nodules, and other irregular strata of an unusually arenaceous variety of tosca-rock. In a well at the depth of seventy feet, according to Ignatio Nunez, much tosca-rock was met with, and at several points, at one hundred feet deep, beds of sand have been found. I have already given a list of the recent marine and estuary shells found in many parts on the surface near Buenos Ayres, as far as three or four leagues from the Plata. Specimens from near Ensenada, given me by Sir W. Parish, where the rock is quarried just beneath the surface of the plain, consist of broken bivalves, cemented by and converted into white crystalline carbonate of lime. I have already alluded, in the first chapter, to a specimen (also given me by Sir W. Parish) from the A. del Tristan, in which shells, resembling in every respect the *Azara labiata*, d'Orbigny, as far as their worn condition permits of comparison, are embedded in a reddish, softish, somewhat arenaceous marly rock: after careful comparison, with the aid of a microscope and acids, I can perceive no difference between the basis of this rock and the specimens collected by me in many parts of the Pampas. I have also stated, on the authority of Sir W. Parish, that northward of Buenos Ayres, on the highest parts of the plain, about forty feet above the Plata, and two or three miles from it, numerous shells of the *Azara labiata* (and I believe of *Venus sinuosa*) occur embedded in a stratified earthy mass, including small marly concretions, and said to be precisely like the great Pampean deposit. Hence we may conclude that the mud of the Pampas continued to be deposited to within the period of this existing estuary shell. Although this formation is of such immense extent, I know of no other instance of the presence of shells in it.

Buenos Ayres to the Rio Colorado.—With the exception of a few metamorphic ridges, the country between these two points, a distance of 400 geographical miles, belongs to the Pampean formation, and in the southern part is generally formed of the harder and more calcareous varieties. I will briefly describe my route: about twenty-five miles S.S.W. of the capital, in a well forty yards in depth, the upper part, and, as I was assured, the entire thickness, was formed of dark red Pampean mud without concretions. North of the River Salado, there are many lakes; and on the banks of one (near the Guardia) there was a little cliff similarly composed, but including many nodular and stalactiform concretions: I found here a large piece of tessellated armour, like that of the Glyptodon, and many fragments of bones. The cliffs on the Salado consist of pale-coloured Pampean mud, including and passing into great masses of tosca-rock: here a skeleton of the Megatherium and the bones of other extinct quadrupeds (see the list at the end of this chapter) were found. Large quantities of crystallised gypsum (of which specimens were given me) occur in the cliffs of this river; and likewise (as I was assured by Mr. Lumb) in the Pampean mud on the River Chuelo, seven leagues from Buenos Ayres: I mention this because M. d'Orbigny lays some stress on the supposed absence of this mineral in the Pampean formation.

Southward of the Salado the country is low and swampy, with tosca-rock appearing at long intervals at the surface. On the banks, however, of the Tapalguen (sixty miles south of the Salado) there is a large extent of tosca-rock, some highly compact and even semi-crystalline, overlying pale Pampean mud with the usual concretions. Thirty miles further south, the small quartz-ridge of Tapalguen is fringed on its northern and southern flank, by little, narrow, flat-topped hills of tosca-rock, which stand higher than the surrounding plain. Between this ridge and the Sierra of Guitru-gueyu, a distance of sixty miles, the country is swampy, with the tosca-rock appearing only in four or five spots: this sierra, precisely like that of Tapalguen, is bordered by horizontal, often cliff-bounded, little hills of tosca-rock, higher than the surrounding plain. Here, also, a new appearance was presented in some extensive and level banks of alluvium or detritus of the neighbouring metamorphic rocks; but I neglected to observe whether it was stratified or not. Between

Guitru-gueyu and the Sierra Ventana, I crossed a dry plain of tosca-rock higher than the country hitherto passed over, and with small pieces of denuded tableland of the same formation, standing still higher.

The marly or calcareous beds not only come up nearly horizontally to the northern and southern foot of the great quartzose mountains of the Sierra Ventana, but interfold between the parallel ranges. The superficial beds (for I nowhere obtained sections more than twenty feet deep) retain, even close to the mountains, their usual character: the uppermost layer, however, in one place included pebbles of quartz, and rested on a mass of detritus of the same rock. At the very foot of the mountains, there were some few piles of quartz and tosca-rock detritus, including land-shells; but at the distance of only half a mile from these lofty, jagged, and battered mountains, I could not, to my great surprise, find on the boundless surface of the calcareous plain even a single pebble. Quartz-pebbles, however, of considerable size have at some period been transported to a distance of between forty and fifty miles to the shores of Bahia Blanca.[1]

> [1] Schmidtmeyer ("Travels in Chile," p. 150) states that he first noticed on the Pampas, very small bits of red granite, when fifty miles distant from the southern extremity of the mountains of Cordova, which project on the plain, like a reef into the sea.

The highest peak of the St. Ventana is, by Captain Fitzroy's measurement, 3,340 feet, and the calcareous plain at its foot (from observations taken by some Spanish officers[2]) 840 feet above the sea-level. On the flanks of the mountains, at a height of three hundred or four hundred feet above the plain, there were a few small patches of conglomerate and breccia, firmly cemented by ferruginous matter to the abrupt and battered face of the quartz—traces being thus exhibited of ancient sea-action. The high plain round this range sinks quite insensibly to the eye on all sides, except to the north, where its surface is broken into low cliffs. Round the Sierras Tapalguen, Guitru-gueyu, and between the latter and the Ventana we have seen (and shall hereafter see round some hills in Banda Oriental), that the tosca-rock forms low, flat-topped, cliff-bounded hills, higher than the surrounding plains of similar composition. From the horizontal stratification and from the appearance of the broken cliffs, the greater height of the Pampean formation round these primary hills ought not to be altogether or in chief part attributed to these several points having been uplifted more energetically than the surrounding country, but to the argillaceo-calcareous mud having collected round them, when they existed as islets or submarine rocks, at a greater height, than at the bottom of the adjoining open sea;—the cliffs having been subsequently worn during the elevation of the whole country in mass.

> [2] "La Plata," etc., by Sir W. Parish, p. 146.

Southward of the Ventana, the plain extends farther than the eye can range; its surface is not very level, having slight depressions with no drainage exits; it is generally covered by a few feet in thickness of sandy earth; and in some places, according to M. Parchappe,[3] beds of clay two yards thick. On the banks of the Sauce, four leagues S.E. of the Ventana, there is an imperfect section about two hundred feet in height, displaying in the upper part tosca-rock and in the lower part red Pampean mud. At the settlement of Bahia Blanca, the uppermost plain is composed of very compact, stratified tosca-rock, containing rounded grains of quartz distinguishable by the naked eye: the lower plain, on which the fortress stands, is described by M. Parchappe[4] as composed of solid tosca-rock; but the sections which I examined appeared more like a redeposited mass of this rock, with small pebbles and fragments of quartz. I shall immediately return to the important sections on the shores of Bahia Blanca. Twenty miles southward of this place, there is a remarkable ridge extending W. by N. and E. by S., formed of small, separate, flat-topped, steep-sided hills, rising between one hundred and two hundred feet above the Pampean plain at its southern base, which plain is a little lower than that to the north. The uppermost stratum in this ridge consists of pale, highly calcareous, compact tosca-rock, resting (as seen in one place) on reddish Pampean mud, and this again on a paler kind: at the foot of the ridge, there is a well in reddish clay or mud. I have seen no other instance of a chain of hills belonging to the Pampean formation; and as the strata show no signs of disturbance, and as the direction of the ridge is the same with that common to all the metamorphic lines in this whole area, I suspect that the Pampean sediment has in this instance been accumulated on and over a ridge of hard rocks, instead of, as in the case of the above-mentioned Sierras, round their submarine flanks. South of this little chain of tosca-rock, a plain of Pampean mud declines towards the banks of the Colorado: in the middle a well has been dug in red Pampean mud, covered by two feet of white, softish, highly calcareous tosca-rock, over which lies sand with small pebbles three feet in thickness—the first appearance of that vast shingle formation described in the First Chapter. In the first section after crossing the Colorado, an old tertiary formation, namely, the Rio Negro sandstone (to be described in the next chapter), is met with: but from the accounts given me by the Gauchos, I believe that at the mouth of the Colorado the Pampean formation extends a little further southwards.

[3] M. d'Orbigny, "Voyage," Part. Géolog., pp. 47, 48.

[4] *Ibid.*

Bahia Blanca.—To return to the shores of this bay. At Monte Hermoso there is a good section, about one hundred feet in height, of four distinct strata, appearing to the eye horizontal, but thickening a little towards the N.W. The uppermost bed, about twenty feet in thickness, consists of obliquely laminated, soft sandstone, including many pebbles of quartz, and falling at the surface into loose sand. The second bed, only six inches thick, is a hard, dark-coloured sandstone. The third bed is pale-coloured Pampean mud; and the fourth is of the same nature, but darker coloured, including in its lower part horizontal layers and lines of concretions of not very compact pinkish tosca-rock. The bottom of the sea, I may remark, to a distance of several miles from the shore, and to a depth of between sixty and one hundred feet, was found by the anchors to be composed of tosca-rock and reddish Pampean mud. Professor Ehrenberg has examined for me specimens of the two lower beds, and finds in them three Polygastrica and six Phytolitharia.[5] Of these, only one (*Spongolithis Fustis?*) is a marine form; five of them are identical with microscopical structures of brackish-water origin, hereafter to be mentioned, which form a central point in the Pampean formation. In these two beds, especially in the lower one, bones of extinct mammifers, some embedded in their proper relative positions and others single, are very numerous in a small extent of the cliffs. These remains consist of, first, the head of Ctenomys antiquus, allied to the living Ctenomys Braziliensis; secondly, a fragment of the remains of a rodent; thirdly, molar teeth and other bones of a large rodent, closely allied to, but distinct from, the existing species of Hydrochoerus, and therefore probably an inhabitant of fresh water; fourth and fifthly, portions of vertebræ, limbs, ribs, and other bones of two rodents; sixthly, bones of the extremities of some great megatheroid quadruped.[6] The number of the remains of rodents gives to this collection a peculiar character, compared with those found in any other locality. All these bones are compact and heavy; many of them are stained red, with their surfaces polished; some of the smaller ones are as black as jet.

[5] The following list is given in the "Monatsberichten der könig. Akad. zu Berlin," April 1845:—

POLYGASTRICA.
- Fragilaria rhabdosoma.
- Gallionella distans.
- Pinnularia?

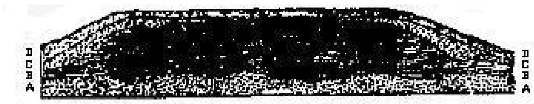
PHYTOLITHARIA.
- Lithodontium Bursa.
- Lithodontium furcatum.
- Lithostylidium exesum.
- Lithostylidium rude.
- Lithostylidium Serra.
- Spongolithis Fustis?

[6] See "Fossil Mammalia" (p. 109) by Professor Owen, in the "Zoology of the Voyage of the *Beagle*;" and Catalogue (p. 36) of Fossil Remains in Museum of Royal College of Surgeons.

Monte Hermoso is between fifty and sixty miles distant in a S.E. line from the Ventana, with the intermediate country gently rising towards it, and all consisting of the Pampean formation. What relation, then, do these beds, at the level of the sea and under it, bear to those on the flanks of the Ventana, at the height of 840 feet, and on the flanks of the other neighbouring sierras, which, from the reasons already assigned, do not appear to owe their greater height to unequal elevation? When the tosca-rock was accumulating round the Ventana, and when, with the exception of a few small rugged primary islands, the whole wide surrounding plains must have been under water, were the strata at Monte Hermoso depositing at the bottom of a great open sea, between eight hundred and one thousand feet in depth? I much doubt this; for if so, the almost perfect carcasses of the several small rodents, the remains of which are so very numerous in so limited a space, must have been drifted to this spot from the distance of many hundred miles. It appears to me far more probable, that during the Pampean period this whole area had commenced slowly rising (and in the cliffs, at several different heights we have proofs of the land having been exposed to sea-action at several levels), and that tracts of land had thus been formed of Pampean sediment round the Ventana and the other primary ranges, on which the several rodents and other quadrupeds lived, and that a stream (in which perhaps the extinct aquatic Hydrochoerus lived) drifted their bodies into the adjoining sea, into which the Pampean mud continued to be poured from the north. As the land continued to rise, it appears that this source of sediment was cut off; and in its place sand and pebbles were borne down by stronger currents, and conformably deposited over the Pampean strata.

Punta Alta is situated about thirty miles higher up on the northern side of this same bay: it consists of a small plain, between twenty and thirty feet in height, cut off on the shore by a line of low cliffs about a mile in length, represented in figure No. 15 with its vertical scale necessarily exaggerated. The lower bed (A) is more extensive than the upper ones; it consists of stratified gravel or conglomerate, cemented by calcareo-arenaceous matter, and is divided by curvilinear layers of pinkish marl, of which some are precisely like tosca-rock, and some more sandy. The beds are curvilinear, owing to the action of currents, and dip in different directions; they include an extraordinary number of bones of gigantic mammifers and many shells. The pebbles are of considerable size, and are of hard sandstone, and of quartz, like that of the Ventana: there are also a few well-rounded masses of tosca-rock.

No. 15
Section of beds with recent shells and extinct mammifers, at Punta Alta in Bahia Blanca.



The second bed (B) is about fifteen feet in thickness, but towards both extremities of the cliff (not included in the diagram) it either thins out and dies away, or passes insensibly into an overlying bed of gravel. It consists of red, tough clayey mud, with minute linear cavities; it is marked with faint horizontal shades of colour; it includes a few pebbles, and rarely a minute particle of shell: in one spot, the dermal armour and a few bones of a Dasypoid quadruped were embedded in it: it fills up furrows in the underlying gravel. With the exception of the few pebbles and particles of shells, this bed resembles the true Pampean mud; but it still more closely resembles the clayey flats (mentioned in the First Chapter) separating the successively rising parallel ranges of sand-dunes.

The bed (C) is of stratified gravel, like the lowest one; it fills up furrows in the underlying red mud, and is sometimes interstratified with it, and sometimes insensibly passes into it; as the red mud thins out, this upper gravel thickens. Shells are more numerous in it than in the lower gravel; but the bones, though some are still present, are less numerous. In one part, however, where this gravel and the red mud passed into each other, I found several bones and a tolerably perfect head of the Megatherium. Some of the large Volutas, though embedded in the gravel-bed (C), were filled with the red mud, including great numbers of the little recent *Paludestrina australis.* These three lower beds are covered by an unconformable mantle (D) of stratified sandy earth, including many pebbles of quartz, pumice and phonolite, land and sea-shells.

M. d’Orbigny has been so obliging as to name for me the twenty species of Mollusca embedded in the two gravel beds: they consist of:—

1. Volutella angulata, d’Orbigny, “Voyage” Mollusq. and Pal.
2. Voluta Braziliana, Sol.
3. Olicancilleria Braziliensis, d’Orbigny.
4. Olicancilleria auricularia, d’Orbigny.
5. Olivina puelchana, d’Orbigny.
6. Buccinanops cochlidium, d’Orbigny.
7. Buccinanops globulosum, d’Orbigny.
8. Colombella sertulariarum, d’Orbigny.

9. Trochus Patagonicus, and var. of ditto, d’Orbigny.
10. Paludestrina Australis, d’Orbigny.
11. Fissurella Patagonica, d’Orbigny.
12. Crepidula muricata, Lam.
13. Venus purpurata, Lam.
14. Venus rostrata, Phillippi.
15. Mytilus Darwinianus, d’Orbigny.
16. Nucula semiornata, d’Orbigny.
17. Cardita Patagonica, d’Orbigny.
18. Corbula Patagonica (?), d’Orbigny.
19. Pecten tethuelchus, d’Orbigny.
20. Ostrea puelchana, d’Orbigny.
21. A living species of Balanus.
22. and 23. An Astræ and encrusting Flustra, apparently identical with species now living in the bay.

All these shells now live on this coast, and most of them in this same bay. I was also struck with the fact, that the proportional numbers of the different kinds appeared to be the same with those now cast up on the beach: in both cases specimens of Voluta, Crepidula, Venus, and Trochus are the most abundant. Four or five of the species are the same with the upraised shells on the Pampas near Buenos Ayres. All the specimens have a very ancient and bleached appearance,[7] and do not emit, when heated, an animal odour: some of them are changed throughout into a white, soft, fibrous substance; others have the space between the external walls, either hollow, or filled up with crystalline carbonate of lime.

[7] A Bulinus, mentioned in the Introduction to the “Fossil Mammalia” in the “Zoology of the Voyage of the *Beagle*” has so much fresher an appearance, than the marine species, that I suspect it must have fallen amongst the others, and been collected by mistake.

The remains of the extinct mammiferous animals, from the two gravel beds have been described by Professor Owen in the “Zoology of the Voyage of the *Beagle*:” they consist of, 1st, one nearly perfect head and three fragments of heads of the *Megatherium Cuvierii*; 2nd, a lower jaw of *Megalonyx Jeffersonii*; 3rd, lower jaw of *Mylodon Darwinii*; 4th, fragments of a head of some gigantic Edental quadruped; 5th, an almost entire skeleton of the great *Scelidotherium leptocephalum*, with most of the bones, including the head, vertebræ, ribs, some of the extremities to the claw-bone, and even, as remarked by Professor Owen, the knee-cap, all nearly in their proper relative positions; 6th, fragments of the jaw and a separate tooth of a Toxodon, belonging either to *T. Platensis*, or to a second species lately discovered near Buenos Ayres; 7th, a tooth of *Equus curvidens*; 8th, tooth of a Pachyderm, closely allied to Palæotherium, of which parts of the head have been lately sent from Buenos Ayres to the British Museum; in all probability this pachyderm is identical with the *Macrauchenia Patagonica* from Port S. Julian, hereafter to be referred to. Lastly, and 9thly, in a cliff of the red clayey bed (B), there was a double piece, about three feet long and two wide, of the bony armour of a large Dasypoid quadruped, with the two sides pressed nearly close together: as the cliff is now rapidly washing away, this fossil probably was lately much more perfect; from between its doubled-up sides, I extracted the middle and ungual phalanges, united together, of one of the feet, and likewise a separate phalanx: hence one or more of the limbs must have been attached to the dermal case, when it was embedded. Besides these several remains in a distinguishable condition, there were very many single bones: the greater number were embedded in a space 200 yards square. The preponderance of the Edental quadrupeds is remarkable; as is, in contrast with the beds of Monte Hermoso, the absence of Rodents. Most of the bones are now in a soft and friable condition, and, like the shells, do not emit when burnt an animal odour. The decayed state of the bones may be partly owing to their late exposure to the air and tidal-waves. Barnacles, Serpulæ, and corallines are attached to many of the bones, but I neglected to observe[8] whether these might not have grown on them since being exposed to the present tidal action; but I believe that some of the barnacles must have grown on the Scelidotherium, soon after being deposited, and before being *wholly* covered up by the gravel. Besides the remains in the condition here described, I found one single fragment of bone very much rolled, and as black as jet, so as perfectly to resemble some of the remains from Monte Hermoso.

[8] After having packed up my specimens at Bahia Blanca, this

point occurred to me, and I noted it; but forgot it on my return, until the remains had been cleaned and oiled: my attention has been lately called to the subject by some remarks by M. d'Orbigny.

Very many of the bones had been broken, abraded, and rolled, before being embedded. Others, even some of those included in the coarsest parts of the the now hard conglomerate, still retain all their minutest prominences perfectly preserved; so that I conclude that they probably were protected by skin, flesh, or ligaments, whilst being covered up. In the case of the Scelidotherium, it is quite certain that the whole skeleton was held together by its ligaments, when deposited in the gravel in which I found it. Some cervical vertebræ and a humerus of corresponding size lay so close together, as did some ribs and the bones of a leg, that I thought that they must originally have belonged to two skeletons, and not have been washed in single; but as remains were here very numerous, I will not lay much stress on these two cases. We have just seen that the armour of the Dasypoid quadruped was certainly embedded together with some of the bones of the feet.

Professor Ehrenberg[9] has examined for me specimens of the finer matter from in contact with these mammiferous remains: he finds in them two Polygastrica, decidedly marine forms; and six Phytolitharia, of which one is probably marine, and the others either of fresh-water or terrestrial origin. Only one of these eight microscopical bodies is common to the nine from Monte Hermoso: but five of them are in common with those from the Pampean mud on the banks of the Parana. The presence of any fresh-water infusoria, considering the aridity of the surrounding country, is here remarkable: the most probable explanation appears to be, that these microscopical organisms were washed out of the adjoining great Pampean formation during its denudation, and afterwards redeposited.

[9] "Monatsberichten der Akad. zu Berlin," April 1845. The list consists of:—

POLYGASTRICA.
  Gallionella sulcata.
  Stauroptera aspera? fragm.
PHYTOLITHARIA.
  Lithasteriscus tuberculatus.
  Lithostylidium Clepsammidium.
  Lithostylidium quadratum.
  Lithostylidium rude.
  Lithostylidium unidentatum.
  Spongolithis acicularis.

We will now see what conclusions may be drawn from the facts above detailed. It is certain that the gravel-beds and intermediate red mud were deposited within the period, when existing species of Mollusca held to each other nearly the same relative proportions as they do on the present coast. These beds, from the number of littoral species, must have been accumulated in shallow water; but not, judging from the stratification of the gravel and the layers of marl, on a beach. From the manner in which the red clay fills up furrows in the underlying gravel, and is in some parts itself furrowed by the overlying gravel, whilst in other parts it either insensibly passes into, or alternates with, this upper gravel, we may infer several local changes in the currents, perhaps caused by slight changes, up or down, in the level of the land. By the elevation of these beds, to which period the alluvial mantle with pumice-pebbles, land and sea-shells belongs, the plain of Punta Alta, from twenty to thirty feet in height, was formed. In this neighbourhood there are other and higher sea-formed plains and lines of cliffs in the Pampean formation worn by the denuding action of the waves at different levels. Hence we can easily understand the presence of rounded masses of tosca-rock in this lowest plain; and likewise, as the cliffs at Monte Hermoso with their mammiferous remains stand at a higher level, the presence of the one much-rolled fragment of bone which was as black as jet: possibly some few of the other much-rolled bones may have been similarly derived, though I saw only the one fragment, in the same condition with those from Monte Hermoso. M. d'Orbigny has suggested[10] that all these mammiferous remains may have been washed out of the Pampean formation, and afterwards redeposited together with the recent shells. Undoubtedly it is a marvellous fact that these numerous gigantic quadrupeds, belonging, with the exception of the *Equus curvidens*, to seven extinct genera, and one, namely, the Toxodon, not falling into any existing family, should have co-existed with Mollusca, all of which are still living species; but analogous facts have been observed in North America and in Europe. In the first place, it should not be overlooked, that most of the co-embedded shells have a more ancient and altered appearance than the bones. In the second place, is it probable that numerous bones not hardened by silex or any other mineral, could have retained their delicate prominences and surfaces perfect if they had been washed out of one deposit, and re-embedded in another:—this later deposit being formed of large, hard pebbles, arranged by the action of currents or breakers in shallow water into variously curved and inclined layers? The bones which are now in so perfect a state of preservation, must, I conceive, have been fresh and sound when embedded, and probably were protected by skin, flesh, or ligaments. The skeleton of the Scelidotherium indisputably was deposited entire: shall we say that when held together by its matrix it was washed out of an old gravel-bed (totally unlike in character to the Pampean formation), and re-embedded in another gravel-bed, composed (I speak after careful comparison) of exactly the same kind of pebbles, in the same kind of cement? I will lay no stress on the two cases of several ribs and bones of the extremities having *apparently* been embedded in their proper relative position: but will any one be so bold as to affirm that it is possible, that a piece of the thin tessellated armour of a Dasypoid quadruped, at least three feet long and two in width, and now so tender that I was unable with the utmost care to extract a fragment more than two or three inches square, could have been washed out of one bed, and re-embedded in another, together with some of the small bones of the feet, without having been dashed into atoms? We must then wholly reject M. d'Orbigny's supposition, and admit as certain, that the Scelidotherium and the large Dasypoid quadruped, and as highly probable, that the Toxodon, Megatherium, etc., some of the bones of which are perfectly preserved, were embedded for the first time, and in a fresh condition, in the strata in which they were found entombed. These gigantic quadrupeds, therefore, though belonging to extinct genera and families, coexisted with the twenty above-enumerated Mollusca, the barnacle and two corals, still living on this coast. From the rolled fragment of black bone, and from the plain of Punta Alta being lower than that of Monte Hermoso, I conclude that the coarse sub-littoral deposits of Punta Alta, are of subsequent origin to the Pampean mud of Monte Hermoso; and the beds at this latter place, as we have seen, are probably of subsequent origin to the high tosca-plain round the Sierra Ventana: we shall, however, return, at the end of this chapter, to the consideration of these several stages in the great Pampean formation.

[10] "Voyage," Part. Géolog., p. 49.

Buenos Ayres to St. Fé Bajada, in Entre Rios.—For some distance northward of Buenos Ayres, the escarpment of the Pampean formation does not approach very near to the Plata, and it is concealed by vegetation: but in sections on the banks of the Rios Luxan, Areco, and Arrecifes, I observed both pale and dark reddish Pampean mud, with small, whitish concretions of tosca; at all these places mammiferous remains have been found. In the cliffs on the Parana, at San Nicolas, the Pampean mud contains but little tosca; here M. d'Orbigny found the remains of two rodents (*Ctenomys Bonariensis* and *Kerodon antiquus*) and the jaw of a Canis: when on the river I could clearly distinguish in this fine line of cliffs, "horizontal lines of variation both in tint and compactness."[11] The plain northward of this point is very level, but with some depressions and lakes; I estimated its height at from forty to sixty feet above the Parana. At the A. Medio the bright red Pampean mud contains scarcely any tosca-rock; whilst at a short distance the stream of the Pabon, forms a cascade, about twenty feet in height, over a cavernous mass of two varieties of tosca-rock; of which one is very compact and semi-crystalline, with seams of crystallised carbonate of lime: similar compact varieties are met with on the Salidillo and Seco. The absolute identity (I speak after a comparison of my specimens) between some of these varieties, and those from Tapalguen, and from the ridge south of Bahia Blanca, a distance of 400 miles of latitude, is very striking.

[11] I quote these words from my note-book, as written down on the spot, on account of the general absence of stratification in the Pampean formation having been insisted on by M. d'Orbigny as a proof of the diluvial origin of this great deposit.

At Rosario there is but little tosca-rock: near this place I first noticed at the edge of the river traces of an underlying formation, which, twenty-five miles higher up in the estancia of Gorodona, consists of a pale yellowish clay, abounding with concretionary cylinders of a ferruginous sandstone. This bed, which is probably the equivalent of the older tertiary marine strata, immediately to be described in Entre Rios, only just rises above the level of the Parana when low. The rest of the cliff at Gorodona, is formed of red Pampean mud, with, in the lower part, many concretions of tosca, some stalacti-formed, and with only a few in the upper part: at the height of six feet above the river, two gigantic skeletons of the *Mastodon Andium* were here embedded; their bones were scattered a few feet apart, but many of them still held their proper relative positions: they were much decayed and as soft as cheese, so that even one of the great molar teeth fell into pieces in my hand. We here see that the Pampean deposit contains mammiferous remains close to its base. On the banks of the Carcarana, a few miles distant, the lowest bed visible was pale Pampean mud, with masses of tosca-rock, in one of which I found a much decayed tooth of the Mastodon: above this bed, there was a thin layer almost composed of small concretions of white tosca, out of which I extracted a well preserved, but slightly broken tooth of *Toxodon Platensis*: above this there was an unusual bed of very soft impure sandstone. In this neighbourhood I noticed many single embedded bones, and I heard of others having been found in so perfect a state that they were long used as gate-posts: the Jesuit Falkner found here the dermal armour of some gigantic Edental quadruped.

In some of the red mud scraped from a tooth of one of the Mastodons at Gorodona, Professor Ehrenberg finds seven Polygastrica and thirteen Phytolitharia,[12] all of them, I believe, with two exceptions, already known species. Of these twenty, the preponderating number are of fresh-water origin; only two species of Coscinodiscus and a Spongolithis show the direct influence of the sea; therefore Professor Ehrenberg arrives at the important conclusion that the deposit must have been of brackish-water origin. Of the thirteen Phytolitharia, nine are met with in the two deposits in Bahia Blanca, where there is evidence from two other species of Polygastrica that the beds were accumulated in brackish water. The traces of coral, sponges, and Polythalamia, found by Dr. Carpenter in the tosca-rock (of which I must observe the greater number of specimens were from the upper beds in the southern parts of the formation), apparently show a more purely marine origin.

[12] “Monatsberichten der könig. Akad. zu Berlin,” April 1845. The list consists of:—

POLYGASTRICA.
Campylodiscus clypeus.
Coscinodiscus subtilis.
Coscinodiscus al. sp.
Eunotia.
Gallionella granulata.
Himantidium gracile.
Pinnularia borealis.

At *St. Fé Bajada*, in Entre Rios, the cliffs, estimated at between sixty and seventy feet in height, expose an interesting section: the lower half consists of tertiary strata with marine shells, and the upper half of the Pampean formation. The lowest bed is an obliquely laminated, blackish, indurated mud, with distinct traces of vegetable remains.[13] Above this there is a thick bed of yellowish sandy clay, with much crystallised gypsum and many shells of Ostreæ, Pectens, and Arcæ: above this there generally comes an arenaceous crystalline limestone, but there is sometimes interposed a bed, about twelve feet thick, of dark green, soapy clay, weathering into small angular fragments. The limestone, where purest, is white, highly crystalline, and full of cavities: it includes small pebbles of quartz, broken shells, teeth of sharks, and sometimes, as I was informed, large bones: it often contains so much sand as to pass into a calcareous sandstone, and in such parts the great *Ostrea Patagonica*[14] chiefly abounds. In the upper part, the limestone alternates with layers of fine white sand. The shells included in these beds have been named for me by M. d’Orbigny: they consist of:—

1. Ostrea Patagonica, d’Orbigny, “Voyage,” Part. Pal.
2. Ostrea Alvarezii, d’Orbigny, “Voyage,” Part. Pal.
3. Pecten Paranensis, d’Orbigny, “Voyage,” Part. Pal.
4. Pecten Darwinianus, d’Orbigny, “Voyage,” Part. Pal.
5. Venus Munsterii, d’Orbigny, “Voyage,” Pal.
6. Arca Bonplandiana, d’Orbigny, “Voyage,” Pal.
7. Cardium Platense, d’Orbigny, “Voyage,” Pal.
8. Tellina, probably nov. spec., but too imperfect for description.

PHYTOLITHARIA.
Lithasteriscus tuberculatus.

Lithodontium bursa.
Lithodontium furcatum.
Lithodontium rostratum.
Lithostylidium Amphiodon.
Lithostylidium Clepsammidium.
Lithostylidium Hamus.
Lithostylidium polyedrum.
Lithostylidium quadratum.
Lithostylidium rude.
Lithostylidium Serra.
Lithostylidium unidentatum.
Spongolithis Fustis.

[13] M. d'Orbigny has given ("Voyage," Part. Géolog., p. 37) a detailed description of this section, but as he does not mention this lowest bed, it may have been concealed when he was there by the river. There is a considerable discrepancy between his description and mine, which I can only account for by the beds themselves varying considerably in short distances.

[14] Captain Sulivan, R.N., has given me a specimen of this shell, which he found in the cliffs at Point Cerrito, between twenty and thirty miles above the Bajada.

These species are all extinct: the six first were found by M. d'Orbigny and myself in the formations of the Rio Negro, S. Josef, and other parts of Patagonia; and therefore, as first observed by M. d'Orbigny, these beds certainly belong to the great Patagonian formation, which will be described in the ensuing chapter, and which we shall see must be considered as a very ancient tertiary one. North of the Bajada, M. d'Orbigny found, in beds which he considers as lying beneath the strata here described, remains of a Toxodon, which he has named as a distinct species from the *T. Platensis* of the Pampean formation. Much silicified wood is found on the banks of the Parana (and likewise on the Uruguay), and I was informed that they come out of these lower beds; four specimens collected by myself are dicotyledonous.

The upper half of the cliff, to a thickness of about thirty feet, consists of Pampean mud, of which the lower part is pale-coloured, and the upper part of a brighter red, with some irregular layers of an arenaceous variety of tosca, and a few small concretions of the ordinary kind. Close above the marine limestone, there is a thin stratum with a concretionary outline of white hard tosca-rock or marl, which may be considered either as the uppermost bed of the inferior deposits, or the lowest of the Pampean formation; at one time I considered this bed as marking a passage between the two formations: but I have since become convinced that I was deceived on this point. In the section on the Parana, I did not find any mammiferous remains; but at two miles distance on the A. Tapas (a tributary of the Conchitas), they were extremely numerous in a low cliff of red Pampean mud with small concretions, precisely like the upper bed on the Parana. Most of the bones were solitary and much decayed; but I saw the dermal armour of a gigantic Edental quadruped, forming a caldron-like hollow, four or five feet in diameter, out of which, as I was informed, the almost entire skeleton had been lately removed. I found single teeth of the *Mastodon Andium, Toxodon Platensis*, and *Equus curvidens*, near to each other. As this latter tooth approaches closely to that of the common horse, I paid particular attention to its true embedment, for I did not at that time know that there was a similar tooth hidden in the matrix with the other mammiferous remains from Punta Alta. It is an interesting circumstance, that Professor Owen finds that the teeth of this horse approach more closely in their peculiar curvature to a fossil specimen brought by Mr. Lyell[15] from North America, than to those of any other species of Equus.

[15] Lyell's "Travels in North America," vol. i, p. 164 and "Proc. of Geolog. Soc.," vol. iv, p. 39.

The underlying marine tertiary strata extend over a wide area: I was assured that they can be traced in ravines in an east and west line across Entre Rios to the Uruguay, a distance of about 135 miles. In a S.E. direction I heard of their existence at the head of the R. Nankay; and at P. Gorda in Banda Oriental, a distance of 170 miles, I found the same limestone, containing the same fossil shells, lying at about the same level above the river as at St. Fe. In a southerly direction, these beds sink in height, for at another P. Gorda in Entre Rios, the limestone is seen at a much less height; and there can be little doubt that the yellowish sandy clay, on a level with the river, between the Carcarana and S. Nicholas, belongs to this same formation; as perhaps do the beds of sand at

Buenos Ayres, which lie at the bottom of the Pampean formation, about sixty feet beneath the surface of the Plata. The southerly declination of these beds may perhaps be due, not to unequal elevation, but to the original form of the bottom of the sea, sloping from land situated to the north; for that land existed at no great distance, we have evidence in the vegetable remains in the lowest bed at St. Fe; and in the silicified wood and in the bones of *Toxodon Paranensis*, found (according to M. d'Orbigny) in still lower strata.

Banda Oriental.—This province lies on the northern side of the Plata, and eastward of the Uruguay: it has a gentle undulatory surface, with a basis of primary rocks; and is in most parts covered up with an unstratified mass, of no great thickness, of reddish Pampean mud. In the eastern half, near Maldonado, this deposit is more arenaceous than in the Pampas, it contains many though small concretions of marl or tosca-rock, and others of highly ferruginous sandstone; in one section, only a few yards in depth, it rested on stratified sand. Near Monte Video this deposit in some spots appears to be of greater thickness; and the remains of the Glyptodon and other extinct mammifers have been found in it. In the long line of cliffs, between fifty and sixty feet in height, called the Barrancas de S. Gregorio, which extend westward of the Rio S. Lucia, the lower half is formed of coarse sand of quartz and feldspar without mica, like that now cast up on the beach near Maldonado; and the upper half of Pampean mud, varying in colour and containing honeycombed veins of soft calcareous matter and small concretions of tosca-rock arranged in lines, and likewise a few pebbles of quartz. This deposit fills up hollows and furrows in the underlying sand; appearing as if water charged with mud had invaded a sandy beach. These cliffs extend far westward, and at a distance of sixty miles, near Colonia del Sacramiento, I found the Pampean deposit resting in some places on this sand, and in others on the primary rocks: between the sand and the reddish mud, there appeared to be interposed, but the section was not a very good one, a thin bed of shells of an existing Mytilus, still partially retaining their colour. The Pampean formation in Banda Oriental might readily be mistaken for an alluvial deposit: compared with that of the Pampas, it is often more sandy, and contains small fragments of quartz; the concretions are much smaller, and there are no extensive masses of tosca-rock.

In the extreme western parts of this province, between the Uruguay and a line drawn from Colonia to the R. Perdido (a tributary of the R. Negro), the formations are far more complicated. Besides primary rocks, we meet with extensive tracts and many flat-topped, horizontally stratified, cliff-bounded, isolated hills of tertiary strata, varying extraordinarily in mineralogical nature, some identical with the old marine beds of St. Fé Bajada, and some with those of the much more recent Pampean formation. There are, also, extensive *low* tracts of country covered with a deposit containing mammiferous remains, precisely like that just described in the more eastern parts of the province. Although from the smooth and unbroken state of the country, I never obtained a section of this latter deposit close to the foot of the higher tertiary hills, yet I have not the least doubt that it is of quite subsequent origin; having been deposited after the sea had worn the tertiary strata into the cliff-bounded hills. This later formation, which is certainly the equivalent of that of the Pampas, is well seen in the valleys in the estancia of Berquelo, near Mercedes; it here consists of reddish earth, full of rounded grains of quartz, and with some small concretions of tosca-rock arranged in horizontal lines, so as perfectly to resemble, except in containing a little calcareous matter, the formation in the eastern parts of Banda Oriental, in Entre Rios, and at other places: in this estancia the skeleton of a great Edental quadruped was found. In the valley of the Sarandis, at the distance of only a few miles, this deposit has a somewhat different character, being whiter, softer, finer-grained, and full of little cavities, and consequently of little specific gravity; nor does it contain any concretions or calcareous matter: I here procured a head, which when first discovered must have been quite perfect, of the *Toxodon Platensis*, another of a Mylodon,[16] perhaps *M. Darwinii*, and a large piece of dermal armour, differing from that of the *Glyptodon clavipes*. These bones are remarkable from their extraordinarily fresh appearance; when held over a lamp of spirits of wine, they give out a strong odour and burn with a small flame; Mr. T. Reeks has been so kind as to analyse some of the fragments, and he finds that they contain about 7 per cent of animal matter, and 8 per cent of water.[17]

[16] This head was at first considered by Professor Owen (in the "Zoology of the *Beagle*'s Voyage") as belonging to a distinct genus, namely, Glossotherium.

[17] Liebig ("Chemistry of Agriculture," p. 194) states that fresh dry bones contain from 32 to 33 per cent of dry gelatine. See also Dr. Daubeny, in *Edin. New Phil. Journ.*, vol. xxxvii, p. 293.

The older tertiary strata, forming the higher isolated hills and extensive tracts of country, vary, as I have said, extraordinarily in composition: within the distance of a few miles, I sometimes passed over crystalline limestone with agate, calcareous tuffs, and marly rocks, all passing into each other,—red and pale mud with concretions of tosca-rock, quite like the Pampean formation,—calcareous conglomerates and sandstones,—bright red sandstones passing either into red conglomerate, or into white sandstone,—hard siliceous sandstones, jaspery and chalcedonic rocks, and numerous other subordinate varieties. I was unable to mark out the relations of all these strata, and will describe only a few distinct sections:—in the cliffs between P. Gorda on the Uruguay and the A. de Vivoras, the upper bed is crystalline cellular limestone often passing into calcareous sandstone, with impressions of some of the same shells as at St. Fé Bajada; at P. Gorda, [18] this limestone is interstratified with and rests on, white sand, which covers a bed about thirty feet thick of pale-coloured clay, with many shells of the great *Ostrea Patagonica*: beneath this, in the vertical cliff, nearly on a level with the river, there is a bed of red mud absolutely like the Pampean deposit, with numerous often large concretions of perfectly characterised white, compact tosca-rock. At the mouth of the Vivoras, the river flows over a pale cavernous tosca-rock, quite like that in the Pampas, and this *appeared* to underlie the crystalline limestone; but the section was not unequivocal like that at P. Gorda. These beds now form only a narrow and much denuded strip of land; but they must once have extended much further; for on the next stream, south of the S. Juan, Captain Sulivan, R.N., found a little cliff, only just above the surface of the river, with numerous shells of the *Venus Munsterii*, D'Orbigny,—one of the species occurring at St. Fé, and of which there are casts at P. Gorda: the line of cliffs of the subsequently deposited true Pampean mud, extend from Colonia to within half a mile of this spot, and no doubt once covered up this denuded marine stratum. Again at Colonia, a Frenchman found, in digging the foundations of a house, a great mass of the *Ostrea Patagonica* (of which I saw many fragments), packed together just beneath the surface, and directly superimposed on the gneiss. These sections are important: M. d'Orbigny is unwilling to believe that beds of the same nature with the Pampean formation ever underlie the ancient marine tertiary strata; and I was as much surprised at it as he could have been; but the vertical cliff at P. Gorda allowed of no mistake, and I must be permitted to affirm, that after having examined the country from the Colorado to St. Fé Bajada, I could not be deceived in the mineralogical character of the Pampean deposit.

[18] In my "Journal" (p. 171, 1st edit.), I have hastily and inaccurately stated that the Pampean mud, which is found over the eastern part of B. Oriental, lies *over* the limestone at P. Gorda; I should have said that there was reason to infer that it was a subsequent or superior deposit.

Moreover, in a precipitous part of the ravine of Las Bocas, a red sandstone is distinctly seen to overlie a thick bed of pale mud, also quite like the Pampean formation, abounding with concretions of true tosca-rock. This sandstone extends over many miles of country: it is as red as the brightest volcanic scoriæ; it sometimes passes into a coarse red conglomerate composed of the underlying primary rocks; and often passes into a soft white sandstone with red streaks. At the Calera de los Huerfanos, only a quarter of a mile south of where I first met with the red sandstone, the crystalline white limestone is quarried: as this bed is the uppermost, and as it often passes into calcareous sandstone, interstratified with pure sand; and as the red sandstone likewise passes into soft white sandstone, and is also the uppermost bed, I believe that these two beds, though so different, are equivalents. A few leagues southward of these two places, on each side of the low primary range of S. Juan, there are some flat-topped, cliff-bounded, separate little hills, very similar to those fringing the primary ranges in the great plain south of Buenos Ayres: they are composed—1st, of calcareous tuff with many particles of quartz, sometimes passing into a coarse conglomerate; 2nd, of a stone undistinguishable on the closest inspection from the compacter varieties of tosca-rock; and 3rd, of semi-crystalline limestone, including nodules of agate: these three varieties pass insensibly into each other, and as they form the uppermost stratum in this district, I believe that they, also, are the equivalents of the pure crystalline limestone, and of the red and white sandstones and conglomerates.

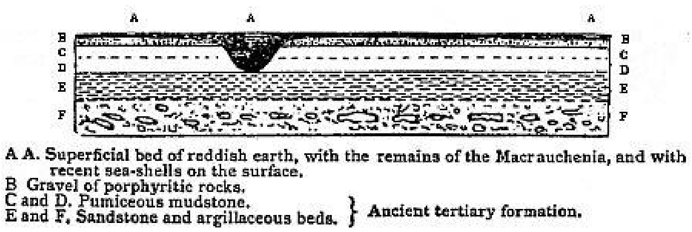
Between these points and Mercedes on the Rio Negro, there are scarcely any good sections, the road passing over limestone, tosca-rock, calcareous and bright red sandstones, and near the source of the San Salvador over a wide extent of jaspery rocks, with much milky agate, like that in the limestone near San Juan. In the estancia of Berquelo, the separate, flat-topped, cliff-bounded hills are rather higher than in the other parts of the country; they range in a N.E. and S.W. direction; their uppermost beds consist of the same bright red sandstone, passing sometimes into a conglomerate, and in the lower part into soft white sandstone, and even into loose sand: beneath this sandstone, I saw in two places layers of calcareous and marly rocks, and in one place red Pampean-like earth; at the base of these sections, there was a hard, stratified, white sandstone, with chalcedonic layers. Near Mercedes, beds of the same nature and apparently of the same age, are associated with compact, white, crystalline limestone, including much botryoidal agate, and singular masses, like porcelain, but really composed of a calcareo-siliceous paste. In sinking wells in this district the chalcedonic strata seem to be the lowest. Beds, such as there described, occur over the whole of this neighbourhood; but twenty miles further up the R. Negro, in the cliffs of Perika, which are about fifty feet in height, the upper bed is a prettily variegated chalcedony, mingled with a pure white tallowy limestone; beneath this there is a conglomerate of quartz and granite; beneath this many sandstones, some highly calcareous; and the whole lower two-thirds of the cliff consists of earthy calcareous beds of various degrees of purity, with one layer of reddish Pampean-like mud.

When examining the agates, the chalcedonic and jaspery rocks, some of the limestones, and even the bright red sandstones, I was forcibly struck with their resemblance to deposits formed in the neighbourhood of volcanic action. I now find that M. Isabelle, in his “Voyage a Buenos Ayres,” has described closely similar beds on Itaquy and Ibicuy (which enter the Uruguay some way north of the R. Negro) and these beds include fragments of red decomposed true scoriæ hardened by zeolite, and of black retinite: we have then here good evidence of volcanic action during our tertiary period. Still further north, near S. Anna,[19] where the Parana makes a remarkable bend, M. Bonpland found some singular amygdaloidal rocks, which perhaps may belong to this same epoch. I may remark that, judging from the size and well-rounded condition of the blocks of rock in the above-described conglomerates, masses of primary formation probably existed at this tertiary period above water: there is, also, according to M. Isabelle, much conglomerate further north, at Salto.

[19] M. d’Orbigny, “Voyage,” Part. Géolog., p. 29.

From whatever source and through whatever means the great Pampean formation originated, we here have, I must repeat, unequivocal evidence of a similar action at a period before that of the deposition of the marine tertiary strata with extinct shells, at Santa Fé and P. Gorda. During also the deposition of these strata, we have in the intercalated layers of red Pampean-like mud and tosca-rock, and in the passage near S. Juan of the semi-crystalline limestones with agate into tosca undistinguishable from that of the Pampas, evidence of the same action, though continued only at intervals and in a feeble manner. We have further seen that in this district, at a period not only subsequent to the deposition of the tertiary strata, but to their upheavement and most extensive denudation, true Pampean mud with its usual characters and including mammiferous remains, was deposited round and between the hills or islets formed of these tertiary strata, and over the whole eastern and low primary districts of Banda Oriental.

No. 16
Section of the lowest plain at Port S. Julian.



Earthy mass, with extinct mammiferous remains, over the porphyritic gravel at S. Julian, lat. 49° 14′ S., in Patagonia.—This case, though not coming strictly under the Pampean formation, may be conveniently given here. On the south side of the harbour, there is a nearly level plain (mentioned in the First Chapter) about seven miles long, and three or four miles wide, estimated at ninety feet in height, and bordered by perpendicular cliffs, of which a section is represented above.

The lower old tertiary strata (to be described in the next chapter) are covered by the usual gravel bed; and this by an irregular earthy, sometimes sandy mass, seldom more than two or three feet in thickness, except where it fills up furrows or gullies worn not only through the underlying gravel, but even through the upper tertiary beds. This earthy mass is of a pale reddish colour, like the less pure varieties of Pampean mud in Banda Oriental; it includes small calcareous concretions, like those of tosca-rock but more arenaceous, and other concretions of a greenish, indurated argillaceous substance: a few pebbles, also, from the underlying gravel-bed are also included in it, and these being occasionally arranged in horizontal lines, show that the mass is of sub-aqueous origin. On the surface and embedded in the superficial parts, there are numerous shells, partially retaining their colours, of three or four of the now commonest littoral species. Near the bottom of one deep furrow (represented in figure No. 16), filled up with this earthy deposit, I found a large part of the skeleton of the *Macrauchenia Patachonica*—a gigantic and most extraordinary pachyderm, allied, according to Professor Owen, to the Palæotherium, but with affinities to the Ruminants, especially to the American division of the Camelidæ. Several of the vertebræ in a chain, and nearly all the bones of one of the limbs, even to the smallest bones of the foot, were embedded in their proper relative positions: hence the skeleton was certainly united by its flesh or ligaments, when enveloped in the mud. This earthy mass, with its concretions and mammiferous remains, filling up furrows in the underlying gravel, certainly presents a very striking resemblance to some of the sections (for instance, at P. Alta in B. Blanca, or at the Barrancas de S. Gregorio) in the Pampean formation; but I must believe that this resemblance is only accidental. I suspect that the mud which at the present day is accumulating in deep and narrow gullies at the head of the harbour, would, after elevation, present a very similar appearance. The southernmost part of the true Pampean formation, namely, on the Colorado, lies 560 miles of latitude north of this point.[20]

[20] In the succeeding chapter I shall have to refer to a great deposit of extinct mammiferous remains, lately discovered by Captain Sulivan, R.N., at a point still further south, namely, at the R. Gallegos; their age must at present remain doubtful.

With respect to the age of the Macrauchenia, the shells on the surface prove that the mass in which the skeleton was enveloped has been elevated above the sea within the recent period: I did not see any of the shells embedded at a sufficient depth to assure me (though it be highly probable) that the whole thickness of the mass was contemporaneous with these *individual specimens.* That the Macrauchenia lived subsequently to the spreading out of the gravel on this plain is certain; and that this gravel, at the height of ninety feet, was spread out long after the existence of recent shells, is scarcely less certain. For, it was shown in the First Chapter, that this line of coast has been upheaved with remarkable equability, and that over a vast space both north and south of S. Julian, recent species of shells are strewed on (or embedded in) the surface of the 250 feet plain, and of the 350 feet plain up to a height of 400 feet. These wide step-formed plains have been formed by the denuding action of the coast-waves on the old tertiary strata; and therefore, when the surface of the 350 feet plain, with the shells on it, first rose above the level of the sea, the 250 feet plain did not exist, and its formation, as well as the spreading out of the gravel on its summit, must have taken place subsequently. So also the denudation and the gravel-covering of the 90 feet plain must have taken place subsequently to the elevation of the 250 feet plain, on which recent shells are also strewed. Hence there cannot be any doubt that the Macrauchenia, which certainly was entombed in a fresh state, and which must have been alive after the spreading out of the gravel on the 90 feet plain, existed, not only subsequently to the upraised shells on the surface of the 250 feet plain, but also to those on the 350 to 400 feet plain: these shells, eight in number (namely, three species of Mytilus, two of Patella, one Fusus, Voluta, and Balanus), are undoubtedly recent species, and are the commonest kinds now living on this coast. At Punta Alta in B. Blanca, I remarked how marvellous it was, that the Toxodon, a mammifer so unlike to all known genera, should have co-existed with twenty-three still living marine animals; and now we find that the Macrauchenia, a quadruped only a little less anomalous than the Toxodon, also co-existed with eight other still existing Mollusca: it should, moreover, be borne in mind, that a tooth of a pachydermatous animal was found with the other remains at Punta Alta, which Professor Owen thinks almost certainly belonged to the Macrauchenia.

Mr. Lyell[21] has arrived at a highly important conclusion with respect to the age of the North American extinct mammifers (many of which are closely allied to, and even identical with, those of the Pampean formation), namely, that they lived subsequently to the period when erratic boulders were transported by the agency of floating ice in temperate latitudes. Now in the valley of the Santa Cruz, only fifty miles of latitude south of the spot where the Macrauchenia was entombed, vast numbers of gigantic, angular boulders, which must have been transported from the Cordillera on icebergs, lie strewed on the plain, at the height of 1,400 feet above the level of the sea. In ascending to this level, several step-formed plains must be crossed, all of which have necessarily required long time for their formation; hence the lowest or ninety feet plain, with its superficial bed containing the remains of the Macrauchenia, must have been formed very long subsequently to the period when the 1,400 feet plain was beneath the sea, and boulders were dropped on it from floating masses of ice.[22] Mr. Lyell's conclusion, therefore, is thus far confirmed in the southern hemisphere; and it is the more important, as one is naturally tempted to admit so simple an explanation, that it was the ice-period that caused the extinction of the numerous great mammifers which so lately swarmed over the two Americas.

[21] "Geological Proceedings," vol. iv, p. 36.

[22] It must not be inferred from these remarks, that the ice-action ceased in South America at this comparatively ancient period; for in Tierra del Fuego boulders were probably transported contemporaneously with, if not subsequently to, the formation of the ninety feet plain at S. Julian, and at other parts of the coast of Patagonia.

Summary and concluding remarks on the Pampean formation.—One of its most striking features is its great extent; I passed continuously over it from the Colorado to St. Fe Bajada, a distance of 500 geographical miles; and M. d'Orbigny traced it for 250 miles further north. In the latitude of the Plata, I examined this formation at intervals over an east and west line of 300 miles from Maldonado to the R. Carcarana; and M. d'Orbigny believes it extends 100 miles further inland: from Mr. Caldcleugh's travels, however, I should have thought that it had extended, south of the Cordovese range, to near Mendoza, and I may add that I heard of great bones having been found high up the R. Quinto. Hence the area of the Pampean formation, as remarked by M. d'Orbigny, is probably at least equal to that of France, and perhaps twice or thrice as great. In a basin, surrounded by gravel-cliff (at a height of nearly three thousand feet), south of Mendoza, there is, as described in the Third Chapter, a deposit very like the Pampean, interstratified with other matter; and again at S. Julian's, in Patagonia, 560 miles south of the Colorado, a small irregular bed of a nearly similar nature contains, as we have just seen, mammiferous remains. In the provinces of Moxos and Chiquitos (1,000 miles northward of the Pampas), and in Bolivia, at a height of 4,000 metres, M. d'Orbigny has described similar deposits, which he believes to have been formed by the same agency contemporaneously with the Pampean formation. Considering the immense distances between these several points, and their different heights, it appears to me infinitely more probable, that this similarity has resulted not from contemporaneousness of origin, but from the similarity of the rocky framework of the continent: it is known that in Brazil an immense area consists of gneissic rocks, and we shall hereafter see, over how great a length the plutonic rocks of the Cordillera, the overlying purple porphyries, and the trachytic ejections, are almost identical in nature.

Three theories on the origin of the Pampean formation have been propounded:—First, that of a great debacle by M. d'Orbigny; this seems founded chiefly on the absence of stratification, and on the number of embedded remains of terrestrial quadrupeds. Although the Pampean formation (like so many argillaceous deposits) is not divided into distinct and separate strata, yet we have seen that in one good section it was striped with horizontal zones of colour, and that in several specified places the upper and lower parts differed, not only considerably in colour, but greatly in constitution. In the southern part of the Pampas the upper mass (to a certain extent stratified) generally consists of hard tosca-rock, and the lower part of red Pampean mud, often itself divided into two or more masses, varying in colour and in the quantity of included calcareous matter. In Western Banda Oriental, beds of a similar nature, but of a greater age, conformably underlie and are intercalated with the regularly stratified tertiary formation. As a general rule, the marly concretions are arranged in horizontal lines, sometimes united into irregular strata: surely, if the mud had been tumultuously deposited in mass, the included calcareous matter would have segregated itself irregularly, and not into nodules arranged in horizontal lines, one above the other and often far apart: this arrangement appears to me to prove that mud, differing slightly in composition, was successively and quietly deposited. On the theory of a debacle, a prodigious amount of mud, without a single pebble, is supposed to have been borne over the wide surface of the Pampas, when under water: on the other hand, over the whole of Patagonia, the same or another debacle is supposed to have borne nothing but gravel,—the gravel and the fine mud in the neighbourhood of the Rios Negro and Colorado having been borne to an equal distance from the Cordillera, or imagined line of disturbance: assuredly directly opposite effects ought not to be attributed to the same agency. Where, again, could a mass of fine sediment, charged with calcareous matter in a fit state for chemical segregation, and in quantity sufficient to cover an area at least 750 miles long, and 400 miles broad, to a depth of from twenty to thirty feet to a hundred feet, have been accumulated, ready to be transported by the supposed debacle? To my mind it is little short of demonstration, that a great lapse of time was necessary for the production and deposition of the enormous amount of mudlike matter forming the Pampas; nor should I have noticed the theory of a debacle, had it not been adduced by a naturalist so eminent as M. d’Orbigny.

A second theory, first suggested, I believe, by Sir W. Parish, is that the Pampean formation was thrown down on low and marshy plains by the rivers of this country before they assumed their present courses. The appearance and composition of the deposit, the manner in which it slopes up and round the primary ranges, the nature of the underlying marine beds, the estuary and sea-shells on the surface, the overlying sandstone beds at M. Hermoso, are all quite opposed to this view. Nor do I believe that there is a single instance of a skeleton of one of the extinct mammifers having been found in an upright position, as if it had been mired.

The third theory, of the truth of which I cannot entertain the smallest doubt, is that the Pampean formation was slowly accumulated at the mouth of the former estuary of the Plata and in the sea adjoining it. I have come to this conclusion from the reasons assigned against the two foregoing theories, and from simple geographical considerations. From the numerous shells of the *Azara labiata* lying loose on the surface of the plains, and near Buenos Ayres embedded in the tosca-rock, we know that this formation not only was formerly covered by, but that the uppermost parts were deposited in, the brackish water of the ancient La Plata. Southward and seaward of Buenos Ayres, the plains were upheaved from under water inhabited by true marine shells. We further know from Professor Ehrenberg’s examination of the twenty microscopical organisms in the mud round the tooth of the Mastodon high up the course of the Parana, that the bottom-most part of this formation was of brackish-water origin. A similar conclusion must be extended to the beds of like composition, at the level of the sea and under it, at M. Hermoso in Bahia Blanca. Dr. Carpenter finds that the harder varieties of tosca-rock, collected chiefly to the south, contain marine spongoid bodies, minute fragments of shells, corals, and Polythalamia; these perhaps may have been drifted inwards by the tides, from the more open parts of the sea. The absence of shells, throughout this deposit, with the exception of the uppermost layers near Buenos Ayres, is a remarkable fact: can it be explained by the brackish condition of the water, or by the deep mud at the bottom? I have stated that both the reddish mud and the concretions of tosca-rock are often penetrated by minute, linear cavities, such as frequently may be observed in fresh-water calcareous deposits:—were they produced by the burrowing of small worms? Only on this view of the Pampean formation having been of estuary origin, can the extraordinary numbers (presently to be alluded to) of the embedded mammiferous remains be explained.[23]

[23] It is almost superfluous to give the numerous cases (for instance, in Sumatra; Lyell’s “Principles,” vol. iii, p. 325, sixth edit.), of the carcasses of animals having been washed out to sea by swollen rivers; but I may refer to a recent account by Mr. Bettington (“Asiatic Soc.,” 1845, June 21st), of oxen, deer, and bears being carried into the Gulf of Cambray; see also the account in my “Journal” (2nd edit., p. 133), of the numbers of animals drowned in the Plata during the great, often recurrent, droughts.

With respect to the first origin of the reddish mud, I will only remark, that the enormous area of Brazil consists in chief part of gneissic and other granitic rocks, which have suffered decomposition, and been converted into a red, gritty, argillaceous mass, to a greater depth than in any other country which I have seen. The mixture of rounded grains, and even of small fragments and pebbles of quartz, in the Pampean mud of Banda Oriental, is evidently due to the neighbouring and underlying primary rocks. The estuary mud was drifted during the Pampean period in a much more southerly course, owing probably to the east and west primary ridges south of the Plata not having been then elevated, than the mud of the Plata at present is; for it was formerly deposited as far south as the Colorado. The quantity of calcareous matter in this formation, especially in those large districts where the whole mass passes into tosca-rock, is very great: I have already remarked on the close resemblance in external and microscopical appearance, between this tosca-rock and the strata at Coquimbo, which have certainly resulted from the decay and attrition of recent shells:[24] I dare not, however, extend this conclusion to the calcareous rocks of the Pampas, more especially as the underlying tertiary strata in western Banda Oriental show that at that period there was a copious emission of carbonate of lime, in connection with volcanic action.

[24] I may add, that there are nearly similar superficial calcareous beds at King George's Sound in Australia; and these undoubtedly have been formed by the disintegration of marine remains (see "Volcanic Islands," etc., p. 144). There is, however, something very remarkable in the frequency of superficial, thin beds of earthy calcareous matter, in districts where the surrounding rocks are not calcareous. Major Charters, in a Paper read before the Geographical Society (April 13th, 1840, and abstracted in the *Athenæum*, p. 317), states that this is the case in parts of Mexico, and that he has observed similar appearances in many parts of South Africa. The circumstance of the uppermost stratum round the ragged Sierra Ventana, consisting of calcareous or marly matter, without any covering of alluvial matter, strikes me as very singular, in whatever manner we view the deposition and elevation of the Pampean formation.

The Pampean formation, judging from its similar composition, and from the apparent absolute specific identity of some of its mammiferous remains, and from the generic resemblance of others, belongs over its vast area—throughout Banda Oriental, Entre Rios, and the wide extent of the Pampas as far south as the Colorado,—to the same geological epoch. The mammiferous remains occur at all depths from the top to the bottom of the deposit; and I may add that nowhere in the Pampas is there any appearance of much superficial denudation: some bones which I found near the Guardia del Monte were embedded close to the surface; and this appears to have been the case with many of those discovered in Banda Oriental: on the Matanzas, twenty miles south of Buenos Ayres, a Glyptodon was embedded five feet beneath the surface; numerous remains were found by S. Muniz, near Luxan, at an average depth of eighteen feet; in Buenos Ayres a skeleton was disinterred at sixty feet depth, and on the Parana I have described two skeletons of the Mastodon only five or six feet above the very base of the deposit. With respect to the age of this formation, as judged of by the ordinary standard of the existence of Mollusca, the only evidence within the limits of the true Pampas which is at all trustworthy, is afforded by the still living *Azara labiata* being embedded in tosca-rock near Buenos Ayres. At Punta Alta, however, we have seen that several of the extinct mammifers, most characteristic of the Pampean formation, co-existed with twenty species of Mollusca, a barnacle and two corals, all still living on this same coast;—for when we remember that the shells have a more ancient appearance than the bones; that many of the bones, though embedded in a coarse conglomerate, are perfectly preserved; that almost all the parts of the skeleton of the Scelidotherium, even to the knee-cap, were lying in their proper relative positions; and that a large piece of the fragile dermal armour of a Dasypoid quadruped, connected with some of the bones of the foot, had been entombed in a condition allowing the two sides to be doubled together, it must assuredly be admitted that these mammiferous remains were embedded in a fresh state, and therefore that the living animals co-existed with the co-embedded shells. Moreover, the *Macrauchenia Patachonica* (of which, according to Professor Owen, remains also occur in the Pampas of Buenos Ayres, and at Punta Alta) has been shown by satisfactory evidence of another kind, to have lived on the plains of Patagonia long after the period when the adjoining sea was first tenanted by its present commonest molluscous animals. We must, therefore, conclude that the Pampean formation belongs, in the ordinary geological sense of the word, to the Recent Period.[25]

> [25] M. d'Orbigny believes ("Voyage," Part. Géolog., p. 81) that this formation, though "très voisine de la nôtre, est néanmoins de beaucoup antérieure à notre création."

At St. Fé Bajada, the Pampean estuary formation, with its mammiferous remains, conformably overlies the marine tertiary strata, which (as first shown by M. d'Orbigny) are contemporaneous with those of Patagonia, and which, as we shall hereafter see, belong to a very ancient tertiary stage. When examining the junction between these two formations, I thought that the concretionary layer of marl marked a passage between the marine and estuary stages. M. d'Orbigny disputes this view (as given in my "Journal"), and I admit that it is erroneous, though in some degree excusable, from their conformability and from both abounding with calcareous matter. It would, indeed, have been a great anomaly if there had been a true passage between a deposit contemporaneous with existing species of mollusca, and one in which all the mollusca appear to be extinct. Northward of Santa Fe, M. d'Orbigny met with ferruginous sandstones, marly rocks, and other beds, which he considers as a distinct and lower formation; but the evidence that they are not parts of the same with an altered mineralogical character, does not appear to me quite satisfactory.

In Western Banda Oriental, while the marine tertiary strata were accumulating, there were volcanic eruptions, much silex and lime were precipitated from solution, coarse conglomerates were formed, being derived probably from adjoining land, and layers of red mud and marly rocks, like those of the Pampean formation, were occasionally deposited. The true Pampean deposit, with mammiferous remains, instead of as at Santa Fe overlying conformably the tertiary strata, is here seen at a lower level folding round and between the flat-topped, cliff-bounded hills, formed by a upheaval and denudation of these same tertiary strata. The upheaval, having occurred here earlier than at Santa Fe, may be naturally accounted for by the contemporaneous volcanic action. At the Barrancas de S. Gregorio, the Pampean deposit, as we have seen, overlies and fills up furrows in coarse sand, precisely like that now accumulating on the shores near the mouth of the Plata. I can hardly believe that this loose and coarse sand is contemporaneous with the old tertiary and often crystalline strata of the more western parts of the province; and am induced to suspect that it is of subsequent origin. If that section near Colonia could be implicitly trusted, in which, at a height of only fifteen feet above the Plata, a bed of fresh-looking mussels, of an existing *littoral* species, appeared to lie between the sand and the Pampean mud, I should conclude that Banda Oriental must have stood, when the coarse sand was accumulating, at only a little below its present level, and had then subsided, allowing the estuary Pampean mud to cover far and wide its surface up to a height of some hundred feet; and that after this subsidence the province had been uplifted to its present level.

In Western Banda Oriental, we know, from two unequivocal sections that there is a mass, absolutely undistinguishable from the true Pampean deposit, beneath the old tertiary strata. This inferior mass must be very much more ancient than the upper deposit with its mammiferous remains, for it lies beneath the tertiary strata in which all the shells are extinct. Nevertheless, the lower and upper masses, as well as some intermediate layers, are so similar in mineralogical character, that I cannot doubt that they are all of estuary origin, and have been derived from the same great source. At first it appeared to me extremely improbable, that mud of the same nature should have been deposited on nearly the same spot, during an immense lapse of time, namely, from a period equivalent perhaps to the Eocene of Europe to that of the Pampean formation. But as, at the very commencement of the Pampean period, if not at a still earlier period, the Sierra Ventana formed a boundary to the south,—the Cordillera or the plains in front of them to the west,—the whole province of Corrientes probably to the north, for, according to M. d'Orbigny, it is not covered by the Pampean deposit,—and Brazil, as known by the remains in the caves, to the north-east; and as again, during the older tertiary period, land already existed in Western Banda Oriental and near St. Fé Bajada, as may be inferred from the vegetable debris, from the quantities of silicified wood, and from the remains of a Toxodon found, according to M. d'Orbigny, in still lower strata, we may conclude, that at this ancient period a great expanse of water was surrounded by the same rocky framework which now bounds the plains of Pampean formation. This having been the case, the circumstance of sediment of the same nature having been deposited in the same area during an immense lapse of time, though highly remarkable, does not appear incredible.

The elevation of the Pampas, at least of the southern parts, has been slow and interrupted by several periods of rest, as may be inferred from the plains, cliffs, and lines of sand-dunes (with shells and pumice-pebbles) standing at different heights. I believe, also, that the Pampean mud continued to be deposited, after parts of this formation had already been elevated, in the same manner as mud would continue to be deposited in the estuary of the Plata, if the mud-banks on its shores were now uplifted and changed into plains: I believe in this from the improbability of so many skeletons and bones having been accumulated at one spot, where M. Hermoso now stands, at a depth of between eight hundred and one thousand feet, and at a vast distance from any land except small rocky islets,—as must have been the case, if the high tosca-plain round the Ventana and adjoining Sierras, had not been already uplifted and converted into land, supporting mammiferous animals. At Punta Alta we have good evidence that the gravel-strata, which certainly belong to the true Pampean period, were accumulated after the elevation in that neighbourhood of the main part of the Pampean deposit, whence the rounded masses of tosca-rock were derived, and that rolled fragment of black bone in the same peculiar condition with the remains at Monte Hermoso.

The number of the mammiferous remains embedded in the Pampas is, as I have remarked, wonderful: it should be borne in mind that they have almost exclusively been found in the cliffs and steep banks of rivers, and that, until lately, they excited no attention amongst the inhabitants: I am firmly convinced that a deep trench could not be cut in any line across the Pampas, without intersecting the remains of some quadruped. It is difficult to form an opinion in what part of the Pampas they are most numerous; in a limited spot they could not well have been more numerous than they were at P. Alta; the number, however, lately found by Senor F. Muniz, near Luxan, in a central spot in the Pampas, is extraordinarily great: at the end of this chapter I will give a list of all the localities at which I have heard of remains having been discovered. Very frequently the remains consist of almost perfect skeletons; but there are, also, numerous single bones, as for instance at St. Fé. Their state of preservation varies much, even when embedded near each other: I saw none others so perfectly preserved as the heads of the Toxodon and Mylodon from the white soft earthy bed on the Sarandis in Banda Oriental. It is remarkable that in two limited sections I found no less than five teeth separately embedded, and I heard of teeth having been similarly found in other parts: may we suppose that the skeletons or heads were for a long time gently drifted by currents over the soft muddy bottom, and that the teeth occasionally, here and there, dropped out?

It may be naturally asked, where did these numerous animals live? From the remarkable discoveries of MM. Lund and Clausen, it appears that some of the species found in the Pampas inhabited the highlands of Brazil: the *Mastodon Andium* is embedded at great heights in the Cordillera from north of the equator[26] to at least as far south as Tarija; and as there is no higher land, there can be little doubt that this Mastodon must have lived on the plains and valleys of that great range. These countries, however, appear too far distant for the habitation of the individuals entombed in the Pampas: we must probably look to nearer points, for instance to the province of Corrientes, which, as already remarked, is said not to be covered by the Pampean formation, and may therefore, at the period of its deposition, have existed as dry land. I have already given my reasons for believing that the animals embedded at M. Hermoso and at P. Alta in Bahia Blanca, lived on adjoining land, formed of parts of the already elevated Pampean deposit. With respect to the food of these many great extinct quadrupeds, I will not repeat the facts given in my “Journal” (second edit., p. 85), showing that there is no correlation between the luxuriance of the vegetation of a country and the size of its mammiferous inhabitants. I do not doubt that large animals could now exist, as far as the amount, not kind, of vegetation is concerned, on the sterile plains of Bahia Blanca and of the R. Negro, as well as on the equally, if not more sterile plains of Southern Africa. The climate, however, may perhaps have somewhat deteriorated since the mammifers embedded at Bahia Blanca lived there; for we must not infer, from the continued existence of the same shells on the present coasts, that there has been no change in climate; for several of these shells now range northward along the shores of Brazil, where the most luxuriant vegetation flourishes under a tropical temperature. With respect to the extinction, which at first fills the mind with astonishment, of the many great and small mammifers of this period, I may also refer to the work above cited (second edit., p. 173), in which I have endeavoured to show, that however unable we may be to explain the precise cause, we ought not properly to feel more surprised at a species becoming extinct than at one being rare; and yet we are accustomed to view the rarity of any particular species as an ordinary event, not requiring any extraordinary agency.

[26] Humboldt states that the Mastodon has been discovered in New Granada: it has been found in Quito. When at Lima, I saw a tooth of a Mastodon in the possession of Don M. Rivero, found at Playa Chica on the Maranon, near the Guallaga. Every one has heard of the numerous remains of Mastodon in Bolivia.

The several mammifers embedded in the Pampean formation, which mostly belong to extinct genera, and some even to extinct families or orders, and which differ nearly, if not quite, as much as do the Eocene mammifers of Europe from living quadrupeds having existed contemporaneously with mollusca, all still inhabiting the adjoining sea, is certainly a most striking fact. It is, however, far from being an isolated one; for, during the late tertiary deposits of Britain, an elephant, rhinoceros, and hippopotamus co-existed with many recent land and fresh-water shells; and in North America, we have the best evidence that a mastodon, elephant, megatherium, megalonyx, mylodon, an extinct horse and ox, likewise co-existed with numerous land, fresh-water, and marine recent shells.[27] The enumeration of these extinct North American animals naturally leads me to refer to the former closer relation of the mammiferous inhabitants of the two Americas, which I have discussed in my “Journal,” and likewise to the vast extent of country over which some of them ranged: thus the same species of the *Megatherium, Megalonyx, Equus* (as far as the state of their remains permits of identification), extended from the Southern United States of North America to Bahia Blanca, in lat. 39° S., on the coast of Patagonia. The fact of these animals having inhabited tropical and temperate regions, does not appear to me any great difficulty, seeing that at the Cape of Good Hope several quadrupeds, such as the elephant and hippopotamus, range from the equator to lat. 35° south. The case of the Mastodon Andium is one of more difficulty, for it is found from lat. 36° S., over, as I have reason to believe, nearly the whole of Brazil, and up the Cordillera to regions which, according to M. d’Orbigny, border on perpetual snow, and which are almost destitute of vegetation: undoubtedly the climate of the Cordillera must have been different when the mastodon inhabited it; but we should not forget the case of the Siberian mammoth and rhinoceros, as showing how severe a climate the larger pachydermata can endure; nor overlook the fact of the guanaco ranging at the present day over the hot low deserts of Peru, the lofty pinnacles of the Cordillera, and the damp forest-clad land of Southern Tierra del Fuego; the puma, also, is found from the equator to the Strait of Magellan, and I have seen its footsteps only a little below the limits of perpetual snow in the Cordillera of Chile.

[27] Many original observations, and a summary on this subject, are given in Mr. Lyell’s paper in the “Geolog. Proc.,” vol. iv, p. 3 and in his “Travels in North America,” vol. i, p. 164 and vol. ii, p. 60. For the European analogous cases see Mr. Lyell’s “Principles of Geology” (6th edit.), vol. i, p. 37.

At the period, so recent in a geological sense, when these extinct mammifers existed, the two Americas must have swarmed with quadrupeds, many of them of gigantic size; for, besides those more particularly referred to in this chapter, we must include in this same period those wonderfully numerous remains, some few of them specifically, and others generically related to those of the Pampas, discovered by MM. Lund and Clausen in the caves of Brazil. Finally, the facts here given show how cautious we ought to be in judging of the antiquity of a formation from even a great amount of difference between the extinct and living species in any one class of animals;—we ought even to be cautious in accepting the general proposition, that change in organic forms and lapse of time are at all, necessarily, correlatives.

Localities within the region of the Pampas where great bones have been

The following list, which includes every account which I have hitherto met with of the discovery of fossil mammiferous remains in the Pampas, may be hereafter useful to a geologist investigating this region, and it tends to show their extraordinary abundance. I heard of and saw many fossils, the original position of which I could not ascertain; and I received many statements too vague to be here inserted. Beginning to the south:—we have the two stations in Bahia Blanca, described in this chapter, where at P. Alta, the Megatherium, Megalonyx, Scelidotherium, Mylodon, Holophractus (or an allied genus), Toxodon, Macrauchenia, and an Equus were collected; and at M. Hermoso a Ctenomys, Hydrochærus, some other rodents and the bones of a great megatheroid quadruped. Close north-east of the S. Tapalguen, we have the Rios 'Huesos' (i.e. *bones*), which probably takes its name from large fossil bones. Near Villa Nuevo, and at Las Averias, not far from the Salado, three nearly perfect skeletons, one of the Megatherium, one of the *Glyptodon clavipes*, and one of some great Dasypoid quadruped, were found by the agent of Sir W. Parish (see his work "Buenos Ayres," etc., p. 171). I have seen the tooth of a Mastodon from the Salado; a little northward of this river, on the borders of a lake near the G. del Monte, I saw many bones, and one large piece of dermal armour; higher up the Salado, there is a place called Monte "Huesos." On the Matanzas, about twenty miles south of Buenos Ayres, the skeleton (*vide* p. 178 of "Buenos Ayres," etc., by Sir W. Parish) of a Glyptodon was found about five feet beneath the surface; here also (see Catalogue of Royal College of Surgeons) remains of *Glyptodon clavipes, G. ornatus*, and *G. reticulatus* were found. Signor Angelis, in a letter which I have seen, refers to some great remains found in Buenos Ayres, at a depth of twenty varas from the surface. Seven leagues north of this city the same author found the skeletons of *Mylodon robustus* and *Glyptodon ornatus.* From this neighbourhood he has lately sent to the British Museum the following fossils:—Remains of three or four individuals of Megatherium; of three species of Glyptodon; of three individuals of the *Mastodon Andium*; of Macrauchenia; of a second species of Toxodon, different from *T. Platensis*; and lastly, of the Machairodus, a wonderful large carnivorous animal. M. d'Orbigny has lately received from the Recolate ("Voyage," Pal., p. 144), near Buenos Ayres, a tooth of *Toxodon Platensis.*

Proceeding northward, along the west bank of the Parana, we come to the Rio Luxan, where two skeletons of the Megatherium have been found; and lately, within eight leagues of the town of Luxan, Dr. F. X. Muniz has collected (*British Packet*, Buenos Ayres, September 25, 1841), from an average depth of eighteen feet, very numerous remains, of no less than, as he believes, nine distinct species of mammifers. At Areco, large bones have been found, which are believed, by the inhabitants, to have been changed from small bones, by the water of the river! At Arrecifes, the Glyptodon, sent to the College of Surgeons, was found; and I have seen two teeth of a Mastodon from this quarter. At S. Nicolas, M. d'Orbigny found remains of a Canis, Ctenomys, and Kerodon; and M. Isabelle ("Voyage," p. 332) refers to a gigantic Armadillo found there. At S. Carlos, I heard of great bones. A little below the mouth of the Carcarana, the two skeletons of Mastodon were found; on the banks of this river, near S. Miguel, I found teeth of the Mastodon and Toxodon; and "Falkner" (p. 55) describes the osseous armour of some great animal; I heard of many other bones in this neighbourhood. I have seen, I may add, in the possession of Mr. Caldcleugh, the tooth of a *Mastodon Andium*, said to have been found in Paraguay; I may here also refer to a statement in this gentleman's travels (vol. i, p. 48), of a great skeleton having been found in the province of Bolivia in Brazil, on the R. de las Contas. The furthest point westward in the Pampas, at which I have *heard* of fossil bones, was high up on the banks of R. Quinto.

In Entre Rios, besides the remains of the Mastodon, Toxodon, Equus, and a great Dasypoid quadruped near St. Fe Bajada, I received an account of bones having been found a little S.E. of P. Gorda (on the Parana), and of an entire skeleton at Matanzas, on the Arroyo del Animal.

In Banda Oriental, besides the remains of the Toxodon, Mylodon, and two skeletons of great animals with osseous armour (distinct from that of the Glyptodon), found on the Arroyos Sarandis and Berquelo, M. Isabelle ("Voyage," p. 322) says, many bones have been found near the R. Negro, and on the R. Arapey, an affluent of the Paraguay, in lat. 30° 40′ south. I heard of bones near the source of the A. Vivoras. I saw the remains of a Dasypoid quadruped from the Arroyo Seco, close to M. Video; and M. d'Orbigny refers ("Voyage," Géolog., p. 24), to another found on the Pedernal, an affluent of the St. Lucia; and Signor Angelis, in a letter, states that a third skeleton of this family has been found, near Canelones. I saw a tooth of the Mastodon from Talas, another affluent of the St. Lucia. The most eastern point at which I heard of great bones having been found, was at Solis Grande, between M. Video and Maldonado.

Chapter V

ON THE OLDER TERTIARY FORMATIONS OF PATAGONIA AND CHILE.

Rio Negro.—S. Josef.—Port Desire, white pumiceous mudstone with infusoria.—Port S. Julian.—Santa Cruz, basaltic lava of.—P. Gallegos.—Eastern Tierra del Fuego; leaves of extinct beech-trees.—Summary on the Patagonian tertiary formations.—Tertiary formations of the Western Coast.—Chonos and Chiloe groups, volcanic rocks of.—Concepcion.—Navidad.—Coquimbo.—Summary.—Age of the tertiary formations.—Lines of elevation.—Silicified wood.—Comparative ranges of the extinct and living mollusca on the West Coast of S. America.—Climate of the tertiary period.—On the causes of the absence of recent conchiferous deposits on the coast of S. America.—On the contemporaneous deposition and preservation of sedimentary formations.

Rio Negro.—I can add little to the details given by M. d'Orbigny[1] on the sandstone formation of this district. The cliffs to the south of the river are about two hundred feet in height, and are composed of sandstone of various tints and degrees of hardness. One layer, which thinned out at both ends, consisted of earthy matter, of a pale reddish colour, with some gypsum, and very like (I speak after comparison of the specimens brought home) Pampean mud: above this was a layer of compact marly rock with dendritic manganese. Many blocks of a conglomerate of pumice-pebbles embedded in hard sandstone were strewed at the foot of the cliff, and had evidently fallen from above. A few miles N.E. of the town, I found, low down in the sandstone, a bed, a few inches in thickness, of a white, friable, harsh-feeling sediment, which adheres to the tongue, is of easy fusibility, and of little specific gravity; examined under the microscope, it is seen to be pumiceous tuff, formed of broken transparent crystals. In the cliffs south of the river, there is, also, a thin layer of nearly similar nature, but finer grained, and not so white; it might easily have been mistaken for a calcareous tuff, but it contains no lime: this substance precisely resembles a most widely extended and thick formation in Southern Patagonia, hereafter to be described, and which is remarkable for being partially formed of infusoria. These beds, conjointly with the conglomerate of pumice, are interesting, as showing the nature of the volcanic action in the Cordillera during this old tertiary period.

[1] "Voyage," Part. Géolog., pp. 57-65.

In a bed at the base of the southern cliffs, M. d'Orbigny found two extinct fresh-water shells, namely, a Unio and Chilina. This bed rested on one with bones of an extinct rodent, namely, the *Megamys Patagoniensis*; and this again on another with extinct marine shells. The species found by M. d'Orbigny in different parts of this formation consist of:—

1. Ostrea Patagonica, d'Orbigny, "Voyage, Pal." (also at St. Fé, and whole coast of Patagonia).
2. Ostrea Ferrarisi, d'Orbigny, "Voyage, Pal."
3. Ostrea Alvarezii, d'Orbigny, "Voyage, Pal." (also at St. Fé, and S. Josef).
4. Pecten Patagoniensis, d'Orbigny, "Voyage, Pal."
5. Venus Munsterii, d'Orbigny, "Voyage, Pal." (also at St. Fé).
6. Arca Bonplandiana, d'Orbigny, "Voyage, Pal." (also at St. Fé).

According to M. d'Orbigny, the sandstone extends westward along the coast as far as Port S. Antonio, and up the R. Negro far into the interior: northward I traced it to the southern side of the Rio Colorado, where it forms a low denuded plain. This formation, though contemporaneous with that of the rest of Patagonia, is quite different in mineralogical composition, being connected with it only by the one thin white layer: this difference may be reasonably attributed to the sediment brought down in ancient times by the Rio Negro; by which agency, also, we can understand the presence of the fresh-water shells, and of the bones of land animals. Judging from the identity of four of the above shells, this formation is contemporaneous (as remarked by M. d'Orbigny) with that under the Pampean deposit in Entre Rios and in Banda Oriental. The gravel capping the sandstone plain, with its calcareous cement and nodules of gypsum, is probably, from the reasons given in the First Chapter, contemporaneous with the uppermost beds of the Pampean formation on the upper plain north of the Colorado.

San Josef.—My examination here was very short: the cliffs are about a hundred feet high; the lower third consists of yellowish-brown, soft, slightly calcareous, muddy sandstone, parts of which when struck emit a fetid smell. In this bed the great Ostræa Patagonica, often marked with dendritic manganese and small coral-lines, were extraordinarily numerous. I found here the following shells:—

1. Ostrea Patagonica, d'Orbigny, "Voyage, Pal." (also at St. Fé and whole coast of Patagonia).
2. Ostrea Alvarezii, d'Orbigny, "Voyage, Pal." (also at St. Fé and R. Negro).
3. Pecten Paranensis, d'Orbigny, "Voyage, Pal." (also at St. Fé, S. Julian, and Port Desire).
4. Pecten Darwinianus, d'Orbigny, "Voyage, Pal." (also at St. Fé).
5. Pecten actinodes, G. B. Sowerby.
6. Terebratula Patagonica, G. B. Sowerby (also S. Julian).
7. Casts of a Turritella.

The four first of these species occur at St. Fé in Entre Rios, and the two first in the sandstone of the Rio Negro. Above this fossiliferous mass, there is a stratum of very fine-grained, pale brown mudstone, including numerous laminæ of selenite. All the strata appear horizontal, but when followed by the eye for a long distance, they are seen to have a small easterly dip. On the surface we have the porphyritic gravel, and on it sand with recent shells.

Nuevo Gulf.—From specimens and notes given me by Lieutenant Stokes, it appears that the lower bed consists of soft muddy sandstone, like that of S. Josef, with many imperfect shells, including the *Pecten Paranensis*, d'Orbigny, casts of a Turritella and Scutella. On this there are two strata of the pale brown mudstone, also like that of *S. Josef*, separated by a darker-coloured, more argillaceous variety, including the *Ostrea Patagonica.* Professor Ehrenberg has examined this mudstone for me: he finds in it three already known microscopic organisms, enveloped in a fine-grained pumiceous tuff, which I shall have immediately to describe in detail. Specimens brought to me from the uppermost bed, north of the Rio Chupat, consist of this same substance, but of a whiter colour.

Tertiary strata, such as here described, appear to extend along the whole coast between Rio Chupat and Port Desire, except where interrupted by the underlying claystone porphyry, and by some metamorphic rocks; these hard rocks, I may add, are found at intervals over a space of about five degrees of latitude, from Point Union to a point between Port S. Julian and S. Cruz, and will be described in the ensuing chapter. Many gigantic specimens of the *Ostrea Patagonica* were collected in the Gulf of St. George.

Port Desire.—A good section of the lowest fossiliferous mass, about forty feet in thickness, resting on claystone porphyry, is exhibited a few miles south of the harbour. The shells sufficiently perfect to be recognised consist of:—

1. Ostrea Patagonica, d'Orbigny, (also at St. Fé, and whole coast of Patagonia).
2. Pecten Paranensis, d'Orbigny, "Voyage, Pal." (also at St. Fé, S. Josef, S. Julian).
3. Pecten centralis, G. B. Sowerby (also at S. Julian and S. Cruz).
4. Cucullæa alta, G. B. Sowerby (also at S. Cruz).
5. Nucula ornata, G. B. Sowerby.
6. Turritella Patagonica, G. B. Sowerby.

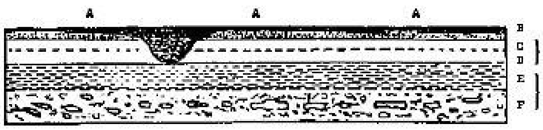
The fossiliferous strata, when not denuded, are conformably covered by a considerable thickness of the fine-grained pumiceous mudstone, divided into two masses: the lower half is very fine-grained, slightly unctuous, and so compact as to break with a semi-conchoidal fracture, though yielding to the nail; it includes laminæ of selenite: the upper half precisely resembles the one layer at the Rio Negro, and with the exception of being whiter, the upper beds at San Josef and Nuevo Gulf. In neither mass is there any trace to the naked eye of organic forms. Taking the entire deposit, it is generally quite white, or yellowish, or feebly tinted with green; it is either almost friable under the finger, or as hard as chalk; it is of easy fusibility, of little specific gravity, is not harsh to the touch, adheres to the tongue, and when breathed on exhales a strong aluminous odour; it sometimes contains a very little calcareous matter, and traces (besides the included laminæ) of gypsum. Under the microscope, according to Professor Ehrenberg,[2] it consists of minute, triturated, cellular, glassy fragments of pumice, with some broken crystals. In the minute glassy fragments, Professor Ehrenberg recognises organic structures, which have been affected by volcanic heat: in the specimens from this place, and from Port S. Julian, he finds sixteen Polygastrica and twelve Phytolitharia. Of these organisms, seven are new forms, the others being previously known: all are of marine, and chiefly of oceanic, origin. This deposit to the naked eye resembles the crust which often appears on weathered surfaces of feldspathic rocks; it likewise resembles those beds of earthy feldspathic matter, sometimes interstratified with porphyritic rocks, as is the case in this very district with the underlying purple claystone porphyry. From examining specimens under a common microscope, and comparing them with other specimens undoubtedly of volcanic origin, I had come to the same conclusion with Professor Ehrenberg, namely, that this great deposit, in its first origin, is of volcanic nature.

[2] “Monatsberichten de könig. Akad. zu Berlin,” vom April 1845.

Port S. Julian.—On the south side of the harbour, the following section (figure No. 17) gives the nature of the beds seen in the cliffs of the ninety feet plain. Beginning at the top:—first, the earthy mass (AA), including the remains of the Macrauchenia, with recent shells on the surface; second, the porphyritic shingle (B), which in its lower part is interstratified (owing, I believe, to redisposition during denudation) with the white pumiceous mudstone; third, this white mudstone, about twenty feet in thickness, and divided into two varieties (C and D), both closely resembling the lower, fine-grained, more unctuous and compact kind at Port Desire; and, as at that place, including much selenite; fourth, a fossiliferous mass, divided into three main beds, of which the uppermost is thin, and consists of ferruginous sandstone, with many shells of the great oyster and *Pecten Paranensis*; the middle bed (E) is a yellowish earthy sandstone abounding with Scutellæ; and the lowest bed (F) is an indurated, greenish, sandy clay, including large concretions of calcareous sandstone, many shells of the great oyster, and in parts almost made up of fragments of Balanidæ. Out of these three beds, I procured the following twelve species, of which the two first were exceedingly numerous in individuals, as were the Terebratulæ and Turritellæ in certain layers:—

1. Ostrea Patagonica, d’Orbigny, “Voyage, Pal.” (also at St. Fé, and whole coast of Patagonia).
2. Pecten Paranensis, d’Orbigny, “Voyage, Pal.” (St. Fé, S. Josef, Port Desire).
3. Pecten centralis, G. B. Sowerby (also at Port Desire and S. Cruz).
4. Pecten geminatus, G. B. Sowerby.
5. Terebratula Patagonica, G. B. Sowerby (also S. Josef).
6. Struthiolaria ornata, G. B. Sowerby (also S. Cruz).
7. Fusus Patagonicus, G. B. Sowerby.
8. Fusus Noachinus, G. B. Sowerby.
9. Scalaria rugulosa, G. B. Sowerby.
10. Turritella ambulacrum, G. B. Sowerby (also S. Cruz).
11. Pyrula, cast of, like P. ventricosa of Sowerby, Tank Cat.
12. Balanus varians, G. B. Sowerby.
13. Scutella, differing from the species from Nuevo Gulf.

No. 17
Section of the strata exhibited in the cliffs of the ninety feet plain at Port S. Julian.



At the head of the inner harbour of Port S. Julian, the fossiliferous mass is not displayed, and the sea-cliffs from the water’s edge to a height of between one and two hundred feet are formed of the white pumiceous mudstone, which here includes innumerable, far-extended, sometimes horizontal, sometimes inclined or vertical laminæ of transparent gypsum, often about an inch in thickness. Further inland, with the exception of the superficial gravel, the whole thickness of the truncated hills, which represent a formerly continuous plain 950 feet in height, appears to be formed of this white mudstone: here and there, however, at various heights, thin earthy layers, containing the great oyster, *Pecten Paranensis* and *Turritella ambulacrum*, are interstratified; thus showing that the whole mass belongs to the same epoch. I nowhere found even a fragment of a shell actually in the white deposit, and only a single cast of a Turritella. Out of the eighteen microscopic organisms discovered by Ehrenberg in the specimens from this place, ten are common to the same deposit at Port Desire. I may add that specimens of this white mudstone, with the same identical characters were brought me from two points,—one twenty miles north of S. Julian, where a wide gravel-capped plain, 350 feet in height, is thus composed; and the other forty miles south of S. Julian, where, on the old charts, the cliffs are marked as "*Chalk Hills.*"

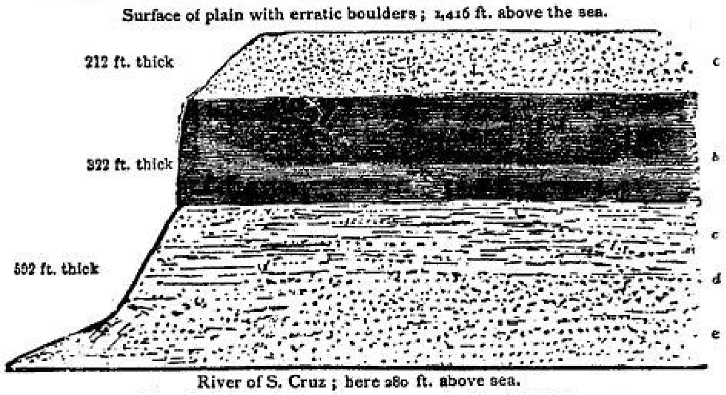
Santa Cruz.—The gravel-capped cliffs at the mouth of the river are 355 feet in height: the lower part, to a thickness of fifty or sixty feet, consists of a more or less hardened, darkish, muddy, or argillaceous sandstone (like the lowest bed of Port Desire), containing very many shells, some silicified and some converted into yellow calcareous spar. The great oyster is here numerous in layers; the Trigonocelia and Turritella are also very numerous: it is remarkable that the *Pecten Paranensis*, so common in all other parts of the coast, is here absent: the shells consist of:—

1. Ostrea Patagonica, d'Orbigny, "Voyage, Pal." (also at St. Fé and whole coast of Patagonia).
2. Pecten centralis, G. B. Sowerby (also P. Desire and S. Julian).
3. Venus meridionalis of G. B. Sowerby.
4. Crassatella Lyellii, G. B. Sowerby.
5. Cardium puelchum, G. B. Sowerby.
6. Cardita Patagonica, G. B. Sowerby.
7. Mactra rugata, G. B. Sowerby.
8. Mactra Darwinii, G. B. Sowerby.
9. Cucullæa alta, G. B. Sowerby (also P. Desire).
10. Trigonocelia insolita, G. B. Sowerby.
11. Nucula (?) glabra, G. B. Sowerby.
12. Crepidula gregaria, G. B. Sowerby.
13. Voluta alta, G. B. Sowerby.
14. Trochus collaris, G. B. Sowerby.
15. Natica solida (?), G. B. Sowerby.
16. Struthiolaria ornata, G. B. Sowerby (also P. Desire).
17. Turritella ambulacrum, G. B. Sowerby (also P. S. Julian).

Imperfect fragments of the genera Byssoarca, Artemis, and Fusus.

The upper part of the cliff is generally divided into three great strata, differing slightly in composition, but essentially resembling the pumiceous mudstone of the places farther north; the deposit, however, here is more arenaceous, of greater specific gravity, and not so white: it is interlaced with numerous thin veins, partially or quite filled with transverse fibres of gypsum; these fibres were too short to reach across the vein, have their extremities curved or bent: in the same veins with the gypsum, and likewise in separate veins as well as in little nests, there is much powdery sulphate of magnesia (as ascertained by Mr. Reeks) in an uncompressed form: I believe that this salt has not heretofore been found in veins. Of the three beds, the central one is the most compact, and more like ordinary sandstone: it includes numerous flattened spherical concretions, often united like a necklace, composed of hard calcareous sandstone, containing a few shells: some of these concretions were four feet in diameter, and in a horizontal line nine feet apart, showing that the calcareous matter must have been drawn to the centres of attraction, from a distance of four feet and a half on both sides. In the upper and lower finer-grained strata, there were other concretions of a grey colour, containing calcareous matter, and so fine-grained and compact, as almost to resemble porcelain-rock: I have seen exactly similar concretions in a volcanic tufaceous bed in Chiloe. Although in this upper fine-grained strata, organic remains were very rare, yet I noticed a few of the great oyster; and in one included soft ferruginous layer, there were some specimens of the *Cucullæa alta* (found at Port Desire in the lower fossiliferous mass) and of the *Mactra rugata*, which latter shell has been partially converted into gypsum.

No. 18
Section of the plain at Patagonia, on the banks of the S. Cruz.



a. Gravel and boulders. b. Basaltic lava.
c. Sedimentary layers. d. Bed of small pebbles. e. Talus.

In ascending the valley of the S. Cruz, the upper strata of the coast-cliffs are prolonged, with nearly the same characters, for fifty miles: at about this point, they begin in the most gradual and scarcely perceptible manner, to be banded with white lines; and after ascending ten miles farther, we meet with distinct thin layers of whitish, greenish, and yellowish fine-grained, fusible sediments. At eighty miles from the coast, [3] in a cliff thus composed, there were a few layers of ferruginous sandstone, and of an argillaceous sandstone with concretions of marl like those in the Pampas. At one hundred miles from the coast, that is at a central point between the Atlantic and the Cordillera, we have the section in figure No. 18.

[3] At this spot, for a space of three-quarters of a mile along the north side of the river, and for a width of half a mile, there has been a great slip, which has formed hills between sixty and seventy feet in height, and has tilted the strata into highly inclined and even vertical positions. The strata generally dipped at an angle of 45° towards the cliff from which they had slided. I have observed in slips, both on a small and large scale, that this inward dip is very general. Is it due to the hydrostatic pressure of water percolating with difficulty through the strata acting with greater force at the base of the mass than against the upper part?

The upper half of the sedimentary mass, under the basaltic lava, consists of innumerable zones of perfectly white bright green, yellowish and brownish, fine-grained, sometimes incoherent, sedimentary matter. The white, pumiceous, trachytic tuff-like varieties are of rather greater specific gravity than the pumiceous mudstone on the coast to the north; some of the layers, especially the browner ones, are coarser, so that the broken crystals are distinguishable with a weak lens. The layers vary in character in short distances. With the exception of a few of the *Ostrea Patagonica*, which appeared to have rolled down from the cliff above, no organic remains were found. The chief difference between these layers taken as a whole, and the upper beds both at the mouth of the river and on the coast northward, seems to lie in the occasional presence of more colouring matter, and in the supply having been intermittent; these characters, as we have seen, very gradually disappear in descending the valley, and this fact may perhaps be accounted for by the currents of a more open sea having blended together the sediment from a distant and intermittent source.

The coloured layers in the foregoing section rest on a mass, apparently of great thickness (but much hidden by the talus), of soft sandstone, almost composed of minute pebbles, from one-tenth to two-tenths of an inch in diameter, of the rocks (with the entire exception of the basaltic lava) composing the great boulders on the surface of the plain, and probably composing the neighbouring Cordillera. Five miles higher up the valley, and again thirty miles higher up[4] (that is twenty miles from the nearest range of the Cordillera), the lower plain included within the upper escarpments, is formed, as seen on the banks of the river, of a nearly similar but finer-grained, more earthy, laminated sandstone, alternating with argillaceous beds, and containing numerous moderately sized pebbles of the same rocks, and some shells of the great *Ostrea Patagonica.* As most of these shells had been rolled before being here embedded, their presence does not prove that the sandstone belongs to the great Patagonian tertiary formation, for they might have been redeposited in it, when the valley existed as a sea-strait; but as amongst the pebbles there were none of basalt, although the cliffs on both sides of the valley are composed of this rock, I believe that the sandstone does belong to this formation. At the highest point to which we ascended, twenty miles distant from the nearest slope of the Cordillera, I could see the horizontally zoned white beds, stretching under the black basaltic lava, close up to the mountains; so that the valley of the S. Cruz gives a fair idea of the constitution of the whole width of Patagonia.

> [4] I found at both places, but not *in situ*, quantities of coniferous and ordinary dicotyledonous silicified wood, which was examined for me by Mr. R. Brown.

Basaltic lava of the S. Cruz.—This formation is first met with sixty-seven miles from the mouth of the river; thence it extends uninterruptedly, generally but not exclusively on the northern side of the valley, close up to the Cordillera. The basalt is generally black and fine-grained, but sometimes grey and laminated; it contains some olivine, and high up the valley much glassy feldspar, where, also, it is often amygdaloidal; it is never highly vesicular, except on the sides of rents and on the upper and lower, spherically laminated surfaces. It is often columnar; and in one place I saw magnificent columns, each face twelve feet in width, with their interstices filled up with calcareous tuff. The streams rest conformably on the white sedimentary beds, but I nowhere saw the actual junction; nor did I anywhere see the white beds actually superimposed on the lava; but some way up the valley at the foot of the uppermost escarpments, they must be thus superimposed. Moreover, at the lowest point down the valley, where the streams thin out and terminate in irregular projections, the spaces or intervals between these projections are filled up to the level of the now denuded and gravel-capped surfaces of the plains, with the white-zoned sedimentary beds; proving that this matter continued to be deposited after the streams had flowed. Hence we may conclude that the basalt is contemporaneous with the upper parts of the great tertiary formation.

The lava where first met with is 130 feet in thickness: it there consists of two, three, or perhaps more streams, divided from each other by vesicular spheroids like those on the surface. From the streams having, as it appears, extended to different distances, the terminal points are of unequal heights. Generally the surface of the basalt is smooth them in one part high up the valley, it was so uneven and hummocky, that until I afterwards saw the streams extending continuously on both sides of the valley up to a height of about three thousand feet close to the Cordillera, I thought that the craters of eruption were probably close at hand. This hummocky surface I believe to have been caused by the crossing and heaping up of different streams. In one place, there were several rounded ridges about twenty feet in height, some of them as broad as high, and some broader, which certainly had been formed whilst the lava was fluid, for in transverse sections each ridge was seen to be concentrically laminated, and to be composed of imperfect columns radiating from common centres, like the spokes of wheels.

The basaltic mass where first met with is, as I have said, 130 feet in thickness, and, thirty-five miles higher up the valley, it increases to 322 feet. In the first fourteen and a half miles of this distance, the upper surface of the lava, judging from three measurements taken above the level of the river (of which the apparently very uniform inclination has been calculated from its total height at a point 135 miles from the mouth), slopes towards the Atlantic at an angle of only 0° 7′ 20″: this must be considered only as an approximate measurement, but it cannot be far wrong. Taking the whole thirty-five miles, the upper surface slopes at an angle of 0° 10′ 53″; but this result is of no value in showing the inclination of any one stream, for halfway between the two points of measurement, the surface suddenly rises between one hundred and two hundred feet, apparently caused by some of the uppermost streams having extended thus far and no farther. From the measurement made at these two points, thirty-five miles apart, the mean inclination of the sedimentary beds, over which the lava has flowed, is *now* (after elevation from under the sea) only 0° 7′ 52″: for the sake of comparison, it may be mentioned that the bottom of the present sea in a line from the mouth of the S. Cruz to the Falkland Islands, from a depth of seventeen fathoms to a depth of eighty-five fathoms, declines at an angle of 0° 1′ 22″; between the beach and the depth of seventeen fathoms, the slope is greater. From a point about half-way up the valley, the basaltic mass rises more abruptly towards the foot of the Cordillera, namely, from a height of 1,204 feet, to about 3,000 feet above the sea.

This great deluge of lava is worthy, in its dimensions, of the great continent to which it belongs. The aggregate streams have flowed from the Cordillera to a distance (unparalleled, I believe, in any case yet known) of about one hundred geographical miles. Near their furthest extremity their total thickness is 130 feet, which increase thirty-five miles farther inland, as we have just seen, to 322 feet. The least inclination given by M. E. de Beaumont of the upper surface of a lava-stream, namely 0° 30′, is that of the great subaerial eruption in 1783 from Skaptar Jukul in Iceland; and M. E. de Beaumont shows[5] that it must have flowed down a mean inclination of less than 0° 20′. But we now see that under the pressure of the sea, successive streams have flowed over a smooth bottom with a mean inclination of not more than 0° 7′ 52″; and that the upper surface of the terminal portion (over a space of fourteen and a half miles) has an inclination of not more than 0° 7′ 20″. If the elevation of Patagonia has been greater nearer the Cordillera than near the Atlantic (as is probable), then these angles are now all too large. I must repeat, that although the foregoing measurements, which were all carefully taken with the barometer, may not be absolutely correct, they cannot be widely erroneous.

[5] "Mémoires pour servir," etc., pp. 178 and 217.

Southward of the S. Cruz, the cliffs of the 840 feet plain extend to Coy Inlet, and owing to the naked patches of the white sediment, they are said on the charts to be "like the coast of Kent." At Coy Inlet the high plain trends inland, leaving flat-topped outliers. At Port Gallegos (lat. 51° 35′, and ninety miles south of S. Cruz), I am informed by Captain Sulivan, R.N., that there is a gravel-capped plain from two to three hundred feet in height, formed of numerous strata, some fine-grained and pale-coloured, like the upper beds at the mouth of the S. Cruz, others rather dark and coarser, so as to resemble gritstones or tuffs; these latter include rather large fragments of apparently decomposed volcanic rocks; there are, also, included layers of gravel. This formation is highly remarkable, from abounding with mammiferous remains, which have not as yet been examined by Professor Owen, but which include some large, but mostly small, species of Pachydermata, Edentata, and Rodentia. From the appearance of the pale-coloured, fine-grained beds, I was inclined to believe that they corresponded with the upper beds of the S. Cruz; but Professor Ehrenberg, who has examined some of the specimens, informs me that the included microscopical organisms are wholly different, being fresh and brackish-water forms. Hence the two to three hundred feet plain at Port Gallegos is of unknown age, but probably of subsequent origin to the great Patagonian tertiary formation.

Eastern Tierra del Fuego.—Judging from the height, the general appearance, and the white colour of the patches visible on the hill sides, the uppermost plain, both on the north and western side of the Strait of Magellan, and along the eastern coast of Tierra del Fuego as far south as near Port St. Polycarp, probably belongs to the great Patagonian tertiary formation. These higher table-ranges are fringed by low, irregular, extensive plains, belonging to the boulder formation,[6] and composed of coarse unstratified masses, sometimes associated (as north of C. Virgin's) with fine, laminated, muddy sandstones. The cliffs in Sebastian Bay are 200 feet in height, and are composed of fine sandstones, often in curvilinear layers, including hard concretions of calcareous sandstone, and layers of gravel. In these beds there are fragments of wood, legs of crabs, barnacles encrusted with corallines still partially retaining their colour, imperfect fragments of a Pholas distinct from any known species, and of a Venus, approaching very closely to, but slightly different in form from, the *V. lenticularis*, a species living on the coast of Chile. Leaves of trees are numerous between the laminæ of the muddy sandstone; they belong, as I am informed by Dr. J. D. Hooker,[7] to three species of deciduous beech, different from the two species which compose the great proportion of trees in this forest-clad land. From these facts it is difficult to conjecture, whether we here see the basal part of the great Patagonian formation, or some later deposit.

[6] Described in the "Geological Transactions," vol. vi, p. 415.

[7] "Botany of the Antarctic Voyage," p. 212.

Summary on the Patagonian tertiary formation.—Four out of the seven fossil shells, from St. Fé in Entre Rios, were found by M. d'Orbigny in the sandstone of the Rio Negro, and by me at San Josef. Three out of the six from San Josef are identical with those from Port Desire and S. Julian, which two places have together fifteen species, out of which three are common to both. Santa Cruz has seventeen species, out of which five are common to Port Desire and S. Julian. Considering the difference in latitude between these several places, and the small number of species altogether collected, namely thirty-six, I conceive the above proportional number of species in common, is sufficient to show that the lower fossiliferous mass belongs nearly, I do not say absolutely, to the same epoch. What this epoch may be, compared with the European tertiary stages, M. d’Orbigny will not pretend to determine. The thirty-six species (including those collected by myself and by M. d’Orbigny) are all extinct, or at least unknown; but it should be borne in mind, that the present coast consists of shingle, and that no one, I believe, has dredged here for shells; hence it is not improbable that some of the species may hereafter be found living. Some few of the species are closely related with existing ones; this is especially the case, according to M. d’Orbigny and Mr. Sowerby, with the *Fusus Patagonicus*; and, according to Mr. Sowerby, with the *Pyrula*, the *Venus meridionalis*, the *Crepidula gregaria*, and the *Turritella ambulacrum*, and *T. Patagonica.* At least three of the genera, namely, Cucullæa, Crassatella, and (as determined by Mr. Sowerby) Struthiolaria, are not found in this quarter of the world; and Trigonocelia is extinct. The evidence taken altogether indicates that this great tertiary formation is of considerable antiquity; but when treating of the Chilean beds, I shall have to refer again to this subject.

The white pumiceous mudstone, with its abundant gypsum, belongs to the same general epoch with the underlying fossiliferous mass, as may be inferred from the shells included in the intercalated layers at Nuevo Gulf, S. Julian, and S. Cruz. Out of the twenty-seven marine microscopic structures found by Professor Ehrenberg in the specimens from S. Julian and Port Desire, ten are common to these two places: the three found at Nuevo Gulf are distinct. I have minutely described this deposit, from its remarkable characters and its wide extension. From Coy Inlet to Port Desire, a distance of 230 miles, it is certainly continuous; and I have reason to believe that it likewise extends to the Rio Chupat, Nuevo Gulf, and San Josef, a distance of 570 miles: we have, also, seen that a single layer occurs at the Rio Negro. At Port S. Julian it is from eight to nine hundred feet in thickness; and at S. Cruz it extends, with a slightly altered character, up to the Cordillera. From its microscopic structure, and from its analogy with other formations in volcanic districts, it must be considered as originally of volcanic origin: it may have been formed by the long-continued attrition of vast quantities of pumice, or judging from the manner in which the mass becomes, in ascending the valley of S. Cruz, divided into variously coloured layers, from the long-continued eruption of clouds of fine ashes. In either case, we must conclude, that the southern volcanic orifices of the Cordillera, now in a dormant state, were at about this period over a wide space, and for a great length of time, in action. We have evidence of this fact, in the latitude of the Rio Negro, in the sandstone-conglomerate with pumice, and demonstrative proof of it, at S. Cruz, in the vast deluges of basaltic lava: at this same tertiary period, also, there is distinct evidence of volcanic action in Western Banda Oriental.

The Patagonian tertiary formation extends continuously, judging from fossils alone, from S. Cruz to near the Rio Colorado, a distance of above six hundred miles, and reappears over a wide area in Entre Rios and Banda Oriental, making a total distance of 1,100 miles; but this formation undoubtedly extends (though no fossils were collected) far south of the S. Cruz, and, according to M. d’Orbigny, 120 miles north of St. Fé. At S. Cruz we have seen that it extends across the continent; being on the coast about eight hundred feet in thickness (and rather more at S. Julian), and rising with the contemporaneous lava-streams to a height of about three thousand feet at the base of the Cordillera. It rests, wherever any underlying formation can be seen, on plutonic and metamorphic rocks. Including the newer Pampean deposit, and those strata in Eastern Tierra del Fuego of doubtful age, as well as the boulder formation, we have a line of more than twenty-seven degrees of latitude, equal to that from the Straits of Gibraltar to the south of Iceland, continuously composed of tertiary formations. Throughout this great space the land has been upraised, without the strata having been in a single instance, as far as my means of observation went, unequally tilted or dislocated by a fault.

Tertiary Formations on the West Coast.

Chonos Archipelago.—The numerous islands of this group, with the exception of Lemus, Ypun, consist of metamorphic schists; these two islands are formed of softish grey and brown, fusible, often laminated sandstones, containing a few pebbles, fragments of black lignite, and numerous mammillated concretions of hard calcareous sandstone. Out of these concretions at Ypun (lat. 40° 30′ S.), I extracted the four following extinct species of shells:—

1. Turritella suturalis, G. B. Sowerby (also Navidad).
2. Sigaretus subglobosus, G. B. Sowerby (also Navidad).
3. Cytheræa (?) sulculosa (?), G. B. Sowerby (also Chiloe and Huafo?).

4. Voluta, fragments of.

In the northern parts of this group there are some cliffs of gravel and of the boulder formation. In the southern part (at P. Andres in Tres Montes), there is a volcanic formation, probably of tertiary origin. The lavas attain a thickness of from two to three hundred feet; they are extremely variable in colour and nature, being compact, or brecciated, or cellular, or amygdaloidal with zeolite, agate and bole, or porphyritic with glassy albitic feldspar. There is also much imperfect rubbly pitchstone, with the interstices charged with powdery carbonate of lime apparently of contemporaneous origin. These lavas are conformably associated with strata of breccia and of brown tuff containing lignite. The whole mass has been broken up and tilted at an angle of 45°, by a series of great volcanic dikes, one of which was thirty yards in breadth. This volcanic formation resembles one, presently to be described, in Chiloe.

Huafo.—This island lies between the Chonos and Chiloe groups: it is about eight hundred feet high, and perhaps has a nucleus of metamorphic rocks. The strata which I examined consisted of fine-grained muddy sandstones, with fragments of lignite and concretions of calcareous sandstone. I collected the following extinct shells, of which the Turritella was in great numbers:—

1. Bulla cosmophila, G. B. Sowerby.
2. Pleurotoma subæqualis, G. B. Sowerby.
3. Fusus cleryanus, d’Orbigny, “Voyage Pal.” (also at Coquimbo).
4. Triton leucostomoides, G. B. Sowerby.
5. Turritella Chilensis, G. B. Sowerby (also Mocha).
6. Venus, probably a distinct species, but very imperfect.
7. Cytheræa (?) sulculosa (?), probably a distinct species, but very imperfect.
8. Dentalium majus, G. B. Sowerby.

Chiloe.—This fine island is about one hundred miles in length. The entire southern part, and the whole western coast, consists of mica-schist, which likewise is seen in the ravines of the interior. The central mountains rise to a height of 3,000 feet, and are said to be partly formed of granite and greenstone: there are two small volcanic districts. The eastern coast, and large parts of the northern extremity of the island are composed of gravel, the boulder formation, and underlying horizontal strata. The latter are well displayed for twenty miles north and south of Castro; they vary in character from common sandstone to fine-grained, laminated mudstones: all the specimens which I examined are easily fusible, and some of the beds might be called volcanic grit-stones. These latter strata are perhaps related to a mass of columnar trachyte which occurs behind Castro. The sandstone occasionally includes pebbles, and many fragments and layers of lignite; of the latter, some are apparently formed of wood and others of leaves: one layer on the N.W. side of Lemuy is nearly two feet in thickness. There is also much silicified wood, both common dicotyledonous and coniferous: a section of one specimen in the direction of the medullary rays has, as I am informed by Mr. R. Brown, the discs in a double row placed alternately, and not opposite as in the true Araucaria. I found marine remains only in one spot, in some concretions of hard calcareous sandstone: in several other districts I have observed that organic remains were exclusively confined to such concretions; are we to account for this fact, by the supposition that the shells lived only at these points, or is it not more probable that their remains were preserved only where concretions were formed? The shells here are in a bad state, they consist of:—

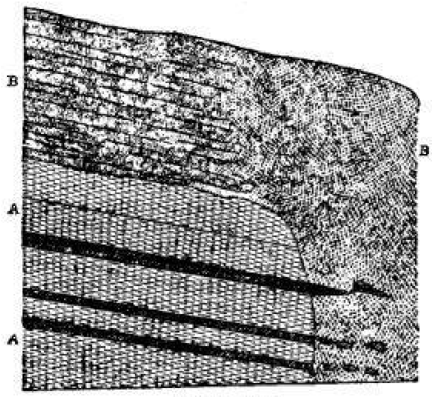
1. Tellinides (?) oblonga, G. B. Sowerby (a solenella in M. d’Orbigny’s opinion).
2. Natica striolata, G. B. Sowerby.
3. Natica (?) pumila, G. B. Sowerby.
4. Cytheræa (?) sulculosa, G. B. Sowerby (also Ypun and Huafo?).

At the northern extremity of the island, near S. Carlos, there is a large volcanic formation, between five and seven hundred feet in thickness. The commonest lava is blackish-grey or brown, either vesicular, or amygdaloidal with calcareous spar and bole: most even of the darkest varieties fuse into a pale-coloured glass. The next commonest variety is a rubbly, rarely well characterised pitchstone (fusing into a white glass) which passes in the most irregular manner into stony grey lavas. This pitchstone, as well as some purple claystone porphyry, certainly flowed in the form of streams. These various lavas often pass, at a considerable depth from the surface, in the most abrupt and singular manner into wacke. Great masses of the solid rock are brecciated, and it was generally impossible to discover whether the recementing process had been an igneous or aqueous action.[8] The beds are obscurely separated from each other; they are sometimes parted by seams of tuff and layers of pebbles. In one place they rested on, and in another place were capped by, tuffs and girt-stones, apparently of submarine origin.

[8] In a cliff of the hardest fragmentary mass, I found several tortuous, vertical veins, varying in thickness from a few tenths of an inch to one inch and a half, of a substance which I have not seen described. It is glossy, and of a brown colour; it is thinly laminated, with the laminæ transparent and elastic; it is a little harder than calcareous spar; it is infusible under the blowpipe, sometimes decrepitates, gives out water, curls up, blackens, and becomes magnetic. Borax easily dissolves a considerable quantity of it, and gives a glass tinged with green. I have no idea what its true nature is. On first seeing it, I mistook it for lignite!

The neighbouring peninsula of Lacuy is almost wholly formed of tufaceous deposits, connected probably in their origin with the volcanic hills just described. The tuffs are pale-coloured, alternating with laminated mudstones and sandstones (all easily fusible), and passing sometimes into fine-grained white beds strikingly resembling the great upper infusorial deposit of Patagonia, and sometimes into brecciolas with pieces of pumice in the last stage of decay; these again pass into ordinary coarse breccias and conglomerates of hard rocks. Within very short distances, some of the finer tuffs often passed into each other in a peculiar manner, namely, by irregular polygonal concretions of one variety increasing so much and so suddenly in size, that the second variety, instead of any longer forming the entire mass, was left merely in thin veins between the concretions. In a straight line of cliffs, at Point Tenuy, I examined the following remarkable section (figure No. 19):—

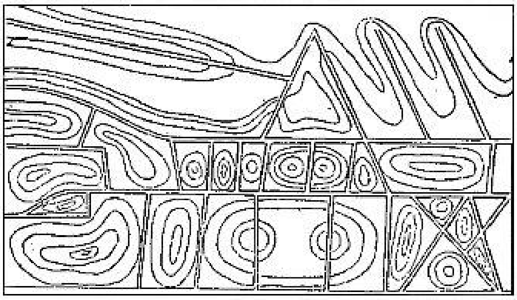
No. 19



Level of sea.

On the left hand, the lower part (AA) consists of regular, alternating strata of brown tuffs and greenish laminated mudstone, gently inclined to the right, and conformably covered by a mass (B *left*) of a white, tufaceous and brecciolated deposit. On the right hand, the whole cliff (BB *right*) consists of the same white tufaceous matter, which on this side presents scarcely a trace of stratification, but to the left becomes very gradually and rather indistinctly divided into strata quite conformable with the underlying beds (AA): moreover, a few hundred yards further to the left, where the surface has been less denuded, the tufaceous strata (B *left*) are conformably covered by another set of strata, like the underlying ones (AA) of this section. In the middle of the diagram, the beds (AA) are seen to be abruptly cut off, and to abut against the tufaceous non-stratified mass; but the line of junction has been accidentally not represented steep enough, for I particularly noticed that before the beds had been tilted to the right, this line must have been nearly vertical. It appears that a current of water cut for itself a deep and steep submarine channel, and at the same time or afterwards filled it up with the tufaceous and brecciolated matter, and spread the same over the surrounding submarine beds; the matter becoming stratified in these more distant and less troubled parts, and being moreover subsequently covered up by other strata (like AA) not shown in the diagram. It is singular that three of the beds (of AA) are prolonged in their proper direction, as represented, beyond the line of junction into the white tufaceous matter: the prolonged portions of two of the beds are rounded; in the third, the terminal fragment has been pushed upwards: how these beds could have been left thus prolonged, I will not pretend to explain. In another section on the opposite side of a promontory, there was at the foot of this same line of junction, that is at the bottom of the old submarine channel, a pile of fragments of the strata (AA), with their interstices filled up with white tufaceous matter: this is exactly what might have been anticipated under such circumstances.

No. 20
Ground plan showing the relation between veins and concretionary zones in a mass of tuff.



The various tufaceous and other beds at this northern end of Chiloe probably belong to about the same age with those near Castro, and they contain, as there, many fragments of black lignite and of silicified and pyritous wood, often embedded close together. They also contain many and singular concretions: some are of hard calcareous sandstone, in which it would appear that broken volcanic crystals and scales of mica have been better preserved (as in the case of the organic remains near Castro) than in the surrounding mass. Other concretions in the white brecciola are of a hard, ferruginous, yet fusible, nature; they are as round as cannon-balls, and vary from two or three inches to two feet in diameter; their insides generally consist either of fine, scarcely coherent volcanic sand,[9] or of an argillaceous tuff; in this latter case, the external crust was quite thin and hard. Some of these spherical balls were encircled in the line of their equators, by a necklace-like row of smaller concretions. Again there were other concretions, irregularly formed, and composed of a hard, compact, ash-coloured stone, with an almost porcelainous fracture, adhesive to the tongue, and without any calcareous matter. These beds are, also, interlaced by many veins, containing gypsum, ferruginous matter, calcareous spar, and agate. It was here seen with remarkable distinctness, how intimately concretionary action and the production of fissures and veins are related together. Figure 20 is an accurate representation of a horizontal space of tuff, about four feet long by two and a half in width: the double lines represent the fissures partially filled with oxide of iron and agate: the curvilinear lines show the course of the innumerable, concentric, concretionary zones of different shades of colour and of coarseness in the particles of tuff. The symmetry and complexity of the arrangement gave the surface an elegant appearance. It may be seen how obviously the fissures determine (or have been determined by) the shape, sometimes of the whole concretion, and sometimes only of its central parts. The fissures also determine the curvatures of the long undulating zones of concretionary action. From the varying composition of the veins and concretions, the amount of chemical action which the mass has undergone is surprisingly great; and it would likewise appear from the difference in size in the particles of the concretionary zones, that the mass, also, has been subjected to internal mechanical movements.

[9] The frequent tendency in iron to form hollow concretions or shell containing incoherent matter is singular; D'Aubuisson ("Traité de Géogn." tome i, p. 318) remarks on this circumstance.

In the peninsula of Lacuy, the strata over a width of four miles have been upheaved by three distinct, and some other indistinct, lines of elevation, ranging within a point of north and south. One line, about two hundred feet in height, is regularly anticlinal, with the strata dipping away on both sides, at an angle of 15°, from a central "valley of elevation," about three hundred yards in width. A second narrow steep ridge, only sixty feet high, is uniclinal, the strata throughout dipping westward; those on both flanks being inclined at an angle of from ten to fifteen degrees; whilst those on the ridge dip in the same direction at an angle of between thirty and forty degrees. This ridge, traced northwards, dies away; and the beds at its terminal point, instead of dipping westward, are inclined 12° to the north. This case interested me, as being the first in which I found in South America, formations perhaps of tertiary origin, broken by lines of elevation.

Valdivia: Island of Mocha.—The formations of Chiloe seem to extend with nearly the same character to Valdivia, and for some leagues northward of it: the underlying rocks are micaceous schists, and are covered up with sandstone and other sedimentary beds, including, as I was assured, in many places layers of lignite. I did not land on Mocha (lat. 38° 20′), but Mr. Stokes brought me specimens of the grey, fine-grained, slightly calcareous sandstone, precisely like that of Huafo, containing lignite and numerous Turritellæ. The island is flat topped, 1,240 feet in height, and appears like an outlier of the sedimentary beds on the mainland. The few shells collected consist of:—

1. Turritella Chilensis, G. B. Sowerby (also at Huafo).
2. Fusus, very imperfect, somewhat resembling F. subreflexus of Navidad, but probably different.
3. Venus, fragments of.

Concepcion.—Sailing northward from Valdivia, the coast-cliffs are seen, first to assume near the R. Tolten, and thence for 150 miles northward, to be continued with the same mineralogical characters, immediately to be described at Concepcion. I heard in many places of beds of lignite, some of it fine and glossy, and likewise of silicified wood; near the Tolten the cliffs are low, but they soon rise in height; and the horizontal strata are prolonged, with a nearly level surface, until coming to a more lofty tract between points Rumena and Lavapie. Here the beds have been broken up by at least eight or nine parallel lines of elevation, ranging E. or E.N.E. and W. or W.S.W. These lines can be followed with the eye many miles into the interior; they are all uniclinal, the strata in each dipping to a point between S. and S.S.E. with an inclination in the central lines of about forty degrees, and in the outer ones of under twenty degrees. This band of symmetrically troubled country is about eight miles in width.

The island of Quiriquina, in the Bay of Concepcion, is formed of various soft and often ferruginous sandstones, with bands of pebbles, and with the lower strata sometimes passing into a conglomerate resting on the underlying metamorphic schists. These beds include subordinate layers of greenish impure clay, soft micaceous and calcareous sandstones, and reddish friable earthy matter with white specks like decomposed crystals of feldspar; they include, also, hard concretions, fragments of shells, lignite, and silicified wood. In the upper part they pass into white, soft sediments and brecciolas, very like those described at Chiloe; as indeed is the whole formation. At Lirguen and other places on the eastern side of the bay, there are good sections of the lower sandstones, which are generally ferruginous, but which vary in character, and even pass into an argillaceous nature; they contain hard concretions, fragments of lignite, silicified wood, and pebbles (of the same rocks with the pebbles in the sandstones of Quiriquina), and they alternate with numerous, often very thin layers of imperfect coal, generally of little specific gravity. The main bed here is three feet thick; and only the coal of this one bed has a glossy fracture. Another irregular, curvilinear bed of brown, compact lignite, is remarkable for being included in a mass of coarse gravel. These imperfect coals, when placed in a heap, ignite spontaneously. The cliffs on this side of the bay, as well as on the island of Quiriquina, are capped with red friable earth, which, as stated in the Second Chapter, is of recent formation. The stratification in this neighbourhood is generally horizontal; but near Lirguen the beds dip N.W. at an angle of 23°; near Concepcion they are also inclined: at the northern end of Quiriquina they have been tilted at an angle of 30°, and at the southern end at angles varying from 15° to 40°: these dislocations must have taken place under the sea.

A collection of shells, from the island of Quiriquina, has been described by M. d’Orbigny: they are all extinct, and from their generic character, M. d’Orbigny inferred that they were of tertiary origin: they consist of:—

1. Scalaria Chilensis, d’Orbigny, “Voyage, Part Pal.”
2. Natica Araucana, d’Orbigny, “Voyage, Part Pal.”
3. Natica australis, d’Orbigny, “Voyage, Part Pal.”
4. Fusus difficilis, d’Orbigny, “Voyage, Part Pal.”
5. Pyrula longirostra, d’Orbigny, “Voyage, Part Pal.”
6. Pleurotoma Araucana, d’Orbigny, “Voyage, Part Pal.”
7. Cardium auca, d’Orbigny, “Voyage, Part Pal.”
8. Cardium acuticostatum, d’Orbigny, “Voyage, Part Pal.”
9. Venus auca, d’Orbigny, “Voyage, Part Pal.”

10. Mactra cecileana, d'Orbigny, "Voyage, Part Pal."
11. Mactra Araucana, d'Orbigny, "Voyage, Part Pal."
12. Arca Araucana, d'Orbigny, "Voyage, Part Pal."
13. Nucula Largillierti, d'Orbigny, "Voyage, Part Pal."
14. Trigonia Hanetiana, d'Orbigny, "Voyage, Part Pal."

During a second visit of the *Beagle* to Concepcion, Mr. Kent collected for me some silicified wood and shells out of the concretions in the sandstone from Tome, situated a short distance north of Lirguen. They consist of:—

1. Natica australis, d'Orbigny, "Voyage, Part Pal."
2. Mactra Araucana, d'Orbigny, "Voyage, Part Pal."
3. Trigonia Hanetiana, d'Orbigny, "Voyage, Part Pal."
4. Pecten, fragments of, probably two species, but too imperfect for description.
5. Baculites vagina, E. Forbes.
6. Nautilus d'Orbignyanus, E. Forbes.

Besides these shells, Captain Belcher[10] found here an *Ammonite*, nearly three feet in diameter, and so heavy that he could not bring it away; fragments are deposited at Haslar Hospital: he also found the silicified vertebræ of some very large animal. From the identity in mineralogical nature of the rocks, and from Captain Belcher's minute description of the coast between Lirguen and Tome, the fossiliferous concretions at this latter place certainly belong to the same formation with the beds examined by myself at Lirguen; and these again are undoubtedly the same with the strata of Quiriquina; moreover; the three first of the shells from Tome, though associated in the same concretions with the Baculite, are identical with the species from Quiriquina. Hence all the sandstone and lignitiferous beds in this neighbourhood certainly belong to the same formation. Although the generic character of the Quiriquina fossils naturally led M. d'Orbigny to conceive that they were of tertiary origin, yet as we now find them associated with the *Baculites vagina* and with an Ammonite, we must, in the opinion of M. d'Orbigny, and if we are guided by the analogy of the northern hemisphere, rank them in the Cretaceous system. Moreover, the *Baculites vagina*, which is in a tolerable state of preservation, appears to Professor E. Forbes certainly to be identical with a species, so named by him, from Pondicherry in India; where it is associated with numerous decidedly cretaceous species, which approach most nearly to Lower Greensand or Neocomian forms: this fact, considering the vast distance between Chile and India, is truly surprising. Again, the *Nautilus d'Orbignyanus*, as far as its imperfect state allows of comparison, resembles, as I am informed by Professor Forbes, both in its general form and in that of its chambers, two species from the Upper Greensand. It may be added that every one of the above-named genera from Quiriquina, which have an apparently tertiary character, are found in the Pondicherry strata. There are, however, some difficulties on this view of the formations at Concepcion being cretaceous, which I shall afterwards allude to; and I will here only state that the *Cardium auca* is found also at Coquimbo, the beds at which place, there can be no doubt, are tertiary.

[10] "Zoology of Captain Beechey's Voyage," p. 163.

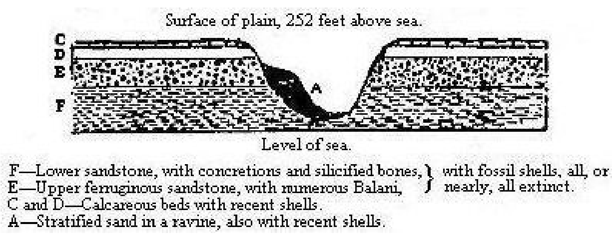
Navidad.[11]—The Concepcion formation extends some distance northward, but how far I know not; for the next point at which I landed was at Navidad, 160 miles north of Concepcion, and 60 miles south of Valparaiso. The cliffs here are about eight hundred feet in height: they consist, wherever I could examine them, of fine-grained, yellowish, earthy sandstones, with ferruginous veins, and with concretions of hard calcareous sandstone. In one part, there were many pebbles of the common metamorphic porphyries of the Cordillera: and near the base of the cliff, I observed a single rounded boulder of greenstone, nearly a yard in diameter. I traced this sandstone formation beneath the superficial covering of gravel, for some distance inland: the strata are slightly inclined from the sea towards the Cordillera, which apparently has been caused by their having been accumulated against or round outlying masses of granite, of which some points project near the coast. The sandstone contains fragments of wood, either in the state of lignite or partially silicified, sharks' teeth, and shells in great abundance, both high up and low down the sea-cliffs. Pectunculus and Oliva were most numerous in individuals, and next to them Turritella and Fusus. I collected in a short time, though suffering from illness, the following thirty-one species, all of which are extinct, and several of the genera do not now range (as we shall hereafter show) nearly so far south:—

1. Gastridium cepa, G. B. Sowerby.
2. Monoceros, fragments of, considered by M. d’Orbigny as a new species.
3. Voluta alta, G. B. Sowerby (considered by M. d’Orbigny as distinct from the V. alta of Santa Cruz).
4. Voluta triplicata, G. B. Sowerby.
5. Oliva dimidiata, G. B. Sowerby.
6. Pleurotoma discors, G. B. Sowerby.
7. Pleurotoma turbinelloides, G. B. Sowerby.
8. Fusus subreflexus, G. B. Sowerby.
9. Fusus pyruliformis, G. B. Sowerby.
10. Fusus, allied to F. regularis (considered by M. d’Orbigny as a distinct species).
11. Turritella suturalis, G. B. Sowerby.
12. Turritella Patagonica, G. B. Sowerby (fragments of).
13. Trochus lævis, G. B. Sowerby.
14. Trochus collaris, G. B. Sowerby (considered by M. d’Orbigny as the young of the T. lævis).
15. Cassis monilifer, G. B. Sowerby.
16. Pyrula distans, G. B. Sowerby.
17. Triton verruculosus, G. B. Sowerby.
18. Sigaretus subglobosus, G. B. Sowerby.
19. Natica solida, G. B. Sowerby. (It is doubtful whether the Natica solida of S. Cruz is the same species with this.)
20. Terebra undulifera, G. B. Sowerby.
21. Terebra costellata, G. B. Sowerby.
22. Bulla (fragments of).
23. Dentalium giganteum, do.
24. Dentalium sulcosum, do.
25. Corbis (?) lævigata, do.
26. Cardium multiradiatum, do.
27. Venus meridionalis, do.
28. Pectunculus dispar, (?) Desh. (considered by M. d’Orbigny as a distinct species).
29. and 30. Cytheræa and Mactra, fragments of (considered by M. d’Orbigny as new species).
30. Pecten, fragments of.

[11] I was guided to this locality by the Report on M. Gay’s “Geological Researches,” in the “Annales des Scienc. Nat.” (1st series, tome 28.

Coquimbo.—For more than two hundred miles northward of Navidad, the coast consists of plutonic and metamorphic rocks, with the exception of some quite insignificant superficial beds of recent origin. At Tonguay, twenty-five miles south of Coquimbo, tertiary beds recommence. I have already minutely described in the Second Chapter, the step-formed plains of Coquimbo, and the upper calcareous beds (from twenty to thirty feet in thickness) containing shells of recent species, but in different proportions from those on the beach. There remains to be described only the underlying ancient tertiary beds, represented in Figure 21 by the letters F and E:—

No. 21
Section of the tertiary formation at Coquimbo.



I obtained good sections of bed (F) only in Herradura Bay: it consists of soft whitish sandstone, with ferruginous veins, some pebbles of granite, and concretionary layers of hard calcareous sandstone. These concretions are remarkable from the great number of large silicified bones, apparently of cetaceous animals, which they contain; and likewise of a shark’s teeth, closely resembling those of the *Carcharias megalodon.* Shells of the following species, of which the gigantic Oyster and Perna are the most conspicuous, are numerously embedded in the concretions:—

1. Bulla ambigua, d’Orbigny, “Voyage,” Pal.

2. Monoceros Blainvillii, d’Orbigny, “Voyage,” Pal.
3. Cardium auca, d’Orbigny, “Voyage,” Pal.
4. Panopæa Coquimbensis, d’Orbigny, “Voyage,” Pal.
5. Perna Gaudichaudi, d’Orbigny, “Voyage,” Pal.
6. Artemis ponderosa; Mr. Sowerby can find no distinguishing character between this fossil and the recent A. ponderosa; it is certainly an Artemis, as shown by the pallial impression.
7. Ostrea Patagonica (?); Mr. Sowerby can point out no distinguishing character between this species and that so eminently characteristic of the great Patagonian formation; but he will not pretend to affirm that they are identical.
8. Fragments of a Venus and Natica.

The cliffs on one side of Herradura Bay are capped by a mass of stratified shingle, containing a little calcareous matter, and I did not doubt that it belonged to the same recent formation with the gravel on the surrounding plains, also cemented by calcareous matter, until to my surprise, I found in the midst of it, a single thin layer almost entirely composed of the above gigantic oyster.

At a little distance inland, I obtained several sections of the bed (E), which, though different in appearance from the lower bed (F), belongs to the same formation: it consists of a highly ferruginous sandy mass, almost composed, like the lowest bed at Port S. Julian, of fragments of Balanidæ; it includes some pebbles, and layers of yellowish-brown mudstone. The embedded shells consist of:—

1. Monoceros Blainvillii, d’Orbigny, “Voyage” Pal.
2. Monoceros ambiguus, G. B. Sowerby.
3. Anomia alternans, G. B. Sowerby.
4. Pecten rudis, G. B. Sowerby.
5. Perna Gaudichaudi, d’Orbigny, “Voyage” Pal.
6. Ostrea Patagonica (?), d’Orbigny, “Voyage” Pal.
7. Ostrea, small species, in imperfect state; it appeared to me like a small kind now living in, but very rare in the bay.
8. Mytilus Chiloensis; Mr. Sowerby can find no distinguishing character between this fossil, as far as its not very perfect condition allows of comparison, and the recent species.
9. Balanus Coquimbensis, G. B. Sowerby.
10. Balanus psittacus? King. This appears to Mr. Sowerby and myself identical with a very large and common species now living on the coast.

The uppermost layers of this ferrugino-sandy mass are conformably covered by, and impregnated to the depth of several inches with, the calcareous matter of the bed (D) called *losa*: hence I at one time imagined that there was a gradual passage between them; but as all the species are recent in the bed (D), whilst the most characteristic shells of the uppermost layers of (E) are the extinct Perna, Pecten, and Monoceros, I agree with M. d’Orbigny, that this view is erroneous, and that there is only a mineralogical passage between them, and no gradual transition in the nature of their organic remains. Besides the fourteen species enumerated from these two lower beds, M. d’Orbigny has described ten other species given to him from this locality; namely:—

1. Fusus Cleryanus, d’Orbigny, “Voyage” Pal.
2. Fusus petitianus, d’Orbigny, “Voyage” Pal.
3. Venus hanetiana, d’Orbigny, “Voyage” Pal.
4. Venus incerta (?) d’Orbigny, “Voyage” Pal.
5. Venus Cleryana, d’Orbigny, “Voyage” Pal.
6. Venus petitiana, d’Orbigny, “Voyage” Pal.
7. Venus Chilensis, d’Orbigny, “Voyage” Pal.
8. Solecurtus hanetianus, d’Orbigny, “Voyage” Pal.
9. Mactra auca, d’Orbigny, “Voyage” Pal.
10. Oliva serena, d’Orbigny, “Voyage” Pal.

Of these twenty-four shells, all are extinct, except, according to Mr. Sowerby, the *Artemis ponderosa, Mytilus Chiloensis,* and probably the great Balanus.

Coquimbo to Copiapo.—A few miles north of Coquimbo, I met with the ferruginous, balaniferous mass (E) with many silicified bones; I was informed that these silicified bones occur also at Tonguay, south of Coquimbo: their number is certainly remarkable, and they seem to take the place of the silicified wood, so common on the coast-formations of Southern Chile. In the valley of Chañeral, I again saw this same formation, capped with the recent calcareous beds. I here left the coast, and did not see any more of the tertiary formations, until descending to the sea at Copiapo: here in one place I found variously coloured layers of sand and soft sandstone, with seams of gypsum, and in another place, a comminuted shelly mass, with layers of rotten-stone and seams of gypsum, including many of the extinct gigantic oyster: beds with these oysters are said to occur at English Harbour, a few miles north of Copiapo.

Coast of Peru.—With the exception of deposits containing recent shells and of quite insignificant dimensions, no tertiary formations have been observed on this coast, for a space of twenty-two degrees of latitude north of Copiapo, until coming to Payta, where there is said to be a considerable calcareous deposit: a few fossils have been described by M. d'Orbigny from this place, namely:—

1. Rostellaria Gaudichaudi, d'Orbigny, "Voyage" Pal.
2. Pectunculus Paytensis, d'Orbigny, "Voyage" Pal.
3. Venus petitiana, d'Orbigny, "Voyage" Pal.
4. Ostrea Patagonica? This great oyster (of which specimens have been given me) cannot be distinguished by Mr. Sowerby from some of the varieties from Patagonia; though it would be hazardous to assert it is the same with that species, or with that from Coquimbo.

Concluding Remarks.—The formations described in this chapter, have, in the case of Chiloe and probably in that of Concepcion and Navidad, apparently been accumulated in troughs formed by submarine ridges extending parallel to the ancient shores of the continent; in the case of the islands of Mocha and Huafo it is highly probable, and in that of Ypun and Lemus almost certain, that they were accumulated round isolated rocky centres or nuclei, in the same manner as mud and sand are now collecting round the outlying islets and reefs in the West Indian Archipelago. Hence, I may remark, it does not follow that the outlying tertiary masses of Mocha and Huafo were ever continuously united at the same level with the formations on the mainland, though they may have been of contemporaneous origin, and been subsequently upraised to the same height. In the more northern parts of Chile, the tertiary strata seem to have been separately accumulated in bays, now forming the mouths of valleys.

The relation between these several deposits on the shores of the Pacific, is not nearly so clear as in the case of the tertiary formations on the Atlantic. Judging from the form and height of the land (evidence which I feel sure is here much more trustworthy than it can ever be in such broken continents as that of Europe), from the identity of mineralogical composition, from the presence of fragments of lignite and of silicified wood, and from the intercalated layers of imperfect coal, I must believe that the coast-formations from Central Chiloe to Concepcion, a distance of 400 miles, are of the same age: from nearly similar reasons, I suspect that the beds of Mocha, Huafo, and Ypun, belong also to the same period. The commonest shell in Mocha and Huafo is the same species of Turritella; and I believe the same Cytheræa is found on the islands of Huafo, Chiloe, and Ypun; but with these trifling exceptions, the few organic remains found at these places are distinct. The numerous shells from Navidad, with the exception of two, namely, the Sigaretus and Turritella found at Ypun, are likewise distinct from those found in any other part of this coast. Coquimbo has *Cardium auca* in common with Concepcion, and *Fusus Cleryanus* with Huafo; I may add, that Coquimbo has *Venus petitiana*, and a gigantic oyster (said by M. d'Orbigny also to be found a little south of Concepcion) in common with Payta, though this latter place is situated twenty-two degrees northward of lat. 27°, to which point the Coquimbo formation extends.

From these facts, and from the generic resemblance of the fossils from the different localities, I cannot avoid the suspicion that they all belong to nearly the same epoch, which epoch, as we shall immediately see, must be a very ancient tertiary one. But as the Baculite, especially considering its apparent identity with the Cretaceous Pondicherry species, and the presence of an Ammonite, and the resemblance of the Nautilus to two upper greensand species, together afford very strong evidence that the formation of Concepcion is a Secondary one; I will, in my remarks on the fossils from the other localities, put on one side those from Concepcion and from Eastern Chiloe, which, whatever their age may be, appear to me to belong to one group. I must, however, again call attention to the fact that the *Cardium auca* is found both at Concepcion and in the undoubtedly tertiary strata of Coquimbo: nor should the possibility be overlooked, that as Trigonia, though known in the northern hemisphere only as a Secondary genus, has living representatives in the

Australian seas, so a Baculite, Ammonite, and Trigonia may have survived in this remote part of the southern ocean to a somewhat later period than to the north of the equator.

Before passing in review the fossils from the other localities, there are two points, with respect to the formations between Concepcion and Chiloe, which deserve some notice. First, that though the strata are generally horizontal, they have been upheaved in Chiloe in a set of parallel anticlinal and uniclinal lines ranging north and south,—in the district near P. Rumena by eight or nine far-extended, most symmetrical, uniclinal lines ranging nearly east and west,—and in the neighbourhood of Concepcion by less regular single lines, directed both N.E. and S.W., and N.W. and S.E. This fact is of some interest, as showing that within a period which cannot be considered as very ancient in relation to the history of the continent, the strata between the Cordillera and the Pacific have been broken up in the same variously directed manner as have the old plutonic and metamorphic rocks in this same district. The second point is, that the sandstone between Concepcion and Southern Chiloe is everywhere lignitiferous, and includes much silicified wood; whereas the formations in Northern Chile do not include beds of lignite or coal, and in place of the fragments of silicified wood there are silicified bones. Now, at the present day, from Cape Horn to near Concepcion, the land is entirely concealed by forests, which thin out at Concepcion, and in Central and Northern Chile entirely disappear. This coincidence in the distribution of the fossil wood and the living forests may be quite accidental; but I incline to take a different view of it; for, as the difference in climate, on which the presence of forests depends, is here obviously in chief part due to the form of the land, and as the Cordillera undoubtedly existed when the lignitiferous beds were accumulating, I conceive it is not improbable that the climate, during the lignitiferous period, varied on different parts of the coast in a somewhat similar manner as it now does. Looking to an earlier epoch, when the strata of the Cordillera were depositing, there were islands which even in the latitude of Northern Chile, where now all is irreclaimably desert, supported large coniferous forests.

Seventy-nine species of fossil shells, in a tolerably recognisable condition, from the coast of Chile and Peru, are described in this volume, and in the Palæontological part of M. d’Orbigny’s “Voyage”: if we put on one side the twenty species exclusively found at Concepcion and Chiloe, fifty-nine species from Navidad and the other specified localities remain. Of these fifty-nine species only an Artemis, a Mytilus and Balanus, all from Coquimbo, are (in the opinion of Mr. Sowerby, but not in that of M. d’Orbigny) identical with living shells; and it would certainly require a better series of specimens to render this conclusion certain. Only the *Turritella Chilensis* from Huafo and Mocha, the *T. Patagonica* and *Venus meridionalis* from Navidad, come very near to recent South American shells, namely, the two Turritellas to *T. cingulata*, and the Venus to *V. exalbida*: some few other species come rather less near; and some few resemble forms in the older European tertiary deposits: none of the species resemble secondary forms. Hence I conceive there can be no doubt that these formations are tertiary,—a point necessary to consider, after the case of Concepcion. The fifty-nine species belong to thirty-two genera; of these, Gastridium is extinct, and three or four of the genera (viz. Panopæa, Rostellaria, Corbis (?), and I believe Solecurtus) are not now found on the west coast of South America. Fifteen of the genera have on this coast living representatives in about the same latitudes with the fossil species; but twelve genera now range very differently to what they formerly did. The idea of the table on the following page, in which the difference between the extension in latitude of the fossil and existing species is shown, is taken from M. d’Orbigny’s work; but the range of the living shells is given on the authority of Mr. Cuming, whose long-continued researches on the conchology of South America are well-known.

When we consider that very few, if any, of the fifty-nine fossil shells are identical with, or make any close approach to, living species; when we consider that some of the genera do not now exist on the west coast of South America, and that no less than twelve genera out of the thirty-two formerly ranged very differently from the existing species of the same genera, we must admit that these deposits are of considerable antiquity, and that they probably verge on the commencement of the tertiary era. May we not venture to believe, that they are of nearly contemporaneous origin with the Eocene formations of the northern hemisphere?

Genera, with living and	Latitudes, in which found

Genera of the tertiary species on the west coast of S. America.[12]	fossil on the coasts of Chile and Peru.	Southernmost latitude, in which found living on the west coast of S. America.
Bulla	30° to 43° 30′	12° near Lima.
Cassis	34°	1° 37′
Pyrula	34° (and 36° 30′ at Concepcion)	5° Payta
Fusus	30° to 43° 30′	23° Mexillones; reappears at the St. of Magellan
Pleurotoma	34° to 43° 30′	2° 18′ St. Elena
Terebra	34°	5° Payta
Sigaretus	34° to 44° 30′	12° Lima
Anomia	30°	7° 48′
Perna	30°	1° 23′ Xixappa
Cardium	30° to 34° (and 36° 30′ at Concepcion)	5° Payta
Artemis	30°	5° Payta
Voluta	34° to 44° 30′	Mr. Cuming does not know of any species living on the west coast, between the equator and lat. 43° south; from this latitude a species is found as far south as Tierra del Fuego.

[12] M. d’Orbigny states that the genus Natica is not found on the coast of Chile; but Mr. Cuming found it at Valparaiso. Scalaria was found at Valparaiso; Arca, at Iquique, in lat. 20°, by Mr. Cuming; Arca, also, was found by Captain King, at Juan Fernandez, in lat. 33° 30′.

Comparing the fossil remains from the coast of Chile (leaving out, as before, Concepcion and Chiloe) with those from Patagonia, we may conclude, from their generic resemblance, and from the small number of the species which from either coast approach closely to living forms, that the formations of both belong to nearly the same epoch; and this is the opinion of M. D’Orbigny. Had not a single fossil shell been common to the two coasts, it could not have been argued that the formations belonged to different ages; for Messrs. Cuming and Hinds have found, on the comparison of nearly two thousand living species from the opposite sides of South America, only one in common, namely, the *Purpura lapillus* from both sides of the Isthmus of Panama: even the shells collected by myself amongst the Chonos Islands and on the coast of Patagonia, are dissimilar, and we must descend to the apex of the continent, to Tierra del Fuego, to find these two great conchological provinces united into one. Hence it is remarkable that four or five of the fossil shells from Navidad, namely, *Voluta alta, Turritella Patagonica, Trochus collaris, Venus meridionalis,* perhaps (Natica solida), and perhaps the large oyster from Coquimbo, are considered by Mr. Sowerby as identical with species from Santa Cruz and P. Desire. M. d’Orbigny, however, admits the perfect identity only of the Trochus.

On the temperature of the Tertiary period.—As the number of the fossil species and genera from the western and eastern coasts is considerable, it will be interesting to consider the probable nature of the climate under which they lived. We will first take the case of Navidad, in lat. 34°, where thirty-one species were collected, and which, as we shall presently see, must have inhabited shallow water, and therefore will necessarily well exhibit the effects of temperature. Referring to the table given in the previous page, we find that the existing species of the genera Cassis, Pyrula, Pleurotoma, Terebra, and Sigaretus, which are generally (though by no means invariably) characteristic of warmer latitudes, do not at the present day range nearly so far south on this line of coast as the fossil species formerly did. Including Coquimbo, we have Perna in the same predicament. The first impression from this fact is, that the climate must formerly have been warmer than it now is; but we must be very cautious in admitting this, for Cardium, Bulla, and Fusus (and, if we include Coquimbo, Anomia and Artemis) likewise formerly ranged farther south than they now do; and as these genera are far from being characteristic of hot climates, their former greater southern range may well have been owing to causes quite distinct from climate: Voluta, again, though generally so tropical a genus, is at present confined on the west coast to colder or more southern latitudes than it was during the tertiary period. The *Trochus collaris*, moreover, and, as we have just seen according to Mr. Sowerby, two or three other species, formerly ranged from Navidad as far south as Santa Cruz in latitude 50 degrees. If, instead of comparing the fossils of Navidad, as we have hitherto done, with the shells now living on the west coast of South America, we compare them with those found in other parts of the world, under nearly similar latitudes; for instance, in the southern parts of the Mediterranean or of Australia, there is no evidence that the sea off Navidad was formerly hotter than what might have been expected from its latitude, even if it was somewhat warmer than it now is when cooled by the great southern polar current. Several of the most tropical genera have no representative fossils at Navidad; and there are only single species of Cassis, Pyrula, and Sigaretus, two of Pleurotoma and two of Terebra, but none of these species are of conspicuous size. In Patagonia, there is even still less evidence in the character of the fossils, of the climate having been formerly warmer.[13] As from the various reasons already assigned, there can be little doubt that the formations of Patagonia and at least of Navidad and Coquimbo in Chile, are the equivalents of an ancient stage in the tertiary formations of the northern hemisphere, the conclusion that the climate of the southern seas at this period was not hotter than what might have been expected from the latitude of each place, appears to me highly important; for we must believe, in accordance with the views of Mr. Lyell, that the causes which gave to the older tertiary productions of the quite temperate zones of Europe a tropical character, *were of a local character and did not affect the entire globe.* On the other hand, I have endeavoured to show, in the “Geological Transactions,” that, at a much later period, Europe and North and South America were nearly contemporaneously subjected to ice-action, and consequently to a colder, or at least more equable, climate than that now characteristic of the same latitudes.

[13] It may be worth while to mention that the shells living at the present day on this eastern side of South America, in lat. 40°, have perhaps a more tropical character than those in corresponding latitudes on the shores of Europe: for at Bahia Blanca and S. Blas, there are two fine species of Voluta and four of Oliva.

On the absence of extensive modern conchiferous deposits in South America; and on the contemporaneousness of the older Tertiary deposits at distant points being due to contemporaneous movements of subsidence.—Knowing from the researches of Professor E. Forbes, that molluscous animals chiefly abound within a depth of 100 fathoms and under, and bearing in mind how many thousand miles of both coasts of South America have been upraised within the recent period by a slow, long-continued, intermittent movement,—seeing the diversity in nature of the shores and the number of shells now living on them,—seeing also that the sea off Patagonia and off many parts of Chile, was during the tertiary period highly favourable to the accumulation of sediment,—the absence of extensive deposits including recent shells over these vast spaces of coast is highly remarkable. The conchiferous calcareous beds at Coquimbo, and at a few isolated points northward, offer the most marked exception to this statement; for these beds are from twenty to thirty feet in thickness, and they stretch for some miles along shore, attaining, however, only a very trifling breadth. At Valdivia there is some sandstone with imperfect casts of shells, which *possibly* may belong to the recent period: parts of the boulder formation and the shingle-beds on the lower plains of Patagonia probably belong to this same period, but neither are fossiliferous: it also so happens that the great Pampean formation does not include, with the exception of the Azara, any mollusca. There cannot be the smallest doubt that the upraised shells along the shores of the Atlantic and Pacific, whether lying on the bare surface, or embedded in mould or in sand-hillocks, will in the course of ages be destroyed by alluvial action: this probably will be the case even with the calcareous beds of Coquimbo, so liable to dissolution by rain-water. If we take into consideration the probability of oscillations of level and the consequent action of the tidal-waves at different heights, their destruction will appear almost certain. Looking to an epoch as far distant in futurity as we now are from the past Miocene period, there seems to me scarcely a chance, under existing conditions, of the numerous shells now living in those zones of depths most fertile in life, and found exclusively on the western and south-eastern coasts of S. America, being preserved to this imaginary distant epoch. A whole conchological series will in time be swept away, with no memorials of their existence preserved in the earth’s crust.

Can any light be thrown on this remarkable absence of recent conchiferous deposits on these coasts, on which, at an ancient tertiary epoch, strata abounding with organic remains were extensively accumulated? I think there can, namely, by considering the conditions necessary for the preservation of a formation to a distant age. Looking to the enormous amount of denudation which on all sides of us has been effected,—as evidenced by the lofty cliffs cutting off on so many coasts horizontal and once far-extended strata of no great antiquity (as in the case of Patagonia),—as evidenced by the level surface of the ground on both sides of great faults and dislocations,—by inland lines of escarpments, by outliers, and numberless other facts, and by that argument of high generality advanced by Mr. Lyell, namely, that every *sedimentary* formation, whatever its thickness may be, and over however many hundred square miles it may extend, is the result and the measure of an equal amount of wear and tear of pre-existing formations; considering these facts, we must conclude that, as an ordinary rule, a formation to resist such vast destroying powers, and to last to a distant epoch, must be of wide extent, and either in itself, or together with superincumbent strata, be of great thickness. In this discussion, we are considering only formations containing the remains of marine animals, which, as before mentioned, live, with some exceptions within (most of them much within) depths of 100 fathoms. How, then, can a thick and widely extended formation be accumulated, which shall include such organic remains? First, let us take the case of the bed of the sea long remaining at a stationary level: under these circumstances it is evident that *conchiferous* strata can accumulate only to the same thickness with the depth at which the shells can live; on gently inclined coasts alone can they accumulate to any considerable width; and from the want of superincumbent pressure, it is probable that the sedimentary matter will seldom be much consolidated: such formations have no very good chance, when in the course of time they are upraised, of long resisting the powers of denudation. The chance will be less if the submarine surface, instead of having remained stationary, shall have gone on slowly rising during the deposition of the strata, for in this case their total thickness must be less, and each part, before being consolidated or thickly covered up by superincumbent matter, will have had successively to pass through the ordeal of the beach; and on most coasts, the waves on the beach tend to wear down and disperse every object exposed to their action. Now, both on the south-eastern and western shores of S. America, we have had clear proofs that the land has been slowly rising, and in the long lines of lofty cliffs, we have seen that the tendency of the sea is almost everywhere to eat into the land. Considering these facts, it ceases, I think, to be surprising, that extensive recent conchiferous deposits are entirely absent on the southern and western shores of America.

Let us take the one remaining case, of the bed of the sea slowly subsiding during a length of time, whilst sediment has gone on being deposited. It is evident that strata might thus accumulate to any thickness, each stratum being deposited in shallow water, and consequently abounding with those shells which cannot live at great depths: the pressure, also, I may observe, of each fresh bed would aid in consolidating all the lower ones. Even on a rather steep coast, though such must ever be unfavourable to widely extended deposits, the formations would always tend to increase in breadth from the water encroaching on the land. Hence we may admit that periods of slow subsidence will commonly be most favourable to the accumulation of *conchiferous* deposits, of sufficient thickness, extension, and hardness, to resist the average powers of denudation.

We have seen that at an ancient tertiary epoch, fossiliferous deposits were extensively deposited on the coasts of S. America; and it is a very interesting fact, that there is evidence that these ancient tertiary beds were deposited during a period of subsidence. Thus, at Navidad, the strata are about eight hundred feet in thickness, and the fossil shells are abundant both at the level of the sea and some way up the cliffs; having sent a list of these fossils to Professor E. Forbes, he thinks they must have lived in water between one and ten fathoms in depth: hence the bottom of the sea on which these shells once lived must have subsided at least 700 feet to allow of the superincumbent matter being deposited. I must here remark, that, as all these and the following fossil shells are extinct species, Professor Forbes necessarily judges of the depths at which they lived only from their generic character, and from the analogical distribution of shells in the northern hemisphere; but there is no just cause from this to doubt the general results. At Huafo the strata are about the same thickness, namely, 800 feet, and Professor Forbes thinks the fossils found there cannot have lived at a greater depth than fifty fathoms, or 300 feet. These two points, namely, Navidad and Huafo, are 570 miles apart, but nearly halfway between them lies Mocha, an island 1,200 feet in height, apparently formed of tertiary strata up to its level summit, and with many shells, including the same Turritella with that found at Huafo, embedded close to the level of the sea. In Patagonia, shells are numerous at Santa Cruz, at the foot of the 350 feet plain, which has certainly been formed by the denudation of the 840 feet plain, and therefore was originally covered by strata that number of feet in thickness, and these shells, according to Professor Forbes, probably lived at a depth of between seven and fifteen fathoms: at Port S. Julian, sixty miles to the north, shells are numerous at the foot of the ninety feet plain (formed by the denudation of the 950 feet plain), and likewise occasionally at the height of several hundred feet in the upper strata; these shells must have lived in water somewhere between five and fifty fathoms in depth. Although in other parts of Patagonia I have no direct evidence of shoal-water shells having been buried under a great thickness of superincumbent submarine strata, yet it should be borne in mind that the lower fossiliferous strata with several of the same species of Mollusca, the upper tufaceous beds, and the high summit-plain, stretch for a considerable distance southward, and for hundreds of miles northward; seeing this uniformity of structure, I conceive it may be fairly concluded that the subsidence by which the shells at Santa Cruz and S. Julian were carried down and covered up, was not confined to these two points, but was co-extensive with a considerable portion of the Patagonian tertiary formation. In a succeeding chapter it will be seen, that we are led to a similar conclusion with respect to the secondary fossiliferous strata of the Cordillera, namely, that they also were deposited during a long-continued and great period of subsidence.

From the foregoing reasoning, and from the facts just given, I think we must admit the probability of the following proposition: namely, that when the bed of the sea is either stationary or rising, circumstances are far less favourable, than when the level is sinking, to the accumulation of *conchiferous* deposits of sufficient thickness and extension to resist, when upheaved, the average vast amount of denudation. This result appears to me, in several respects, very interesting: every one is at first inclined to believe that at innumerable points, wherever there is a supply of sediment, fossiliferous strata are now forming, which at some future distant epoch will be upheaved and preserved; but on the views above given, we must conclude that this is far from being the case; on the contrary, we require (1st), a long-continued supply of sediment; (2nd), an extensive shallow area; and (3rd), that this area shall slowly subside to a great depth, so as to admit the accumulation of a widely extended thick mass of superincumbent strata. In how few parts of the world, probably, do these conditions at the present day concur! We can thus, also, understand the general want of that close sequence in fossiliferous formations which we might theoretically have anticipated; for, without we suppose a subsiding movement to go on at the same spot during an enormous period, from one geological era to another, and during the whole of this period sediment to accumulate at the proper rate, so that the depth should not become too great for the continued existence of molluscous animals, it is scarcely possible that there should be a perfect sequence at the same spot in the fossil shells of the two geological formations.[14] So far from a very long-continued subsidence being probable, many facts lead to the belief that the earth's surface oscillates up and down; and we have seen that during the elevatory movements there is but a small chance of *durable* fossiliferous deposits accumulating.

[14] Professor H. D. Rogers, in his excellent address to the Association of American Geologists (*Silliman's Journal,* vol. xlvii, p. 277) makes the following remark: "I question if we are at all aware how *completely* the whole history of all departed time lies indelibly recorded with the amplest minuteness of detail in the successive sediments of the globe, how effectually, in other words, every period of time *has written its own history*, carefully preserving every created form and every trace of action." I think the correctness of such remarks is more than doubtful, even if we except (as I suppose he would) all those numerous organic forms which contain no hard parts.)

Lastly, these same considerations appear to throw some light on the fact that certain periods appear to have been favourable to the deposition, or at least to the preservation, of contemporaneous formations at very distant points. We have seen that in S. America an enormous area has been rising within the recent period; and in other quarters of the globe immense spaces appear to have risen contemporaneously. From my examination of the coral-reefs of the great oceans, I have been led to conclude that the bed of the sea has gone on slowly sinking within the present era, over truly vast areas: this, indeed, is in itself probable, from the simple fact of the rising areas having been so large. In South America we have distinct evidence that at nearly the same tertiary period, the bed of the sea off parts of the coast of Chile and off Patagonia was sinking, though these regions are very remote from each other. If, then, it holds good, as a general rule, that in the same quarter of the globe the earth's crust tends to sink and rise contemporaneously over vast spaces, we can at once see, that we have at distant points, at the same period, those very conditions which appear to be requisite for the accumulation of fossiliferous masses of sufficient extension, thickness, and hardness, to resist denudation, and consequently to last unto an epoch distant in futurity.[15]

[15] Professor Forbes has some admirable remarks on this subject, in his "Report on the Shells of the Ægean Sea." In a letter to Mr. Maclaren (*Edinburgh New Phil. Journal,* January 1843), I partially entered into this discussion, and endeavoured to show that it was highly improbable, that upraised atolls or barrier-reefs, though of great thickness, should, owing to their small extension or breadth, be preserved to a distant future period.

Chapter VI

PLUTONIC AND METAMORPHIC ROCKS:— CLEAVAGE AND FOLIATION.

Brazil, Bahia, gneiss with disjointed metamorphosed dikes.—Strike of foliation.—Rio de Janeiro, gneiss-granite, embedded fragment in, decomposition of.—La Plata, metamorphic and old volcanic rocks of.—S. Ventana.—Claystone porphyry formation of Patagonia; singular metamorphic rocks; pseudo-dikes.—Falkland Islands, Palæozoic fossils of.—Tierra del Fuego, clay-slate formation, cretaceous fossils of; cleavage and foliation; form of land.—Chonos Archipelago, mica-schists, foliation disturbed by granitic axis; dikes.—Chiloe.—Concepcion, dikes, successive formation of.—Central and Northern Chile.—Concluding remarks on cleavage and foliation.—Their close analogy and similar origin. —Stratification of metamorphic schists.—Foliation of intrusive rocks.—Relation of cleavage and foliation to the lines of tension during metamorphosis.

The metamorphic and plutonic formations of the several districts visited by the *Beagle* will be here chiefly treated of, but only such cases as appear to me new, or of some special interest, will be described in detail; at the end of the chapter I will sum up all the facts on cleavage and foliation,—to which I particularly attended.

Bahia, Brazil: lat. 13° south.—The prevailing rock is gneiss, often passing, by the disappearance of the quartz and mica, and by the feldspar losing its red colour, into a brilliantly grey primitive greenstone. Not unfrequently quartz and hornblende are arranged in layers in almost amorphous feldspar. There is some fine-grained syenitic granite, orbicularly marked by ferruginous lines, and weathering into vertical, cylindrical holes, almost touching each other. In the gneiss, concretions of granular feldspar and others of garnets with mica occur. The gneiss is traversed by numerous dikes composed of black, finely crystallised, hornblendic rock, containing a little glassy feldspar and sometimes mica, and varying in thickness from mere threads to ten feet: these threads, which are often curvilinear, could sometimes be traced running into the larger dikes. One of these dikes was remarkable from having been in two or three places laterally disjointed, with unbroken gneiss interposed between the broken ends, and in one part with a portion of the gneiss driven, apparently whilst in a softened state, into its side or wall. In several neighbouring places, the gneiss included angular, well-defined, sometimes bent, masses of hornblende rock, quite like, except in being more perfectly crystallised, that forming the dikes, and, at least in one instance, containing (as determined by Professor Miller) augite as well as hornblende. In one or two cases these angular masses, though now quite separate from each other by the solid gneiss, had, from their exact correspondence in size and shape, evidently once been united; hence I cannot doubt that most or all of the fragments have been derived from the breaking up of the dikes, of which we see the first stage in the above-mentioned laterally disjointed one. The gneiss close to the fragments generally contained many large crystals of hornblende, which are entirely absent or rare in other parts: its folia or laminæ were gently bent round the fragments, in the same manner as they sometimes are round concretions. Hence the gneiss has certainly been softened, its composition modified, and its folia arranged, subsequently to the breaking up of the dikes,[1] these latter also having been at the same time bent and softened.

[1] Professor Hitchcock ("Geology of Massachusetts," vol. ii, p. 673, gives a closely similar case of a greenstone dike in syenite.

I must here take the opportunity of premising, that by the term *cleavage* I imply those planes of division which render a rock, appearing to the eye quite or nearly homogeneous, fissile. By the term *foliation*, I refer to the layers or plates of different mineralogical nature of which most metamorphic schists are composed; there are, also, often included in such masses, alternating, homogeneous, fissile layers or folia, and in this case the rock is both foliated and has a cleavage. By *stratification*, as applied to these formations, I mean those alternate, parallel, large masses of different composition, which are themselves frequently either foliated or fissile,—such as the alternating so-called strata of mica-slate, gneiss, glossy clay-slate, and marble.

The folia of the gneiss within a few miles round Bahia generally strike irregularly, and are often curvilinear, dipping in all directions at various angles: but where best defined, they extended most frequently in a N.E. by N. (or East 50° N.) and S.W. by S. line, corresponding nearly with the coast-line northwards of the bay. I may add that Mr. Gardner[2] found in several parts of the province of Ceara, which lies between four and five hundred miles north of Bahia, gneiss with the folia extending E. 45° N.; and in Guyana according to Sir R. Schomburgk, the same rock strikes E. 57° N. Again, Humboldt describes the gneiss-granite over an immense area in Venezuela and even in Colombia, as striking E. 50° N., and dipping to the N.W. at an angle of fifty degrees. Hence all the observations hitherto made tend to show that the gneissic rocks over the whole of this part of the continent have their folia extending generally within almost a point of the compass of the same direction.[3]

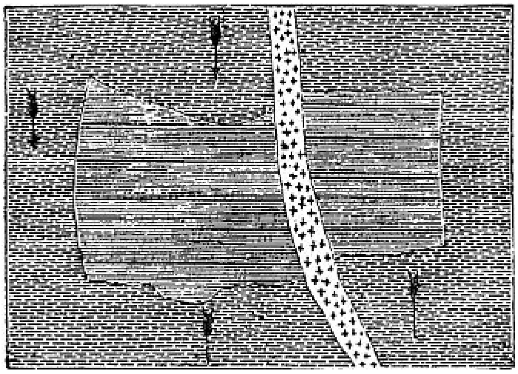
[2] "Geological Section of the Brit. Assoc.," 1840. For Sir R. Schomburgk's observations see *Geograph. Journal,* 1842, p. 190. See also Humboldt's discussion on Loxodrism in the "Personal Narrative."

[3] I landed at only one place north of Bahia, namely, at Pernambuco. I found there only soft, horizontally stratified matter, formed from disintegrated granitic rocks, and some yellowish impure limestone, probably of a tertiary epoch. I have described a most singular natural bar of hard sandstone, which protects the harbour, in the 19th vol. (1841) p. 258 of the *London and Edin. Phil. Magazine.*

ABROLHOS ISLETS, *lat. 18° S. off the coast of Brazil.*—Although not strictly in place, I do not know where I can more conveniently describe this little group of small islands. The lowest bed is a sandstone with ferruginous veins; it weathers into an extraordinary honeycombed mass; above it there is a dark-coloured argillaceous shale; above this a coarser sandstone—making a total thickness of about sixty feet; and lastly, above these sedimentary beds, there is a fine conformable mass of greenstone, in some parts having a columnar structure. All the strata, as well as the surface of the land, dip at an angle of about 12° to N. by W. Some of the islets are composed entirely of the sedimentary, others of the trappean rocks, generally, however, with the sandstone, cropping out on the southern shores.

Rio de Janeiro.—This whole district is almost exclusively formed of gneiss, abounding with garnets, and porphyritic with large crystals, even three and four inches in length, of orthoclase feldspar: in these crystals mica and garnets are often enclosed. At the western base of the Corcovado, there is some ferruginous carious quartz-rock; and in the Tijeuka range, much fine-grained granite. I observed boulders of greenstone in several places; and on the islet of Villegagnon, and likewise on the coast some miles northward, two large trappean dikes. The porphyritic gneiss, or gneiss-granite as it has been called by Humboldt, is only so far foliated that the constituent minerals are arranged with a certain degree of regularity, and may be said to have a "*grain*," but they are not separated into distinct folia or laminæ. There are, however, several other varieties of gneiss regularly foliated, and alternating with each other in so-called strata. The stratification and foliation of the ordinary gneisses, and the foliation or "grain" of the gneiss-granite, are parallel to each other, and generally strike within a point of N.E. and S.W. dipping at a high angle (between 50° and 60°) generally to S.E.: so that here again we meet with the strike so prevalent over the more northern parts of this continent. The mountains of gneiss-granite are to a remarkable degree abruptly conical, which seems caused by the rock tending to exfoliate in thick, conically concentric layers: these peaks resemble in shape those of phonolite and other injected rocks on volcanic islands; nor is the grain or foliation (as we shall afterwards see) any difficulty on the idea of the gneiss-granite having been an intrusive rather than a metamorphic formation. The lines of mountains, but not always each separate hill, range nearly in the same direction with the foliation and so-called stratification, but rather more easterly.

No. 22
Fragment of gneiss embedded in another variety of the same rock.



On a bare gently inclined surface of the porphyritic gneiss in Botofogo Bay, I observed the appearance here represented.

A fragment seven yards long and two in width, with angular and distinctly defined edges, composed of a peculiar variety of gneiss with dark layers of mica and garnets, is surrounded on all sides by the ordinary gneiss-granite; both having been dislocated by a granitic vein. The folia in the fragment and in the surrounding rock strike in the same N.N.E. and S.S.W. line; but in the fragment they are vertical, whereas in the gneiss-granite they dip at a small angle, as shown by the arrows, to S.S.E. This fragment, considering its great size, its solitary position, and its foliated structure parallel to that of the surrounding rock, is, as far as I know, a unique case: and I will not attempt any explanation of its origin.

The numerous travellers[4] in this country, have all been greatly surprised at the depth to which the gneiss and other granitic rocks, as well as the talcose slates of the interior, have been decomposed. Near Rio, every mineral except the quartz has been completely softened, in some places to a depth little less than one hundred feet.[5] The minerals retain their positions in folia ranging in the usual direction; and fractured quartz veins may be traced from the solid rock, running for some distance into the softened, mottled, highly coloured, argillaceous mass. It is said that these decomposed rocks abound with gems of various kinds, often in a fractured state, owing, as some have supposed, to the collapse of geodes, and that they contain gold and diamonds. At Rio, it appeared to me that the gneiss had been softened before the excavation (no doubt by the sea) of the existing, broad, flat-bottomed valleys; for the depth of decomposition did not appear at all conformable with the present undulations of the surface. The porphyritic gneiss, where now exposed to the air, seems to withstand decomposition remarkably well; and I could see no signs of any tendency to the production of argillaceous masses like those here described. I was also struck with the fact, that where a bare surface of this rock sloped into one of the quiet bays, there were no marks of erosion at the level of the water, and the parts both beneath and above it preserved a uniform curve. At Bahia, the gneiss rocks are similarly decomposed, with the upper parts insensibly losing their foliation, and passing, without any distinct line of separation, into a bright red argillaceous earth, including partially rounded fragments of quartz and granite. From this circumstance, and from the rocks appearing to have suffered decomposition before the excavation of the valleys, I suspect that here, as at Rio, the decomposition took place under the sea. The subject appeared to me a curious one, and would probably well repay careful examination by an able mineralogist.

[4] Spix and Martius have collected in an Appendix to their "Travels," the largest body of facts on this subject. See also some remarks by M. Lund in his communications to the Academy at Copenhagen; and others by M. Gaudichaud in Freycinet's "Voyage."

[5] Dr. Benza describes granitic rock (*Madras Journal of Lit.,* etc., Oct. 183? p. 246), in the Neelgherries, decomposed to a depth of forty feet.

The Northern Provinces of La Plata.—According to some observations communicated to me by Mr. Fox, the coast from Rio de Janeiro to the mouth of the Plata seems everywhere to be granitic, with a few trappean dikes. At Port Alegre, near the boundary of Brazil, there are porphyries and diorites.[6] At the mouth of the Plata, I examined the country for twenty-five miles west, and for about seventy miles north of Maldonado: near this town, there is some common gneiss, and much, in all parts of the country, of a coarse-grained mixture of quartz and reddish feldspar, often, however, assuming a little dark-green imperfect hornblende, and then immediately becoming foliated. The abrupt hillocks thus composed, as well as the highly inclined folia of the common varieties of gneiss, strike N.N.E. or a little more easterly, and S.S.W. Clay-slate is occasionally met with, and near the L. del Potrero, there is white marble, rendered fissile from the presence of hornblende, mica, and asbestus; the cleavage of these rocks and their stratification, that is the alternating masses thus composed, strike N.N.E. and S.S.W. like the foliated gneisses, and have an almost vertical dip. The Sierra Larga, a low range five miles west of Maldonado, consists of quartzite, often ferruginous, having an arenaceous feel, and divided into excessively thin, almost vertical laminæ or folia by microscopically minute scales, apparently of mica, and striking in the usual N.N.E. and S.S.W. direction. The range itself is formed of one principal line with some subordinate ones; and it extends with remarkable uniformity far northward (it is said even to the confines of Brazil), in the same line with the vertically ribboned quartz rock of which it is composed. The S. de Las Animas is the highest range in the country; I estimated it at 1,000 feet; it runs north and south, and is formed of feldspathic porphyry; near its base there is a N.N.W. and S.S.E. ridge of a conglomerate in a highly porphyritic basis.

[6] M. Isabelle, “Voyage à Buenos Ayres,” p. 479.

Northward of Maldonado, and south of Las Minas, there is an E. and W. hilly band of country, some miles in width, formed of siliceous clay-slate, with some quartz, rock, and limestone, having a tortuous irregular cleavage, generally ranging east and west. E. and S.E. of Las Minas there is a confused district of imperfect gneiss and laminated quartz, with the hills ranging in various directions, but with each separate hill generally running in the same line with the folia of the rocks of which it is composed: this confusion appears to have been caused by the intersection of the [E. and W.] and [N.N.E. and S.S.W.] strikes. Northward of Las Minas, the more regular northerly ranges predominate: from this place to near Polanco, we meet with the coarse-grained mixture of quartz and feldspar, often with the imperfect hornblende, and then becoming foliated in a N. and S. line—with imperfect clay-slate, including laminæ of red crystallised feldspar—with white or black marble, sometimes containing asbestus and crystals of gypsum—with quartz-rock—with syenite—and lastly, with much granite. The marble and granite alternate repeatedly in apparently vertical masses: some miles northward of the Polanco, a wide district is said to be entirely composed of marble. It is remarkable, how rare mica is in the whole range of country north and westward of Maldonado. Throughout this district, the cleavage of the clay-slate and marble—the foliation of the gneiss and the quartz—the stratification or alternating masses of these several rocks—and the range of the hills, all coincide in direction; and although the country is only hilly, the planes of division are almost everywhere very highly inclined or vertical.

Some ancient submarine volcanic rocks are worth mentioning, from their rarity on this eastern side of the continent. In the valley of the Tapas (fifty or sixty miles N. of Maldonado) there is a tract three or four miles in length, composed of various trappean rocks with glassy feldspar —of apparently metamorphosed grit-stones—of purplish amygdaloids with large kernels of carbonate of lime[7]—and much of a harshish rock with glassy feldspar intermediate in character between claystone porphyry and trachyte. This latter rock was in one spot remarkable from being full of drusy cavities, lined with quartz crystals, and arranged in planes, dipping at an angle of 50° to the east, and striking parallel to the foliation of an adjoining hill composed of the common mixture of quartz, feldspar, and imperfect hornblende: this fact perhaps indicates that these volcanic rocks have been metamorphosed, and their constituent parts rearranged, at the same time and according to the same laws, with the granitic and metamorphic formations of this whole region. In the valley of the Marmaraya, a few miles south of the Tapas, a band of trappean and amygdaloidal rock is interposed between a hill of granite and an extensive surrounding formation of red conglomerate, which (like that at the foot of the S. Animas) has its basis porphyritic with crystals of feldspar, and which hence has certainly suffered metamorphosis.

[7] Near the Pan de Azucar there is some greenish porphyry, in one place amygdaloidal with agate.

Monte Video.—The rocks here consist of several varieties of gneiss, with the feldspar often yellowish, granular and imperfectly crystallised, alternating with, and passing insensibly into, beds, from a few yards to nearly a mile in thickness, of fine or coarse grained, dark-green hornblendic slate; this again often passing into chloritic schist. These passages seem chiefly due to changes in the mica, and its replacement by other minerals. At Rat Island I examined a mass of chloritic schist, only a few yards square, irregularly surrounded on all sides by the gneiss, and intricately penetrated by many curvilinear veins of quartz, which gradually *blend* into the gneiss: the cleavage of the chloritic schist and the foliation of the gneiss were exactly parallel. Eastward of the city there is much fine-grained, dark-coloured gneiss, almost assuming the character of hornblende-slate, which alternates in thin laminæ with laminæ of quartz, the whole mass being transversely intersected by numerous large veins of quartz: I particularly observed that these veins were absolutely continuous with the alternating laminæ of quartz. In this case and at Rat Island, the passage of the gneiss into imperfect hornblendic or into chloritic slate, seemed to be connected with the segregation of the veins of quartz.[8]

[8] Mr. Greenough (p. 78, "Critical Examination," etc.) observes that quartz in mica-slate sometimes appears in beds and sometimes in veins. Von Buch also in his "Travels in Norway" (p. 236), remarks on alternating laminæ of quartz and hornblende-slate replacing mica-schist.

The Mount, a hill believed to be 450 feet in height, from which the place takes its name, is much the highest land in this neighbourhood: it consists of hornblendic slate, which (except on the eastern and disturbed base) has an east and west nearly vertical cleavage; the longer axis of the hill also ranges in this same line. Near the summit the hornblende-slate gradually becomes more and more coarsely crystallised, and less plainly laminated, until it passes into a heavy, sonorous greenstone, with a slaty conchoidal fracture; the laminæ on the north and south sides near the summit dip inwards, as if this upper part had expanded or bulged outwards. This greenstone must, I conceive, be considered as metamorphosed hornblende-slate. The Cerrito, the next highest, but much less elevated point, is almost similarly composed. In the more western parts of the province, besides gneiss, there is quartz-rock, syenite, and granite; and at Colla, I heard of marble.

Near M. Video, the space which I more accurately examined was about fifteen miles in an east and west line, and here I found the foliation of the gneiss and the cleavage of the slates generally well developed, and extending parallel to the alternating strata composed of the gneiss, hornblendic and chloritic schists. These planes of division all range within one point of east and west, frequently east by south and west by north; their dip is generally almost vertical, and scarcely anywhere under 45°: this fact, considering how slightly undulatory the surface of the country is, deserves attention. Westward of M. Video, towards the Uruguay, wherever the gneiss is exposed, the highly inclined folia are seen striking in the same direction; I must except one spot where the strike was N.W. by W. The little Sierra de S. Juan, formed of gneiss and laminated quartz, must also be excepted, for it ranges between [N. to N.E.] and [S. to S.W.] and seems to belong to the same system with the hills in the Maldonado district. Finally, we have seen that, for many miles northward of Maldonado and for twenty-five miles westward of it, as far as the S. de las Animas, the foliation, cleavage, so-called stratification and lines of hills, all range N.N.E. and S.S.W., which is nearly coincident with the adjoining coast of the Atlantic. Westward of the S. de las Animas, as far as even the Uruguay, the foliation, cleavage, and stratification (but not lines of hills, for there are no defined ones) all range about E. by S. and W. by N., which is nearly coincident with the direction of the northern shore of the Plata; in the confused country near Las Minas, where these two great systems appear to intersect each other, the cleavage, foliation, and stratification run in various directions, but generally coincide with the line of each separate hill.

Southern La Plata.—The first ridge, south of the Plata, which projects through the Pampean formation, is the Sierra Tapalguen and Vulcan, situated 200 miles southward of the district just described. This ridge is only a few hundred feet in height, and runs from C. Corrientes in a W.N.W. line for at least 150 miles into the interior: at Tapalguen, it is composed of unstratified granular quartz, remarkable from forming tabular masses and small plains, surrounded by precipitous cliffs: other parts of the range are said to consist of granite: and marble is found at the S. Tinta. It appears from M. Parchappe's[9] observations, that at Tandil there is a range of quartzose gneiss, very like the rocks of the S. Larga near Maldonado, running in the same N.N.E. and S.S.W. direction; so that the framework of the country here is very similar to that on the northern shore of the Plata.

[9] M. d’Orbigny’s “Voyage,” Part. Géolog., p. 46. I have given a short account of the peculiar forms of the quartz hills of Tapalguen, so unusual in a metamorphic formation, in my “Journal of Researches” (2nd edit.), p. 116.

The Sierra Guitru-gueyu is situated sixty miles south of the S. Tapalguen: it consists of numerous parallel, sometimes blended together ridges, about twenty-three miles in width, and five hundred feet in height above the plain, and extending in a N.W. and S.E. direction. Skirting round the extreme S.E. termination, I ascended only a few points, which were composed of a fine-grained gneiss, almost composed of feldspar with a little mica, and passing in the upper parts of the hills into a rather compact purplish clay-slate. The cleavage was nearly vertical, striking in a N.W. by W. and S.E. by E. line, nearly, though not quite, coincident with the direction of the parallel ridges.

The Sierra Ventana lies close south of that of Guitru-gueyu; it is remarkable from attaining a height, very unusual on this side of the continent, of 3,340 feet. It consists up to its summit, of quartz, generally pure and white, but sometimes reddish, and divided into thick laminæ or strata: in one part there is a little glossy clay-slate with a tortuous cleavage. The thick layers of quartz strike in a W. 30° N. line, dipping southerly at an angle of 45° and upwards. The principal line of mountains, with some quite subordinate parallel ridges, range about W. 45° N.: but at their S.E. termination, only W. 25° N. This Sierra is said to extend between twenty and thirty leagues into the interior.

Patagonia.—With the exception perhaps of the hill of S. Antonio (600 feet high) in the Gulf of S. Matias, which has never been visited by a geologist, crystalline rocks are not met with on the coast of Patagonia for a space of 380 miles south of the S. Ventana. At this point (lat. 43° 50′), at Points Union and Tombo, plutonic rocks are said to appear, and are found, at rather wide intervals, beneath the Patagonian tertiary formation for a space of about three hundred miles southward, to near Bird Island, in latitude 48° 56′. Judging from specimens kindly collected for me by Mr. Stokes, the prevailing rock at Ports St. Elena, Camerones, Malaspina, and as far south as the Paps of Pineda, is a purplish-pink or brownish claystone porphyry, sometimes laminated, sometimes slightly vesicular, with crystals of opaque feldspar and with a few grains of quartz; hence these porphyries resemble those immediately to be described at Port Desire, and likewise a series which I have seen from P. Alegre on the southern confines of Brazil. This porphyritic formation further resembles in a singularly close manner the lowest stratified formation of the Cordillera of Chile, which, as we shall hereafter see, has a vast range, and attains a great thickness. At the bottom of the Gulf of St. George, only tertiary deposits appear to be present. At Cape Blanco, there is quartz rock, very like that of the Falkland Islands, and some hard, blue siliceous clay-slate.

At Port Desire there is an extensive formation of the claystone porphyry, stretching at least twenty-five miles into the interior: it has been denuded and deeply worn into gullies before being covered up by the tertiary deposits, through which it here and there projects in hills; those north of the bay being 440 feet in height. The strata have in several places been tilted at small angles, generally either to N.N.W. or S.S.E. By gradual passages and alternations, the porphyries change incessantly in nature. I will describe only some of the principal mineralogical changes, which are highly instructive, and which I carefully examined. The prevailing rock has a compact purplish base, with crystals of earthy or opaque feldspar, and often with grains of quartz. There are other varieties, with an almost truly trachytic base, full of little angular vesicles and crystals of glassy feldspar; and there are beds of black perfect pitchstone, as well as of a concretionary imperfect variety. On a casual inspection, the whole series would be thought to be of the same plutonic or volcanic nature with the trachytic varieties and pitchstone; but this is far from being the case, as much of the porphyry is certainly of metamorphic origin. Besides the true porphyries, there are many beds of earthy, quite white or yellowish, friable, easily fusible matter, resembling chalk, which under the microscope is seen to consist of minute broken crystals, and which, as remarked in a former chapter, singularly resembles the upper tufaceous beds of the Patagonian tertiary formation. This earthy substance often becomes coarser, and contains minute rounded fragments of porphyries and rounded grains of quartz, and in one case so many of the latter as to resemble a common sandstone. These beds are sometimes marked with true lines of aqueous deposition, separating particles of different degrees of coarseness; in other cases there are parallel ferruginous lines not of true deposition, as shown by the arrangement of the particles, though singularly resembling them. The more indurated varieties often include many small and some larger angular cavities, which appear due to the removal of earthy matter: some varieties contain mica. All these earthy and generally white stones insensibly pass into more indurated sonorous varieties, breaking with a conchoidal fracture, yet of small specific gravity; many of these latter varieties assume a pale purple tint, being singularly banded and veined with different shades, and often become plainly porphyritic with crystals of feldspar. The formation of these crystals could be most clearly traced by minute angular and often partially hollow patches of earthy matter, first assuming a *fibrous structure*, then passing into opaque imperfectly shaped crystals, and lastly, into perfect glassy crystals. When these crystals have appeared, and when the basis has become compact, the rock in many places could not be distinguished from a true claystone porphyry without a trace of mechanical structure.

In some parts, these earthy or tufaceous beds pass into jaspery and into beautifully mottled and banded porcelain rocks, which break into splinters, translucent at their edges, hard enough to scratch glass, and fusible into white transparent beads: grains of quartz included in the porcelainous varieties can be seen melting into the surrounding paste. In other parts, the earthy or tufaceous beds either insensibly pass into, or alternate with, breccias composed of large and small fragments of various purplish porphyries, with the matrix generally porphyritic: these breccias, though their subaqueous origin is in many places shown both by the arrangement of their smaller particles and by an oblique or current lamination, also pass into porphyries, in which every trace of mechanical origin and stratification has been obliterated.

Some highly porphyritic though coarse-grained masses, evidently of sedimentary origin, and divided into thin layers, differing from each other chiefly in the number of embedded grains of quartz, interested me much from the peculiar manner in which here and there some of the layers terminated in abrupt points, quite unlike those produced by a layer of sediment naturally thinning out, and apparently the result of a subsequent process of metamorphic aggregation. In another common variety of a finer texture, the aggregating process had gone further, for the whole mass consisted of quite short, parallel, often slightly curved layers or patches, of whitish or reddish finely granulo-crystalline feldspathic matter, generally terminating at both ends in blunt points; these layers or patches further tended to pass into wedge or almond-shaped little masses, and these finally into true crystals of feldspar, with their centres often slightly drusy. The series was so perfect that I could not doubt that these large crystals, which had their longer axes placed parallel to each other, had primarily originated in the metamorphosis and aggregation of alternating layers of tuff; and hence their parallel position must be attributed (unexpected though the conclusion may be), not to laws of chemical action, but to the original planes of deposition. I am tempted briefly to describe three other singular allied varieties of rock; the first without examination would have passed for a stratified porphyritic breccia, but all the included angular fragments consisted of a border of pinkish crystalline feldspathic matter, surrounding a dark translucent siliceous centre, in which grains of quartz not quite blended into the paste could be distinguished: this uniformity in the nature of the fragments shows that they are not of mechanical, but of concretionary origin, having resulted perhaps from the self-breaking up and aggregation of layers of indurated tuff containing numerous grains of quartz,—into which, indeed, the whole mass in one part passed. The second variety is a reddish non-porphyritic claystone, quite full of spherical cavities, about half an inch in diameter, each lined with a collapsed crust formed of crystals of quartz. The third variety also consists of a pale purple non-porphyritic claystone, almost wholly formed of concretionary balls, obscurely arranged in layers, of a less compact and paler coloured claystone; each ball being on one side partly hollow and lined with crystals of quartz.

Pseudo-dikes.—Some miles up the harbour, in a line of cliffs formed of slightly metamorphosed tufaceous and porphyritic claystone beds, I observed three vertical dikes, so closely resembling in general appearance ordinary volcanic dikes, that I did not doubt, until closely examining their composition, that they had been injected from below. The first is straight, with parallel sides, and about four feet wide; it consists of whitish, indurated tufaceous matter, precisely like some of the beds intersected by it. The second dike is more remarkable; it is slightly tortuous, about eighteen inches thick, and can be traced for a considerable distance along the beach; it is of a purplish-red or brown colour, and is formed chiefly of *rounded* grains of quartz, with broken crystals of earthy feldspar, scales of black mica, and minute fragments of claystone porphyry, all firmly united together in a hard sparing base. The structure of this dike shows obviously that it is of mechanical and sedimentary origin; yet it thinned out upwards, and did not cut through the uppermost strata in the cliffs. This fact at first appears to indicate that the matter could not have been washed in from above;[10] but if we reflect on the suction which would result from a deep-seated fissure being formed, we may admit that if the fissure were in any part open to the surface, mud and water might well be drawn into it along its whole course. The third dike consisted of a hard, rough, white rock, almost composed of broken crystals of glassy feldspar, with numerous scales of black mica, cemented in a scanty base; there was little in the appearance of this rock, to preclude the idea of its having been a true injected feldspathic dike. The matter composing these three pseudo-dikes, especially the second one, appears to have suffered, like the surrounding strata, a certain degree of metamorphic action; and this has much aided the deceptive appearance. At Bahia, in Brazil, we have seen that a true injected hornblendic dike, not only has suffered metamorphosis, but has been dislocated and even diffused in the surrounding gneiss, under the form of separate crystals and of fragments.

[10] Upfilled fissures are known to occur both in volcanic and in ordinary sedimentary formations. At the Galapagos Archipelago (“Volcanic Islands” etc.), there are some striking examples of pseudo-dikes composed of hard tuff.

Falkland Islands.—I have described these islands in a paper published in the third volume of the *Geological Journal.* The mountain-ridges consist of quartz, and the lower country of clay-slate and sandstone, the latter containing Palæozoic fossils. These fossils have been separately described by Messrs. Morris and Sharpe: some of them resemble Silurian, and others Devonian forms. In the eastern part of the group the several parallel ridges of quartz extend in a west and east line; but further westward the line becomes W.N.W. and E.S.E., and even still more northerly. The cleavage-planes of the clay-slate are highly inclined, generally at an angle of above 50°, and often vertical; they strike almost invariably in the same direction with the quartz ranges. The outline of the indented shores of the two main islands, and the relative positions of the smaller islets, accord with the strike both of the main axes of elevation and of the cleavage of the clay-slate.

Tierra del Fuego.—My notes on the geology of this country are copious, but as they are unimportant, and as fossils were found only in one district, a brief sketch will be here sufficient. The east coast from the S. of Magellan (where the boulder formation is largely developed) to St. Polycarp’s Bay is formed of horizontal tertiary strata, bounded some way towards the interior by a broad mountainous band of clay-slate. This great clay-slate formation extends from St. Le Maire westward for 140 miles, along both sides of the Beagle Channel to near its bifurcation. South of this channel, it forms all Navarin Island, and the eastern half of Hoste Island and of Hardy Peninsula; north of the Beagle Channel it extends in a north-west line on both sides of Admiralty Sound to Brunswick Peninsula in the St. of Magellan, and I have reason to believe, stretches far up the eastern side of the Cordillera. The western and broken side of Tierra del Fuego towards the Pacific is formed of metamorphic schists, granite and various trappean rocks: the line of separation between the crystalline and clay-slate formations can generally be distinguished, as remarked by Captain King,[11] by the parallelism in the clay-slate districts of the shores and channels, ranging in a line between [W. 20° to 40° N.] and [E. 20° to 40° S.].

[11] *Geographical Journal,* vol. i, p. 155.

The clay-slate is generally fissile, sometimes siliceous or ferruginous, with veins of quartz and calcareous spar; it often assumes, especially on the loftier mountains, an altered feldspathic character, passing into feldspathic porphyry: occasionally it is associated with breccia and grauwacke. At Good Success Bay, there is a little intercalated black crystalline limestone. At Port Famine much of the clay-slate is calcareous, and passes either into a mudstone or into grauwacke, including odd-shaped concretions of dark argillaceous limestone. Here alone, on the shore a few miles north of Port Famine, and on the summit of Mount Tarn (2,600 feet high), I found organic remains; they consist of:—

1. Ancyloceras simplex, d’Orbigny, “Pal Franc,” Mount Tarn.
2. Fusus (in imperfect state), d’Orbigny, “Pal Franc,” Mount Tarn.
3. Natica, d’Orbigny, “Pal Franc,” Mount Tarn.

4. Pentacrimus, d'Orbigny, "Pal Franc," Mount Tarn.
5. Lucina excentrica, G. B. Sowerby, Port Famine.
6. Venus (in imperfect state), G. B. Sowerby, Port Famine.
7. Turbinolia (?), G. B. Sowerby, Port Famine.
8. Hamites elatior, G. B. Sowerby, Port Famine.

M. d'Orbigny states[12] that MM. Hombron and Grange found in this neighbourhood an Ancyloceras, perhaps *A. simplex*, an Ammonite, a Plicatula and Modiola. M. d'Orbigny believes from the general character of these fossils, and from the Ancyloceras being identical (as far as its imperfect condition allows of comparison) with the *A. simplex* of Europe, that the formation belongs to an early stage of the Cretaceous system. Professor E. Forbes, judging only from my specimens, concurs in the probability of this conclusion. The *Hamites elatior* of the above list, of which a description has been given by Mr. Sowerby, and which is remarkable from its large size, has not been seen either by M. d'Orbigny or Professor E. Forbes, as, since my return to England, the specimens have been lost. The great clay-slate formation of Tierra del Fuego being cretaceous, is certainly a very interesting fact,—whether we consider the appearance of the country, which, without the evidence afforded by the fossils, would form the analogy of most known districts, probably have been considered as belonging to the Palæozoic series,—or whether we view it as showing that the age of this terminal portion of the great axis of South America, is the same (as will hereafter be seen) with the Cordillera of Chile and Peru.

[12] "Voyage," Part Géolog., p. 242.

The clay-slate in many parts of Tierra del Fuego, is broken by dikes[13] and by great masses of greenstone, often highly hornblendic: almost all the small islets within the clay-slate districts are thus composed. The slate near the dikes generally becomes paler-coloured, harder, less fissile, of a feldspathic nature, and passes into a porphyry or greenstone: in one case, however, it became more fissile, of a red colour, and contained minute scales of mica, which were absent in the unaltered rock. On the east side of Ponsonby Sound some dikes composed of a pale sonorous feldspathic rock, porphyritic with a little feldspar, were remarkable from their number,—there being within the space of a mile at least one hundred,—from their nearly equalling in bulk the intermediate slate,—and more especially from the excessive fineness (like the finest inlaid carpentry) and perfect parallelism of their junctions with the almost vertical laminæ of clay-slate. I was unable to persuade myself that these great parallel masses had been injected, until I found one dike which abruptly thinned out to half its thickness, and had one of its walls jagged, with fragments of the slate embedded in it.

[13] In a greenstone-dike in the Magdalen Channel, the feldspar cleaved with the angle of albite. This dike was crossed, as well as the surrounding slate, by a large vein of quartz, a circumstance of unusual occurrence.

In Southern Tierra del Fuego, the clay-slate towards its S.W. boundary, becomes much altered and feldspathic. Thus on Wollaston Island slate and grauwacke can be distinctly traced passing into feldspathic rocks and greenstones, including iron pyrites and epidote, but still retaining traces of cleavage with the usual strike and dip. One such metamorphosed mass was traversed by large vein-like masses of a beautiful mixture (as ascertained by Professor Miller) of green epidote, garnets, and white calcareous spar. On the northern point of this same island, there were various ancient submarine volcanic rocks, consisting of amygdaloids with dark bole and agate,—of basalt with decomposed olivine—of compact lava with glassy feldspar,—and of a coarse conglomerate of red scoriæ, parts being amygdaloidal with carbonate of lime. The southern part of Wollaston Island and the whole of Hermite and Horn Islands, seem formed of cones of greenstone; the outlying islets of Il Defenso and D. Raminez are said[14] to consist of porphyritic lava. In crossing Hardy Peninsula, the slate still retaining traces of its usual cleavage, passes into columnar feldspathic rocks, which are succeeded by an irregular tract of trappean and basaltic rocks, containing glassy feldspar and much iron pyrites: there is, also, some harsh red claystone porphyry, and an almost true trachyte, with needles of hornblende, and in one spot a curious slaty rock divided into quadrangular columns, having a base almost like trachyte, with drusy cavities lined by crystals, too imperfect, according to Professor Miller, to be measured, but resembling Zeagonite.[15] In the midst of these singular rocks, no doubt of ancient submarine volcanic origin, a high hill of feldspathic clay-slate projected, retaining its usual cleavage. Near this point, there was a small hillock, having the aspect of granite, but formed of white albite, brilliant crystals of hornblende (both ascertained by the reflecting goniometer) and mica; but with no quartz. No recent volcanic district has been observed in any part of Tierra del Fuego.

[14] Determined by Professor Jameson. Weddell’s “Voyage,” p. 169.

[15] See Mr. Brooke’s Paper in the *London Phil. Mag.,* vol. x. This mineral occurs in an ancient volcanic rock near Rome.

Five miles west of the bifurcation of the Beagle Channel, the slate-formation, instead of becoming, as in the more southern parts of Tierra del Fuego, feldspathic, and associated with trappean or old volcanic rocks, passes by alternations into a great underlying mass of fine gneiss and glossy clay-slate, which at no great distance is succeeded by a grand formation of mica-slate containing garnets. The folia of these metamorphic schists strike parallel to the cleavage-planes of the clay-slate, which have a very uniform direction over the whole of this part of the country: the folia, however, are undulatory and tortuous, whilst the cleavage-laminæ of the slate are straight. These schists compose the chief mountain-chain of Southern Tierra del Fuego, ranging along the north side of the northern arm of the Beagle Channel, in a short W.N.W. and E.S.E. line, with two points (Mounts Sarmiento and Darwin) rising to heights of 6,800 and 6,900 feet. On the south-western side of this northern arm of the Beagle Channel, the clay-slate is seen with its *strata* dipping from the great chain, so that the metamorphic schists here form a ridge bordered on each side by clay-slate. Further north, however, to the west of this great range, there is no clay-slate, but only gneiss, mica, and hornblendic slates, resting on great barren hills of true granite, and forming a tract about sixty miles in width. Again, westward of these rocks, the outermost islands are of trappean formation, which, from information obtained during the voyages of the *Adventure* and *Beagle,*[16] seem, together with granite, chiefly to prevail along the western coast as far north as the entrance of the St. of Magellan: a little more inland, on the eastern side of Clarence Island and S. Desolation, granite, greenstone, mica-slate, and gneiss appear to predominate. I am tempted to believe, that where the clay-slate has been metamorphosed at great depths beneath the surface, gneiss, mica-slate, and other allied rocks have been formed, but where the action has taken place nearer the surface, feldspathic porphyries, greenstones, etc., have resulted, often accompanied by submarine volcanic eruptions.

[16] See the Paper by Captain King in the *Geograph. Journal*; also a Letter to Dr. Fitton in “Geolog. Proc.,” vol. i, p. 29; also some observations by Captain Fitzroy, “Voyages,” vol. i, p. 375. I am indebted also to Mr. Lyell for a series of specimens collected by Lieutenant Graves.

Only one other rock, met with in both arms of the Beagle Channel, deserves any notice, namely a granulo-crystalline mixture of white albite, black hornblende (ascertained by measurement of the crystals, and confirmed by Professor Miller), and more or less of brown mica, but without any quartz. This rock occurs in large masses, closely resembling in external form granite or syenite: in the southern arm of the Channel, one such mass underlies the mica-slate, on which clay-slate was superimposed: this peculiar plutonic rock which, as we have seen, occurs also in Hardy Peninsula, is interesting, from its perfect similarity with that (hereafter often to be referred to under the name of andesite) forming the great injected axes of the Cordillera of Chile.

The stratification of the clay-slate is generally very obscure, whereas the cleavage is remarkably well defined: to begin with the extreme eastern parts of Tierra del Fuego; the cleavage-planes near the St. of Le Maire strike either W. and E. or W.S.W. and E.N.E., and are highly inclined; the form of the land, including Staten Island, indicates that the axes of elevation have run in this same line, though I was unable to distinguish the planes of stratification. Proceeding westward, I accurately examined the cleavage of the clay-slate on the northern, eastern, and western sides (thirty-five miles apart) of Navarin Island, and everywhere found the laminæ ranging with extreme regularity, W.N.W. and E.S.E., seldom varying more than one point of the compass from this direction.[17] Both on the east and west coasts, I crossed at right angles the cleavage-planes for a space of about eight miles, and found them dipping at an angle of between 45° and 90°, generally to S.S.W., sometimes to N.N.E., and often quite vertically. The S.S.W. dip was occasionally succeeded abruptly by a N.N.E. dip, and this by a vertical cleavage, or again by the S.S.W. dip; as in a lofty cliff on the eastern end of the island the laminæ of slate were seen to be folded into very large steep curves, ranging in the usual W.N.W. line, I suspect that the varying and opposite dips may possibly be accounted for by the cleavage-laminæ, though to the eye appearing straight, being parts of large abrupt curves, with their summits cut off and worn down.

[17] The clay-slate in this island was in many places crossed by parallel smooth joints. Out of five cases, the angle of intersection between the strike of these joints and that of the cleavage-laminæ was in two cases 45° and in two others 79°.

In several places I was particularly struck with the fact, that the fine laminæ of the clay-slate, where cutting straight through the bands of stratification, and therefore indisputably true cleavage-planes, differed slightly in their greyish and greenish tints of colour, in compactness, and in some of the laminæ having a rather more jaspery appearance than others. I have not seen this fact recorded, and it appears to me important, for it shows that the same cause which has produced the highly fissile structure, has altered in a slight degree the mineralogical character of the rock in the same planes. The bands of stratification, just alluded to, can be distinguished in many places, especially in Navarin Island, but only on the weathered surfaces of the slate; they consist of slightly undulatory zones of different shades of colour and of thicknesses, and resemble the marks (more closely than anything else to which I can compare them) left on the inside of a vessel by the draining away of some dirty slightly agitated liquid: no difference in composition, corresponding with these zones, could be seen in freshly fractured surfaces. In the more level parts of Navarin Island, these bands of stratification were nearly horizontal; but on the flanks of the mountains they were inclined from them, but in no instance that I saw at a very high angle. There can, I think, be no doubt that these zones, which appear only on the weathered surfaces, are the last vestiges of the original planes of stratification, now almost obliterated by the highly fissile and altered structure which the mass has assumed.

The clay-slate cleaves in the same W.N.W. and E.S.E. direction, as on Navarin Island, on both sides of the Beagle Channel, on the eastern side of Hoste Island, on the N.E. side of Hardy Peninsula, and on the northern point of Wollaston Island; although in these two latter localities the cleavage has been much obscured by the metamorphosed and feldspathic condition of the slate. Within the area of these several islands, including Navarin Island, the direction of the stratification and of the mountain-chains is very obscure; though the mountains in several places appeared to range in the same W.N.W. line with the cleavage: the outline of the coast, however, does not correspond with this line. Near the bifurcation of the Beagle Channel, where the underlying metamorphic schists are first seen, they are foliated (with some irregularities), in this same W.N.W. line, and parallel, as before stated, to the main mountain-axis of this part of the country. Westward of this main range, the metamorphic schists are foliated, though less plainly, in the same direction, which is likewise common to the zone of old erupted trappean rocks, forming the outermost islets. Hence the area, over which the cleavage of the slate and the foliation of the metamorphic schists extends with an average W.N.W. and E.S.E. strike, is about forty miles in a north and south line, and ninety miles in an east and west line.

Further northward, near Port Famine, the stratification of the clay-slate and of the associated rocks, is well defined, and there alone the cleavage and strata-planes are parallel. A little north of this port there is an anticlinal axis ranging N.W. (or a little more westerly) and S.E.: south of the port, as far as Admiralty Sound and Gabriel Channel, the outline of the land clearly indicates the existence of several lines of elevation in this same N.W. direction, which, I may add, is so uniform in the western half of the St. of Magellan, that, as Captain King[18] has remarked, "a parallel ruler placed on the map upon the projecting points of the south shore, and extended across the strait, will also touch the headlands on the opposite coast." It would appear, from Captain King's observations, that over all this area the cleavage extends in the same line. Deep-water channels, however, in all parts of Tierra del Fuego have burst through the trammels both of stratification and cleavage; most of them may have been formed during the elevation of the land by long-continued erosion, but others, for instance the Beagle Channel, which stretches like a narrow canal for 120 miles obliquely through the mountains, can hardly have thus originated.

[18] *Geograph. Journal,* vol. i, p. 170.

Finally, we have seen that in the extreme eastern point of Tierra del Fuego, the cleavage and coast-lines extend W. and E. and even W.S.W. and E.N.E.: over a large area westward, the cleavage, the main range of mountains, and some subordinate ranges, but not the outlines of the coast, strike W.N.W., and E.S.E.: in the central and western parts of the St. of Magellan, the stratification, the mountain-ranges, the outlines of the coast, and the cleavage all strike nearly N.W. and S.E. North of the strait, the outline of the coast, and the mountains on the mainland, run nearly north and south. Hence we see, at this southern point of the continent, how gradually the Cordillera bend, from their north and south course of so many thousand miles in length, into an E. and even E.N.E. direction.

West coast, from the Southern Chonos Islands to Northern Chile.—The first place at which we landed north of the St. of Magellan was near Cape Tres Montes, in lat. 47° S. Between this point and the Northern Chonos Islands, a distance of 200 miles, the *Beagle* visited several points, and specimens were collected for me from the intermediate spaces by Lieutenant Stokes. The predominant rock is mica-slate, with thick folia of quartz, very frequently alternating with and passing into a chloritic, or into a black, glossy, often striated, slightly anthracitic schist, which soils paper, and becomes white under a great heat, and then fuses. Thin layers of feldspar, swelling at intervals into well crystallised kernels, are sometimes included in these black schists; and I observed one mass of the ordinary black variety insensibly lose its fissile structure, and pass into a singular mixture of chlorite, epidote, feldspar, and mica. Great veins of quartz are numerous in the mica-schists; wherever these occur the folia are much convoluted. In the southern part of the Peninsula of Tres Montes, a compact altered feldspathic rock with crystals of feldspar and grains of quartz is the commonest variety; this rock[19] exhibits occasionally traces of an original brecciated structure, and often presents (like the altered state of Tierra del Fuego) traces of cleavage-planes, which strike in the same direction with the folia of mica-schist further northward. At Inchemo Island, a similar rock gradually becomes granulo-crystalline and acquires scales of mica; and this variety at S. Estevan becomes highly laminated, and though still exhibiting some rounded grains of quartz, passes into the black, glossy, slightly anthracitic schist, which, as we have seen, repeatedly alternates with and passes into the micaceous and chloritic schists. Hence all the rocks on this line of coast belong to one series, and insensibly vary from an altered feldspathic clay-slate into largely foliated, true mica-schist.

[19] The peculiar, abruptly conical form of the hills in this neighbourhood, would have led any one at first to have supposed that they had been formed of injected or intrusive rocks.

The cleavage of the homogeneous schists, the foliation of those composed of more or less distinct minerals in layers, and the planes of alternation of the different varieties or so-called stratification, are all parallel, and preserve over this 200 miles of coast a remarkable degree of uniformity in direction. At the northern end of the group, at Low's Harbour, the well-defined folia of mica-schist everywhere ranged within eight degrees (or less than one point of the compass) of N. 19° W. and S. 19° E.; and even the point of dip varied very little, being always directed to the west and generally at an angle of forty degrees; I should mention that I had here good opportunities of observation, for I followed the naked rock on the beach, transversely to the strike, for a distance of four miles and a half, and all the way attended to the dip. Along the outer islands for 100 miles south of Low's Harbour, Lieutenant Stokes, during his boat-survey, kindly observed for me the strike of the foliation, and he assures me that it was invariably northerly, and the dip with one single exception to the west. Further south at Vallenar Bay, the strike was almost universally N. 25° W. and the dip, generally at an angle of about 40° to W. 25° S., but in some places almost vertical. Still farther south, in the neighbourhood of the harbours of Anna Pink, S. Estevan and S. Andres, and (judging from a distance) along the southern part of Tres Montes, the foliation and cleavage extended in a line between [N. 11° to 22° W.] and [S. 11° to 22° E.]; and the planes dipped generally westerly, but often easterly, at angles varying from a gentle inclination to vertical. At A. Pink's Harbour, where the schists generally dipped easterly, wherever the angle became very high, the strike changed from N. 11° W. to even as much as N. 45° W.: in an analogous manner at Vallenar Bay, where the dip was westerly (viz. on an average directed to W. 25° S.), as soon as the angle became very high, the planes struck in a line more than 25° west of north. The average result from all the observations on this 200 miles of coast, is a strike of N. 19° W. and S. 19° E.: considering that in each specified place my examination extended over an area of several miles, and that Lieutenant Stokes' observations apply to a length of 100 miles, I think this remarkable uniformity is pretty well established. The prevalence, throughout the northern half of this line of coast, of a dip in one direction, that is to the west, instead of being sometimes west and sometimes east, is, judging from what I have elsewhere seen, an unusual circumstance. In Brazil, La Plata, the Falkland Islands, and Tierra del Fuego, there is generally an obvious relation between the axis of elevation, the outline of the coast, and the strike of the cleavage or foliation: in the Chonos Archipelago, however, neither the minor details of the coast-line, nor the chain of the Cordillera, nor the subordinate transverse mountain-axes, accord with the strike of the foliation and cleavage: the seaward face of the numerous islands composing this Archipelago, and apparently the line of the Cordillera, range N. 11° E., whereas, as we have just seen, the average strike of the foliation is N. 19° W.

There is one interesting exception to the uniformity in the strike of the foliation. At the northern point of Tres Montes (lat. 45° 52′) a bold chain of granite, between two and three thousand feet in height, runs from the coast far into the interior,[20] in an E.S.E. line, or more strictly E. 28° S. and W. 28° N. In a bay, at the northern foot of this range, there are a few islets of mica-slate, with the folia in some parts horizontal, but mostly inclined at an average angle of 20° to the north. On the northern steep flank of the range, there are a few patches (some quite isolated, and not larger than half-a-crown!) of the mica-schist, foliated with the same northerly dip. On the broad summit, as far as the southern crest, there is much mica-slate, in some places even 400 feet in thickness, with the folia all dipping north, at angles varying from 5° to 20°, but sometimes mounting up to 30°. The southern flank consists of bare granite. The mica-slate is penetrated by small veins[21] of granite, branching from the main body. Leaving out of view the prevalent strike of the folia in other parts of this Archipelago, it might have been expected that they would have dipped N. 28° E., that is directly from the ridge, and, considering its abruptness, at a high inclination; but the real dip, as we have just seen, both at the foot and on the northern flank, and over the entire summit, is at a small angle, and directed nearly due north. From these considerations it occurred to me, that perhaps we here had the novel and curious case of already inclined laminæ obliquely tilted at a subsequent period by the granitic axis. Mr. Hopkins, so well known from his mathematical investigations, has most kindly calculated the problem: the proposition sent was,—Take a district composed of laminæ, dipping at an angle of 40 degrees to W. 19° S., and let an axis of elevation traverse it in an E. 28° S. line, what will the position of the laminæ be on the northern flank after a tilt, we will first suppose, of 45°? Mr. Hopkins informs me, that the angle of the dip will be 28° 31′, and its direction to north 30° 33′ west.[22] By varying the supposed angle of the tilt, our previously inclined folia can be thrown into any angle between 26°, which is the least possible angle, and 90°; but if a small inclination be thus given to them, their point of dip will depart far from the north, and therefore not accord with the actual position of the folia of mica-schist on our granitic range. Hence it appears very difficult, without varying considerably the elements of the problem, thus to explain the anomalous strike and dip of the foliated mica-schist, especially in those parts, namely, at the base of the range, where the folia are almost horizontal. Mr. Hopkins, however, adds, that great irregularities and lateral thrusts might be expected in every great line of elevation, and that these would account for considerable deviations from the calculated results: considering that the granitic axis, as shown by the veins, has indisputably been injected after the perfect formation of the mica-slate, and considering the uniformity of the strike of the folia throughout the rest of the Archipelago, I cannot but still think that their anomalous position at this one point is someway directly and mechanically related to the intrusion of this W.N.W. and E.S.E. mountain-chain of granite.

[20] In the distance, other mountains could be seen apparently ranging N.N.E. and S.S.W. at right angles to this one. I may add, that not far from Vallenar Bay there is a fine range, apparently of granite, which has burst through the mica-slate in a N.E. by E. and S.W. by S. line.

[21] The granite within these veins, as well as generally at the junction with the mica-slate, is more quartzose than elsewhere. The granite, I may add, is traversed by dikes running for a very great length in the line of the mountains; they are composed of a somewhat laminated eurite, containing crystals of feldspar, hornblende, and octagons of quartz.

[22] On the south side of the axis (where, however, I did not see any mica-slate) the dip of the folia would be at an angle of 77° 55′, directed to west 35° 33′ south. Hence the two points of dip on the opposite sides of the range, instead of being as in ordinary cases directly opposed to each other at an angle of 180°, would here be only 86° 50′ apart.

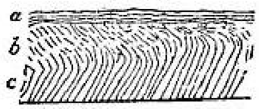
Dikes are frequent in the metamorphic schists of the Chonos Islands, and seem feebly to represent that great band of trappean and ancient volcanic rocks on the south-western coast of Tierra del Fuego. At S. Andres I observed in the space of half-a-mile, seven broad, parallel dikes, composed of three varieties of trap, running in a N.W. and S.E. line, parallel to the neighbouring mountain-ranges of altered clay-slate; but they must be of long subsequent origin to these mountains; for they intersected the volcanic formation described in the last chapter. North of Tres Montes, I noticed three dikes differing from each other in composition, one of them having a euritic base including large octagons of quartz; these dikes, as well as several of porphyritic greenstone at Vallenar Bay, extended N.E. and S.W., nearly at right angles to the foliation of the schists, but in the line of their joints. At Low's Harbour, however, a set of great parallel dikes, one ninety yards and another sixty yards in width, have been guided by the foliation of the mica-schist, and hence are inclined westward at an angle of 45°: these dikes are formed of various porphyritic traps, some of which are remarkable from containing numerous rounded grains of quartz. A porphyritic trap of this latter kind, passed in one of the dikes into a most curious hornstone, perfectly white, with a waxy fracture and pellucid edges, fusible, and containing many grains of quartz and specks of iron pyrites. In the ninety-yard dike several large, apparently now quite isolated, fragments of mica-slate were embedded: but as their foliation was exactly parallel to that of the surrounding solid rock, no doubt these new separate fragments originally formed wedge-shaped depending portions of a continuous vault or crust, once extending over the dike, but since worn down and denuded.

Chiloe, Valdivia, Concepcion.—In Chiloe, a great formation of mica-schist strikingly resembles that of the Chonos Islands. For a space of eleven miles on the S.E. coast, the folia were very distinct, though slightly convoluted, and ranged within a point of N.N.W. and S.S.E., dipping either E.N.E. or more commonly W.S.W., at an average angle of 22° (in one spot, however, at 60°), and therefore decidedly at a lesser inclination than amongst the Chonos Islands. On the west and north-western shores, the foliation was often obscure, though, where best defined, it ranged within a point of N. by W. and S. by E., dipping either easterly or westerly, at varying and generally very small angles. Hence, from the southern part of Tres Montes to the northern end of Chiloe, a distance of 300 miles, we have closely allied rocks with their folia striking on an average in the same direction, namely between N. 11° and 22° W. Again, at Valdivia, we meet with the same mica-schist, exhibiting nearly the same mineralogical passages as in the Chonos Archipelago, often, however, becoming more ferruginous, and containing so much feldspar as to pass into gneiss. The folia were generally well defined; but nowhere else in South America did I see them varying so much in direction: this seemed chiefly caused by their forming parts, as I could sometimes distinctly trace, of large flat curves: nevertheless, both near the settlement and towards the interior, a N.W. and S.E. strike seemed more frequent than any other direction; the angle of the dip was generally small. At Concepcion, a highly glossy clay-slate had its cleavage often slightly curvilinear, and inclined, seldom at a high angle, towards various points of the compass:[23] but here, as at Valdivia, a N.W. and S.E. strike seemed to be the most frequent one. In certain spots large quartz veins were numerous, and near them, the cleavage, as was the case with the foliation of the schists in the Chonos Archipelago, became extremely tortuous.

[23] I observed in some parts that the tops of the laminæ of the clay-slate (*b* of the diagram) under the superficial detritus and soil (*a*) were bent, sometimes without being broken, as represented in the accompanying diagram, which is copied from one given by Sir H. De la Beche (p. 42 "Geological Manual") of an exactly similar phenomenon in Devonshire. Mr. R. A. C. Austen, also, in his excellent paper on S.E. Devon ("Geolog. Transact.," vol. vi, p. 437), has described this phenomenon; he attributes it to the action of frosts, but at the same time doubts whether the frosts of the present day penetrate to a sufficient depth. As it is known that earthquakes particularly affect the surface of the ground, it occurred to me that this appearance might perhaps be due, at least at Concepcion, to their frequent occurrence; the superficial

layers of detritus being either jerked in one direction, or, where the surface was inclined, pushed a little downwards during each strong vibration. In North Wales I have seen a somewhat analogous but less regular appearance, though on a greater scale (*London Phil. Mag.,* vol. xxi, p. 184), and produced by a quite different cause, namely, by the stranding of great icebergs; this latter appearance has also been observed in N. America.

No. 23



At the northern end of Quiriquina Island, in the Bay of Concepcion, at least eight rudely parallel dikes, which have been guided to a certain extent by the cleavage of the slate, occur within the space of a quarter of a mile. They vary much in composition, resembling in many respects the dikes at Low’s Harbour: the greater number consist of feldspathic porphyries, sometimes containing grains of quartz: one, however, was black and brilliant, like an augitic rock, but really formed of feldspar; others of a feldspathic nature were perfectly white, with either an earthy or crystalline fracture, and including grains and regular octagons of quartz; these white varieties passed into ordinary greenstones. Although, both here and at Low’s Harbour, the nature of the rock varied considerably in the same dike, yet I cannot but think that at these two places and in other parts of the Chonos group, where the dikes, though close to each other and running parallel, are of different composition, that they must have been formed at different periods. In the case of Quiriquina this is a rather interesting conclusion, for these eight parallel dikes cut through the metamorphic schists in a N.W. and S.E. line, and since their injection the overlying cretaceous or tertiary strata have been tilted (whilst still under the sea) from a N.W. by N. and S.E. by S. line; and again, during the great earthquake of February 1835, the ground in this neighbourhood was fissured in N.W. and S.E. lines; and from the manner in which buildings were thrown down, it was evident that the surface undulated in this same direction.[24]

[24] “Geolog. Trans.,” vol. vi, pp. 602 and 617. “Journal of Researches” (2nd edit.), p. 307.

Central and Northern Chile.—Northward of Concepcion, as far as Copiapo, the shores of the Pacific consist, with the exception of some small tertiary basins, of gneiss, mica-schist, altered clay-slate, granite, greenstone and syenite: hence the coast from Tres Montes to Copiapo, a distance of 1,200 miles, and I have reason to believe for a much greater space, is almost similarly constituted.

Near Valparaiso the prevailing rock is gneiss, generally including much hornblende: concretionary balls formed of feldspar, hornblende and mica, from two or three feet in diameter, are in very many places conformably enfolded by the foliated gneiss: veins of quartz and feldspar, including black schorl and well-crystallised epidote, are numerous. Epidote likewise occurs in the gneiss in thin layers, parallel to the foliation of the mass. One large vein of a coarse granitic character was remarkable from in one part quite changing its character, and insensibly passing into a blackish porphyry, including acicular crystals of glassy feldspar and of hornblende: I have never seen any other such case.[25]

[25] Humboldt (“Personal Narrative,” vol. iv, p. 60) has described with much surprise, concretionary balls, with concentric divisions, composed of partially vitreous feldspar, hornblende, and garnets, included within great veins of gneiss, which cut across the mica-slate near Venezuela.

I shall in the few following remarks on the rocks of Chile allude exclusively to their foliation and cleavage. In the gneiss round Valparaiso the strike of the foliation is very variable, but I think about N. by W. and S. by E. is the commonest direction; this likewise holds good with the cleavage of the altered feldspathic clay-slates, occasionally met with on the coast for ninety miles north of Valparaiso. Some feldspathic slate, alternating with strata of claystone porphyry in the Bell of Quillota and at Jajuel, and therefore, perhaps, belonging to a later period than the metamorphic schists on the coast, cleaved in this same direction. In the Eastern Cordillera, in the Portillo Pass, there is a grand mass of mica-slate, foliated in a north and south line, and with a high westerly dip: in the Uspallata range, clay-slate and grauwacke have a highly inclined, nearly north and south cleavage, though in some parts the strike is irregular: in the main or Cumbre range, the direction of the cleavage in the feldspathic clay-slate is N.W. and S.E.

Between Coquimbo and Guasco there are two considerable formations of mica-slate, in one of which the rock passed sometimes into common clay-slate and sometimes into a glossy black variety, very like that in the Chonos Archipelago. The folia and cleavage of these rocks ranged between [N. and N.W. by N.] and [S. and S.W. by S.]. Near the Port of Guasco several varieties of altered clay-slate have a quite irregular cleavage. Between Guasco and Copiapo, there are some siliceous and talcaceous slates cleaving in a north and south line, with an easterly dip of between 60° and 70°: high up, also, the main valley of Copiapo, there is mica-slate with a high easterly dip. In the whole space between Valparaiso and Copiapo an easterly dip is much more common than an opposite or westerly one.

Concluding Remarks on Cleavage and Foliation.

In this southern part of the southern hemisphere, we have seen that the cleavage-laminæ range over wide areas with remarkable uniformity, cutting straight through the planes of stratification,[26] but yet being parallel in strike to the main axes of elevation, and generally to the outlines of the coast. The dip, however, is as variable, both in angle and in direction (that is, sometimes being inclined to the one side and sometimes to the directly opposite side), as the strike is uniform. In all these respects there is a close agreement with the facts given by Professor Sedgwick in his celebrated memoir in the "Geological Transactions," and by Sir R. I. Murchison in his various excellent discussions on this subject. The Falkland Islands, and more especially Tierra del Fuego, offer striking instances of the lines of cleavage, the principle axes of elevation, and the outlines of the coast, gradually changing together their courses. The direction which prevails throughout Tierra del Fuego and the Falkland Islands, namely, from west with some northing to east with some southing, is also common to the several ridges in Northern Patagonia and in the western parts of Banda Oriental: in this latter province, in the Sierra Tapalguen, and in the Western Falkland Island, the W. by N., or W.N.W. and E.S.E., ridges, are crossed at right angles by others ranging N.N.E. and S.S.W.

[26] In my paper on the Falkland Islands (*Geological Journal,* vol. iii, p. 267), I have given a curious case on the authority of Captain Sulivan, R.N., of much folded beds of clay-slate, in some of which the cleavage is perpendicular to the horizon, and in others it is perpendicular to each curvature or fold of the bed: this appears a new case.

The fact of the cleavage-laminæ in the clay-slate of Tierra del Fuego, where seen cutting straight through the planes of stratification, and where consequently there could be no doubt about their nature, differing slightly in colour, texture, and hardness, appears to me very interesting. In a thick mass of laminated, feldspathic and altered clay-slate, interposed between two great strata of porphyritic conglomerate in Central Chile, and where there could be but little doubt about the bedding, I observed similar slight differences in composition, and likewise some distinct thin layers of epidote, parallel to the highly inclined cleavage of the mass. Again, I incidentally noticed in North Wales,[27] where glaciers had passed over the truncated edges of the highly inclined laminæ of clay-slate, that the surface, though smooth, was worn into small parallel undulations, caused by the competent laminæ being of slightly different degrees of hardness. With reference to the slates of North Wales, Professor Sedgwick describes the planes of cleavage, as "coated over with chlorite and semi-crystalline matter, which not only merely define the planes in question, but strike in parallel flakes through the whole mass of the rock."[28] In some of those glossy and hard varieties of clay-slate, which may often be seen passing into mica-schist, it has appeared to me that the cleavage-planes were formed of excessively thin, generally slighted convoluted, folia, composed of microscopically minute scales of mica. From these several facts, and more especially from the case of the clay-slate in Tierra del Fuego, it must, I think, be concluded, that the same power which has impressed on the slate its fissile structure or cleavage has tended to modify its mineralogical character in parallel planes.

[27] *London Phil. Mag.*, vol. xxi, p. 182.

[28] "Geological Trans.," vol. iii, p. 471.

Let us now turn to the foliation of the metamorphic schists, a subject which has been much less attended to. As in the case of cleavage-laminæ, the folia preserve over very large areas a uniform strike: thus Humboldt[29] found for a distance of 300 miles in Venezuela, and indeed over a much larger space, gneiss, granite, mica, and clay-slate, striking very uniformly N.E. and S.W., and dipping at an angle of between 60° and 70° to N.W.; it would even appear from the facts given in this chapter, that the metamorphic rocks throughout the north-eastern part of South America are generally foliated within two points of N.E. and S.W. Over the eastern parts of Banda Oriental, the foliation strikes with a high inclination, very uniformly N.N.E. to S.S.W., and over the western parts, in a W. by N. and E. by S. line. For a space of 300 miles on the shores of the Chonos and Chiloe Islands, we have seen that the foliation seldom deviates more than a point of the compass from a N. 19° W. and S. 19° E. strike. As in the case of cleavage, the angle of the dip in foliated rocks is generally high but variable, and alternates from one side of the line of strike to the other side, sometimes being vertical: in the Northern Chonos Islands, however, the folia are inclined almost always to the west; in nearly the same manner, the cleavage-laminæ in Southern Tierra del Fuego certainly dip much more frequently to S.S.W. than to the opposite point. In Eastern Banda Oriental, in parts of Brazil, and in some other districts, the foliation runs in the same direction with the mountain-ranges and adjoining coast-lines: amongst the Chonos Islands, however, this coincidence fails, and I have given my reasons for suspecting that one granitic axis has burst through and tilted the already inclined folia of mica-schist: in the case of cleavage,[30] the coincidence between its strike and that of the main stratification seems sometimes to fail. Foliation and cleavage resemble each other in the planes winding round concretions, and in becoming tortuous where veins of quartz abound.[31] On the flanks of the mountains both in Tierra del Fuego and in other countries, I have observed that the cleavage-planes frequently dip at a high angle inwards; and this was long ago observed by Von Buch to be the case in Norway: this fact is perhaps analogous to the folded, fan-like or radiating structure in the metamorphic schists of the Alps,[32] in which the folia in the central crests are vertical and on the two flanks inclined inwards. Where masses of fissile and foliated rocks alternate together, the cleavage and foliation, in all cases which I have seen, are parallel. Where in one district the rocks are fissile, and in another adjoining district they are foliated, the planes of cleavage and foliation are likewise generally parallel: this is the case with the feldspathic homogeneous slates in the southern part of the Chonos group, compared with the fine foliated mica-schists of the northern part; so again the clay-slate of the whole eastern side of Tierra del Fuego cleaves in exactly the same line with the foliated gneiss and mica-slate of the western coast; other analogous instances might have been adduced.[33]

[29] "Personal Narrative," vol. vi, p. 59 *et seq.*

[30] Cases are given by Mr. Jukes in his "Geology of Newfoundland," p. 130.

[31] I have seen in Brazil and Chile concretions thus enfolded by foliated gneiss; and Macculloch ("Highlands," vol. i, p. 64) has described a similar case. For analogous cases in clay-slate, see Professor Henslow's Memoir in "Cambridge Phil. Trans.," vol. i, p. 379, and Macculloch's "Class. of Rocks," p. 351. With respect to both foliation and cleavage becoming tortuous where quartz-veins abound, I have seen instances near Monte Video, at Concepcion, and in the Chonos Islands. See also Mr. Greenough's "Critical Examination," p. 78.

[32] Studer in *Edin. New Phil. Journal,* vol. xxiii, p. 144.

[33] I have given a case in Australia. See my "Volcanic Islands."

With respect to the origin of the folia of quartz, mica, feldspar, and other minerals composing the metamorphic schists, Professor Sedgwick, Mr. Lyell, and most authors believe, that the constituent parts of each layer were separately deposited as sediment, and then metamorphosed. This view, in the majority of cases, I believe to be quite untenable. In those not uncommon instances, where a mass of clay-slate, in approaching granite, gradually passes into gneiss,[34] we clearly see that folia of distinct minerals can originate through the metamorphosis of a homogeneous fissile rock. The deposition, it may be remarked, of numberless alternations of pure quartz, and of the elements of mica or feldspar does not appear a probable event.[35] In those districts in which the metamorphic schists are foliated in planes parallel to the cleavage of the rocks in an adjoining district, are we to believe that the folia are due to sedimentary layers, whilst the cleavage-laminæ, though parallel, have no relation whatever to such planes of deposition? On this view, how can we reconcile the vastness of the areas over which the strike of the foliation is uniform, with what we see in disturbed districts composed of true strata: and especially, how can we understand the high and even vertical dip throughout many wide districts, which are not mountainous, and throughout some, as in Western Banda Oriental, which are not even hilly? Are we to admit that in the northern part of the Chonos Archipelago, mica-slate was first accumulated in parallel horizontal folia to a thickness of about four geographical miles, and then upturned at an angle of forty degrees; whilst, in the southern part of this same Archipelago, the cleavage-laminæ of closely allied rocks, which none would imagine had ever been horizontal, dip at nearly the same angle, to nearly the same point?

[34] I have described in "Volcanic Islands" a good instance of such a passage at the Cape of Good Hope.

[35] See some excellent remarks on this subject, in D'Aubuisson's "Traité de Géog.," tome i, p. 297. Also some remarks by Mr. Dana in *Silliman's American Journ.,* vol. xlv, p. 108.

Seeing, then, that foliated schists indisputably are sometimes produced by the metamorphosis of homogeneous fissile rocks; seeing that foliation and cleavage are so closely analogous in the several above-enumerated respects; seeing that some fissile and almost homogeneous rocks show incipient mineralogical changes along the planes of their cleavage, and that other rocks with a fissile structure alternate with, and pass into varieties with a foliated structure, I cannot doubt that in most cases foliation and cleavage are parts of the same process: in cleavage there being only an incipient separation of the constituent minerals; in foliation a much more complete separation and crystallisation.

The fact often referred to in this chapter, of the foliation and the so-called strata in the metamorphic series,—that is, the alternating masses of different varieties of gneiss, mica-schist, and hornblende-slate, etc.,—being parallel to each other, at first appears quite opposed to the view, that the folia have no relation to the planes of original deposition. Where the so-called beds are not very thick and of widely different mineralogical composition from each other, I do not think that there is any difficulty in supposing that they have originated in an analogous manner with the separate folia. We should bear in mind what thick strata, in ordinary sedimentary masses, have obviously been formed by a concretionary process. In a pile of volcanic rocks on the Island of Ascension, there are strata, differing quite as much in appearance as the ordinary varieties of the metamorphic schists, which undoubtedly have been produced, not by successive flowings of lava, but by internal molecular changes. Near Monte Video, where the stratification, as it would be called, of the metamorphic series is, in most parts, particularly well developed, being as usual, parallel to the foliation, we have seen that a mass of chloritic schist, netted with quartz-veins, is entangled in gneiss, in such a manner as to show that it had certainly originated in some process of segregation: again, in another spot, the gneiss tended to pass into hornblendic schist by alternating with layers of quartz; but these layers of quartz almost certainly had never been separately deposited, for they were absolutely continuous with the numerous intersecting veins of quartz. I have never had an opportunity of tracing for any distance, along the line both of strike and of dip, the so-called beds in the metamorphic schists, but I strongly suspect that they would not be found to extend with the same character, very far in the line either of their dip or strike. Hence I am led to believe, that most of the so-called beds are of the nature of complex folia, and have not been separately deposited. Of course, this view cannot be extended to *thick* masses included in the metamorphic series, which are of totally different composition from the adjoining schists, and which are far extended, as is sometimes the case with quartz and marble; these must generally be of the nature of true strata.[36] Such strata, however, will almost always strike in the same direction with the folia, owing to the axes of elevation being in most countries parallel to the strike of the foliation; but they will generally dip at a different angle from that of the foliation; and the angle of the foliation in itself almost always varies much: hence, in crossing a metamorphosed schistose district, it would require especial attention to discriminate between true strata of deposition and complex foliated masses. The mere presence of true strata in the midst of a set of metamorphic schists, is no argument that the foliation is of sedimentary origin, without it be further shown in each case, that the folia not only strike, but dip throughout in parallel planes with those of the true stratification.

[36] Macculloch states ("Classification of Rocks," p. 364) states that primary limestones are often found in irregular masses or great nodules, "which can scarcely be said to possess a stratified shape!"

As in some cases it appears that where a fissile rock has been exposed to partial metamorphic action, for instance from the irruption of granite, the foliation has supervened on the already existing cleavage-planes; so perhaps in some instances, the foliation of a rock may have been determined by the original planes of deposition or of oblique current-laminæ: I have, however, myself, never seen such a case, and I must maintain that in most extensive metamorphic areas, the foliation is the extreme result of that process, of which cleavage is the first effect. That foliation may arise without any previous structural arrangement in the mass, we may infer from injected, and therefore once liquified, rocks, both of volcanic and plutonic origin, sometimes having a "grain" (as expressed by Professor Sedgwick), and sometimes being composed of distinct folia or laminæ of different compositions. In my work on "Volcanic Islands," I have given several instances of this structure in volcanic rocks, and it is not uncommonly seen in plutonic masses—thus, in the Cordillera of Chile, there are gigantic mountain-like masses of red granite, which have been injected whilst liquified, and which, nevertheless, display in parts a decidedly laminar structure.[37]

[37] As remarked in a former part of this chapter, I suspect that the boldly conical mountains of gneiss-granite, near Rio de Janeiro, in which the constituent minerals are arranged in parallel planes, are of intrusive origin. We must not, however, forget the lesson of caution taught by the curious claystone porphyries of Port Desire, in which we have seen that the breaking up and aggregation of a thinly stratified tufaceous mass, has yielded a rock semi-porphyritic with crystals of feldspar, arranged in the planes of original deposition.

Finally, we have seen that the planes of cleavage and of foliation, that is, of the incipient process and of the final result, generally strike parallel to the principal axes of elevation, and to the outline of the land: the strike of the axes of elevation (that is, of the lines of fissures with the strata on their edges upturned), according to the reasoning of Mr. Hopkins, is determined by the form of the area undergoing changes of level, and the consequent direction of the lines of tension and fissure. Now, in that remarkable pile of volcanic rocks at Ascension, which has several times been alluded to (and in some other cases), I have endeavoured to show,[38] that the lamination of the several varieties, and their alternations, have been caused by the moving mass, just before its final consolidation, having been subjected (as in a glacier) to planes of different tension; this difference in the tension affecting the crystalline and concretionary processes. One of the varieties of rock thus produced at Ascension, at first sight, singularly resembles a fine-grained gneiss; it consists of quite straight and parallel zones of excessive tenuity, of more or less coloured crystallised feldspar, of distinct crystals of quartz, diopside, and oxide of iron. These considerations, notwithstanding the experiments made by Mr. Fox, showing the influence of electrical currents in producing a structure like that of cleavage, and notwithstanding the apparently inexplicable variation, both in the inclination of the cleavage-laminæ and in their dipping first to one side and then to the other side of the line of strike, lead me to suspect that the planes of cleavage and foliation are intimately connected with the planes of different tension, to which the area was long subjected, *after* the main fissures or axes of upheavement had been formed, but *before* the final consolidation of the mass and the total cessation of all molecular movement.

[38] In "Volcanic Islands."

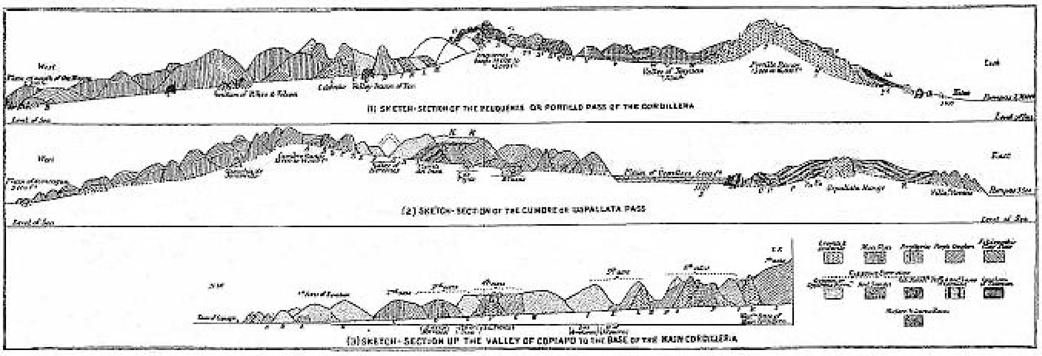


Plate V

For enlargements of the above plate use the following links:
left section
center section
right section

Chapter VII

CENTRAL CHILE:—STRUCTURE OF THE CORDILLERA.

Central Chile.—Basal formations of the Cordillera.—Origin of the porphyritic clay-stone conglomerate.—Andesite.—Volcanic rocks.—Section of the Cordillera by the Peuquenes are Portillo Pass.—Great gypseous formation.—Peuquenes line; thickness of strata, fossils of.—Portillo line.—Conglomerate, orthitic granite, mica-schist, volcanic rocks of.—Concluding remarks on the denudation and elevation of the Portillo line.—Section by the Cumbre, or Uspallata Pass.—Porphyries.—Gypseous strata.—Section near the Puente del Inca; fossils of.—Great subsidence.—Intrusive porphyries.—Plain of Uspallata.—Section of the Uspallata chain.—Structure and nature of the strata.—Silicified vertical trees.—Great subsidence.—Granitic rocks of axis.—Concluding remarks on the Uspallata range; origin subsequent to that of the main Cordillera; two periods of subsidence; comparison with the Portillo chain.

The district between the Cordillera and the Pacific, on a rude average, is from about eighty to one hundred miles in width. It is crossed by many chains of mountains, of which the principal ones, in the latitude of Valparaiso and southward of it, range nearly north and south; but in the more northern parts of the province, they run in almost every possible direction. Near the Pacific, the mountain-ranges are generally formed of syenite or granite, and or of an allied euritic porphyry; in the low country, besides these granitic rocks and greenstone, and much gneiss, there are, especially northward of Valparaiso, some considerable districts of true clay-slate with quartz veins, passing into a feldspathic and porphyritic slate; there is also some grauwacke and quartzose and jaspery rocks, the latter occasionally assuming the character of the basis of claystone porphyry: trap-dikes are numerous. Nearer the Cordillera the ranges (such as those of S. Fernando, the Prado,[1] and Aconcagua) are formed partly of granitic rocks, and partly of purple porphyritic conglomerates, claystone porphyry, greenstone porphyry, and other rocks, such as we shall immediately see, form the basal strata of the main Cordillera. In the more northern parts of Chile, this porphyritic series extends over large tracts of country far from the Cordillera; and even in Central Chile such occasionally occur in outlying positions.

[1] Meyen “Reise um Erde” Th. I, s. 235.

I will describe the Campana of Quillota, which stands only fifteen miles from the Pacific, as an instance of one of these outlying masses. This hill is conspicuous from rising to the height of 6,400 feet: its summit shows a nucleus, uncovered for a height of 800 feet, of fine greenstone, including epidote and octahedral magnetic iron ore; its flanks are formed of great strata of porphyritic claystone conglomerate associated with various true porphyries and amygdaloids, alternating with thick masses of a highly feldspathic, sometimes porphyritic, pale-coloured slaty rock, with its cleavage-laminæ dipping inwards at a high angle. At the base of the hill there are syenites, a granular mixture of quartz and feldspar, and harsh quartzose rocks, all belonging to the basal metamorphic series. I may observe that at the foot of several hills of this class, where the porphyries are first seen (as near S. Fernando, the Prado, Las Vacas, etc.), similar harsh quartzose rocks and granular mixtures of quartz and feldspar occur, as if the more fusible constituent parts of the granitic series had been drawn off to form the overlying porphyries.

In Central Chile, the flanks of the main Cordillera, into which I penetrated by four different valleys, generally consist of distinctly stratified rocks. The strata are inclined at angles varying from sometimes even under ten, to twenty degrees, very rarely exceeding forty degrees: in some, however, of the quite small, exterior, spur-like ridges, the inclination was not unfrequently greater. The dip of the strata in the main outer lines was usually outwards or from the Cordillera, but in Northern Chile frequently inwards,—that is, their basset-edges fronted the Pacific. Dikes occur in extraordinary numbers. In the great, central, loftiest ridges, the strata, as we shall presently see, are almost always highly inclined and often vertical. Before giving a detailed account of my two sections across the Cordillera, it will, I think, be convenient to describe the basal strata as seen, often to a thickness of four or five thousand feet, on the flanks of the outer lines.

Basal strata of the Cordillera.—The prevailing rock is a purplish or greenish, porphyritic claystone conglomerate. The embedded fragments vary in size from mere particles to blocks as much as six or eight inches (rarely more) in diameter; in many places, where the fragments were minute, the signs of aqueous deposition were unequivocally distinct; where they were large, such evidence could rarely be detected. The basis is generally porphyritic with perfect crystals of feldspar, and resembles that of a true injected claystone porphyry: often, however, it has a mechanical or sedimentary aspect, and sometimes (as at Jajuel) is jaspery. The included fragments are either angular, or partially or quite rounded;[2] in some parts the rounded, in others the angular fragments prevail, and usually both kinds are mixed together: hence the word *breccia* ought strictly to be appended to the term *porphyritic conglomerate.* The fragments consist of many varieties of claystone porphyry, usually of nearly the same colour with the surrounding basis, namely, purplish-reddish, brownish, mottled or bright green; occasionally fragments of a laminated, pale-coloured, feldspathic rock, like altered clay-slate are included; as are sometimes grains of quartz, but only in one instance in Central Chile (namely, at the mines of Jajuel) a few pebbles of quartz. I nowhere observed mica in this formation, and rarely hornblende; where the latter mineral did occur, I was generally in doubt whether the mass really belonged to this formation, or was of intrusive origin. Calcareous spar occasionally occurs in small cavities; and nests and layers of epidote are common. In some few places in the finer-grained varieties (for instance, at Quillota), there were short, interrupted layers of earthy feldspar, which could be traced, exactly as at Port Desire, passing into large crystals of feldspar: I doubt, however, whether in this instance the layers had ever been separately deposited as tufaceous sediment.

[2] Some of the rounded fragments in the porphyritic conglomerate near the Baths of Cauquenes, were marked with radii and concentric zones of different shades of colour: any one who did not know that pebbles, for instance flint pebbles from the chalk, are sometimes zoned concentrically with their worn and rounded surfaces, might have been led to infer, that these balls of porphyry were not true pebbles, but had originated in concretionary action.)

All the varieties of porphyritic conglomerates and breccias pass into each other, and by innumerable gradations into porphyries no longer retaining the least trace of mechanical origin: the transition appears to have been effected much more easily in the finer-grained, than in the coarser-grained varieties. In one instance, near Cauquenes, I noticed that a porphyritic conglomerate assumed a spheroidal structure, and tended to become columnar. Besides the porphyritic conglomerates and the perfectly characterised porphyries, of metamorphic origin, there are other porphyries, which, though differing not at all or only slightly in composition, certainly have had a different origin: these consist of pink or purple claystone porphyries, sometimes including grains of quartz,—of greenstone porphyry, and of other dusky rocks, all generally porphyritic with fine, large, tabular, opaque crystals, often placed crosswise, of feldspar cleaving like albite (judging from several measurements), and often amygdaloidal with silex, agate, carbonate of lime, green and brown bole.[3] These several porphyritic and amygdaloidal varieties never show any signs of passing into masses of sedimentary origin: they occur both in great and small intrusive masses, and likewise in strata alternating with those of the porphyritic conglomerate, and with the planes of junction often quite distinct, yet not seldom blended together. In some of these intrusive masses, the porphyries exhibit, more or less plainly, a brecciated structure, like that often seen in volcanic masses. These brecciated porphyries could generally be distinguished at once from the metamorphosed, porphyritic breccia-conglomerates, by all the fragments being angular and being formed of the same variety, and by the absence of every trace of aqueous deposition. One of the porphyries above specified, namely, the greenstone porphyry with large tabular crystals of albite, is particularly abundant, and in some parts of the Cordillera (as near St. Jago) seemed more common even than the purplish porphyritic conglomerate. Numerous dikes likewise consist of this greenstone porphyry; others are formed of various fine-grained trappean rocks; but very few of claystone porphyry: I saw no true basaltic dikes.

[3] This bole is a very common mineral in the amygdaloidal rocks; it is generally of a greenish-brown colour, with a radiating structure; externally it is black with an almost metallic lustre, but often coated by a bright green film. It is soft and can be scratched by a quill; under the blowpipe swells greatly and becomes scaly, then fuses easily into a black magnetic bead. This substance is evidently similar to that which often occurs in submarine volcanic rocks. An examination of some very curious specimens of a fine porphyry (from Jajuel) leads me to suspect that some of these amygdaloidal balls, instead of having been deposited in pre-existing air-vesicles, are of concretionary origin; for in these specimens, some of the pea-shaped little masses (often externally marked with minute pits) are formed of a mixture of green earth with stony matter, like the basis of the porphyry, including minute imperfect crystals of feldspar; and these pea-shaped little masses are themselves amygdaloidal with minute spheres of the green earth, each enveloped by a film of white, apparently feldspathic, earthy matter: so that the porphyry is doubly amygdaloidal. It should not, however, be overlooked, that all the strata here have undergone metamorphic action, which may have caused crystals of feldspar to appear, and other changes to be effected, in the originally simple amygdaloidal balls. Mr. J. D. Dana, in an excellent paper on Trap-rocks (*Edin. New Phil. Journ.,* vol. xli, p. 198), has argued with great force, that all amygdaloidal minerals have been deposited by aqueous infiltration. I may take this opportunity of alluding to a curious case, described in my work on "Volcanic Islands," of an amygdaloid with many of its cells only half filled up with a mesotypic mineral.

M. Rose has described an amygdaloid, brought by Dr. Meyen ("Reise um Erde," Th. I, s. 316) from Chile, as consisting of crystallised quartz, with crystals of stilbite within, and lined externally by green earth.

In several places in the lower part of the series, but not everywhere, thick masses of a highly feldspathic, often porphyritic, slaty rock occur interstratified with the porphyritic conglomerate; I believe in one or two cases blackish limestone has been found in a similar position. The feldspathic rock is of a pale grey or greenish colour; it is easily fusible; where porphyritic, the crystals of feldspar are generally small and vitreous: it is distinctly laminated, and sometimes includes parallel layers of epidote;[4] the lamination appears to be distinct from stratification. Occasionally this rock is somewhat curious; and at one spot, namely, at the C. of Quillota, it had a brecciated structure. Near the mines of Jajuel, in a thick stratum of this feldspathic, porphyritic slate, there was a layer of hard, blackish, siliceous, infusible, compact clay-slate, such as I saw nowhere else; at the same place I was able to follow for a considerable distance the junction between the slate and the conformably underlying porphyritic conglomerate, and they certainly passed gradually into each other. Wherever these slaty feldspathic rocks abound, greenstone seems common; at the C. of Quillota a bed of well-crystallised greenstone lay conformably in the midst of the feldspathic slate, with the upper and lower junctions passing insensibly into it. From this point, and from the frequently porphyritic condition of the slate, I should perhaps have considered this rock as an erupted one (like certain laminated feldspathic lavas in the trachytic series), had I not seen in Tierra del Fuego how readily true clay-slate becomes feldspathic and porphyritic, and had I not seen at Jajuel the included layer of black, siliceous clay-slate, which no one could have thought of igneous origin. The gentle passage of the feldspathic slate, at Jajuel, into the porphyritic conglomerate, which is certainly of aqueous origin, should also be taken in account.

[4] This mineral is extremely common in all the formations of Chile; in the gneiss near Valparaiso and in the granitic veins crossing it, in the injected greenstone crowning the C. of Quillota, in some granitic porphyries, in the porphyritic conglomerate, and in the feldspathic clay-slates.

The alternating strata of porphyries and porphyritic conglomerate, and with the occasionally included beds of feldspathic slate, together make a grand formation; in several places within the Cordillera, I estimated its thickness at from six to seven thousand feet. It extends for many hundred miles, forming the western flank of the Chilean Cordillera; and even at Iquique in Peru, 850 miles north of the southernmost point examined by me in Chile, the coast-escarpment which rises to a height of between two and three thousand feet is thus composed. In several parts of Northern Chile this formation extends much further towards the Pacific, over the granitic and metamorphic lower rocks, than it does in Central Chile; but the main Cordillera may be considered as its central line, and its breadth in an east and west direction is never great. At first the origin of this thick, massive, long but narrow formation, appeared to me very anomalous: whence were derived, and how were dispersed the innumerable fragments, often of large size, sometimes angular and sometimes rounded, and almost invariably composed of porphyritic rocks? Seeing that the interstratified porphyries are never vesicular and often not even amygdaloidal, we must conclude that the pile was formed in deep water; how then came so many fragments to be well rounded and so many to remain angular, sometimes the two kinds being equally mingled, sometimes one and sometimes the other preponderating? That the claystone, greenstone, and other porphyries and amygdaloids, which lie *conformably* between the beds of conglomerate, are ancient submarine lavas, I think there can be no doubt; and I believe we must look to the craters whence these streams were erupted, as the source of the breccia-conglomerate; after the great explosion, we may fairly imagine that the water in the heated and scarcely quiescent crater would remain for a considerable time[5] sufficiently agitated to triturate and round the loose fragments, few or many in number, would be shot forth at the next eruption, associated with few or many angular fragments, according to the strength of the explosion. The porphyritic conglomerate being purple or reddish, even when alternating with dusty-coloured or bright green porphyries and amygdaloids, is probably an analogous circumstance to the scoriæ of the blackish basalts being often bright red. The ancient submarine orifices whence the porphyries and their fragments were ejected having been arranged in a band, like most still active volcanoes, accounts for the thickness, the narrowness, and linear extension of this formation.

[5] This certainly seems to have taken place in some recent volcanic archipelagos, as at the Galapagos, where numerous craters are exclusively formed of tuff and fragments of lava.

This whole great pile of rock has suffered much metamorphic action, as is very obvious in the gradual formation and appearance of the crystals of albitic feldspar and of epidote—in the bending together of the fragments—in the appearance of a laminated structure in the feldspathic slate—and, lastly, in the disappearance of the planes of stratification, which could sometimes be seen on the same mountain quite distinct in the upper part, less and less plain on the flanks, and quite obliterated at the base. Partly owing to this metamorphic action, and partly to the close relationship in origin, I have seen fragments of porphyries—taken from a metamorphosed conglomerate—from a neighbouring stream of lava—from the nucleus or centre (as it appeared to me) of the whole submarine volcano—and lastly from an intrusive mass of quite subsequent origin, all of which were absolutely undistinguishable in external characters.

One other rock, of plutonic origin, and highly important in the history of the Cordillera, from having been injected in most of the great axes of elevation, and from having apparently been instrumental in metamorphosing the superincumbent strata, may be conveniently described in this preliminary discussion. It has been called by some authors *Andesite*: it mainly consists of well-crystallised white albite[6] (as determined with the goniometer in numerous specimens both by Professor Miller and myself), of less perfectly crystallised green hornblende, often associated with much mica, with chlorite and epidote, and occasionally with a few grains of quartz: in one instance in Northern Chile, I found crystals of orthitic or potash feldspar, mingled with those of albite. Where the mica and quartz are abundant, the rock cannot be distinguished from granite; and it may be called andesitic granite. Where these two minerals are quite absent, and when, as often then happens, the crystals of albite are imperfect and blend together, the rock may be called andesitic porphyry, which bears nearly the same relation to andesitic granite that euritic porphyry does to common granite. These andesitic rocks form mountain masses of a white colour, which, in their general outline and appearance—in their joints—in their occasionally including dark-coloured, angular fragments, apparently of some pre-existing rock—and in the great dikes branching from them into the superincumbent strata, manifest a close and striking resemblance to masses of common granite and syenite: I never, however, saw in these andesitic rocks, those granitic veins of segregation which are so common in true granites. We have seen that andesite occurs in three places in Tierra del Fuego; in Chile, from S. Fernando to Copiapo, a distance of 450 miles, I found it under most of the axes of elevation; in a collection of specimens from the Cordillera of Lima in Peru, I immediately recognised it; and Erman[7] states that it occurs in Eastern Kamtschatka. From its wide range, and from the important part it has played in the history of the Cordillera, I think this rock has well deserved its distinct name of Andesite.

[6] I here, and elsewhere, call by this name, those feldspathic minerals which cleave like albite: but it now appears (*Edin. New Phil. Journal.,* vol. xxiv, p. 181) that Abich has analysed a mineral from the Cordillera, associated with hornblende and quartz (probably the same rock with that here under discussion), which cleaves like albite, but which is a new and distinct kind, called by him *Andesine.* It is allied to leucite, with the greater proportion of its potash replaced by lime and soda. This mineral seems scarcely distinguishable from albite, except by analysis.

[7] *Geograph. Journal,* vol. ix, p. 510.

The few still active volcanoes in Chile are confined to the central and loftiest ranges of the Cordillera; and volcanic matter, such as appears to have been of subaerial eruption, is everywhere rare. According to Meyen,[8] there is a hill of pumice high up the valley of the Maypu, and likewise a trachytic formation at Colina, a village situated north of St. Jago. Close to this latter city, there are two hills formed of a pale feldspathic porphyry, remarkable from being doubly columnar, great cylindrical columns being subdivided into smaller four- or five-sided ones; and a third hillock (Cerro Blanco) is formed of a fragmentary mass of rock, which I believed to be of volcanic origin, intermediate in character between the above feldspathic porphyry and common trachyte, and containing needles of hornblende and granular oxide of iron. Near the Baths of Cauquenes, between two short parallel lines of elevation, where they are intersected by the valley, there is a small, though distinct volcanic district; the rock is a dark grey (andesitic) trachyte, which fuses into a greenish-grey bead, and is formed of long crystals of fractured glassy albite (judging from one measurement) mingled with well-formed crystals, often twin, of augite. The whole mass is vesicular, but the surface is darker coloured and much more vesicular than any other part. This trachyte forms a cliff-bounded, horizontal, narrow strip on the steep southern side of the valley, at the height of four or five hundred feet above the river-bed; judging from an apparently corresponding line of cliff on the northern side, the valley must once have been filled up to this height by a field of lava. On the summit of a lofty mountain some leagues higher up this same valley of the Cachapual, I found columnar pitchstone porphyritic with feldspar; I do not suppose this rock to be of volcanic origin, and only mention it here, from its being intersected by masses and dikes of a *vesicular* rock, approaching in character to trachyte; in no other part of Chile did I observe vesicular or amygdaloidal dikes, though these are so common in ordinary volcanic districts.

[8] "Reise um Erde," Th. I, ss. 338 and 362.

Passage of the Andes by the Portillo or Pequenes Pass.

Although I crossed the Cordillera only once by this pass, and only once by that of the Cumbre or Uspallata (presently to be described), riding slowly and halting occasionally to ascend the mountains, there are many circumstances favourable to obtaining a more faithful sketch of their structure than would at first be thought possible from so short an examination. The mountains are steep and absolutely bare of vegetation; the atmosphere is resplendently clear; the stratification distinct; and the rocks brightly and variously coloured: some of the natural sections might be truly compared for distinctness to those coloured ones in geological works. Considering how little is known of the structure of this gigantic range, to which I particularly attended, most travellers having collected only specimens of the rocks, I think my sketch-sections, though necessarily imperfect, possess some interest. Plate V sections (between and 441) which I will now describe in detail, is on a horizontal scale of a third of an inch to a nautical mile, and on a vertical scale of one inch to a mile (or 6,000 feet). The width of the range (excluding a few outlying hillocks), from the plain on which St. Jago the capital of Chile stands, to the Pampas, is sixty miles, as far as I can judge from the maps, which differ from each other and are all *exceedingly* imperfect. The St. Jago plain at the mouth of the Maypu, I estimate from adjoining known points at 2,300 feet, and the Pampas at 3,500 feet, both above the level of the sea. The height of the Pequenes line, according to Dr. Gillies,[9] is 13,210 feet; and that of the Portillo line (both in the gaps where the road crosses them) is 14,345 feet; the lowest part of the intermediate valley of Tenuyan is 7,530 feet—all above the level of the sea.

[9] *Journal of Nat. and Geograph. Science,* August 1830.

The Cordillera here, and indeed I believe throughout Chile, consist of several parallel, anticlinal and uniclinal mountain-lines, ranging north, or north with a little westing, and south. Some exterior and much lower ridges often vary considerably from this course, projecting like oblique spurs from the main ranges: in the district towards the Pacific, the mountains, as before remarked, extend in various directions, even east and west. In the main exterior lines, the strata, as also before remarked, are seldom inclined at a high angle; but in the central lofty ridges they are almost always highly inclined, broken by many great faults, and often vertical. As far as I could judge, few of the ranges are of great length: and in the central parts of the Cordillera, I was frequently able to follow with my eye a ridge gradually becoming higher and higher, as the stratification increased in inclination, from one end where its height was trifling and its strata gently inclined to the other end where vertical strata formed snow-clad pinnacles. Even outside the main Cordillera, near the baths of Cauquenes, I observed one such case, where a north and south ridge had its strata in the valley inclined at 37°, and less than a mile south of it at 67°: another parallel and similarly inclined ridge rose at the distance of about five miles, into a lofty mountain with absolutely vertical strata. Within the Cordillera, the height of the ridges and the inclination of the strata often became doubled and trebled in much shorter distances than five miles; this peculiar form of upheaval probably indicates that the stratified crust was thin, and hence yielded to the underlying intrusive masses unequally, at certain points on the lines of fissure.

The valleys, by which the Cordillera are drained, follow the anticlinal or rarely synclinal troughs, which deviate most from the usual north and south course; or still more commonly those lines of faults or of unequal curvature (that is, lines with the strata on both hands dipping in the same direction, but at a somewhat different angle) which deviate most from a northerly course. Occasionally the torrents run for some distance in the north and south valleys, and then recover their eastern or western course by bursting through the ranges at those points where the strata have been least inclined and the height consequently is less. Hence the valleys, along which the roads run, are generally zigzag; and, in drawing an east and west section, it is necessary to contract greatly that which is actually seen on the road.

Commencing at the western end of our section [Plate V] where the R. Maypu debouches on the plain of St. Jago, we immediately enter on the porphyritic conglomerate formation, and in the midst of it find some hummocks [A] of granite and syenite, which probably (for I neglected to collect specimens) belong to the andesitic class. These are succeeded by some rugged hills [B] of dark-green, crystalline, feldspathic and in some parts slaty rocks, which I believe belong to the altered clay-slate formation. From this point, great mountains of purplish and greenish, generally thinly stratified, highly porphyritic conglomerates, including many strata of amygdaloidal and greenstone porphyries, extend up the valley to the junction of the rivers Yeso and Volcan. As the valley here runs in a very southerly course, the width of the porphyritic conglomerate formation is quite conjectural; and from the same cause, I was unable to make out much about the stratification. In most of the exterior mountains the dip was gentle and directed inwards; and at only one spot I observed an inclination as high as 50°. Near the junction of the R. Colorado with the main stream, there is a hill of whitish, brecciated, partially decomposed feldspathic porphyry, having a volcanic aspect but not being really of that nature: at Tolla, however, in this valley, Dr. Meyen[10] met with a hill of pumice containing mica. At the junction of the Yeso and Volcan [D] there is an extensive mass, in white conical hillocks, of andesite, containing some mica, and passing either into andesitic granite, or into a spotted, semi-granular mixture of albitic (?) feldspar and hornblende: in the midst of this formation Dr. Meyen found true trachyte. The andesite is covered by strata of dark-coloured, crystalline, obscurely porphyritic rocks, and above them by the ordinary porphyritic conglomerates,—the strata all dipping away at a small angle from the underlying mass. The surrounding lofty mountains appear to be entirely composed of the porphyritic conglomerate, and I estimated its thickness here at between six and seven thousand feet.

[10] "Reise um Erde," Th. I, ss. 338, 341.)

Beyond the junction of the Yeso and Volcan, the porphyritic strata appear to dip towards the hillocks of andesite at an angle of 40°; but at some distant points on the same ridge they are bent up and vertical. Following the valley of the Yeso, trending N.E. (and therefore still unfavourable for our transverse section), the same porphyritic conglomerate formation is prolonged to near the Cuestadel Indio, situated at the western end of the basin (like a drained lake) of Yeso. Some way before arriving at this point, distant lofty pinnacles capped by coloured strata belonging to the great gypseous formation could first be seen. From the summit of the Cuesta, looking southward, there is a magnificent sectional view of a mountain-mass, at least 2,000 feet in thickness [E], of fine andesite granite (containing much black mica, a little chlorite and quartz), which sends great white dikes far into the superincumbent, dark-coloured, porphyritic conglomerates. At the line of junction the two formations are wonderfully interlaced together: in the lower part of the porphyritic conglomerate, the stratification has been quite obliterated, whilst in the upper part it is very distinct, the beds composing the crests of the surrounding mountains being inclined at angles of between 70 and 80 degrees, and some being even vertical. On the northern side of the valley, there is a great corresponding mass of andesitic granite, which is encased by porphyritic conglomerate, dipping both on the western and eastern sides, at about 80° to west, but on the eastern side with the tips of the strata bent in such a manner, as to render it probable that the whole mass has been on that side thrown over and inverted.

In the valley basin of the Yeso, which I estimated at 7,000 feet above the level of the sea, we first reach at [F] the gypseous formation. Its thickness is very great. It consists in most parts of snow-white, hard, compact gypsum, which breaks with a saccharine fracture, having translucent edges; under the blowpipe gives out much vapour; it frequently includes nests and exceedingly thin layers of crystallised, blackish carbonate of lime. Large, irregularly shaped concretions (externally still exhibiting lines of aqueous deposition) of blackish-grey, but sometimes white, coarsely and brilliantly crystallised, hard anhydrite, abound within the common gypsum. Hillocks, formed of the hardest and purest varieties of the white gypsum, stand up above the surrounding parts, and have their surfaces cracked and marked, just like newly baked bread. There is much pale brown, soft argillaceous gypsum; and there were some intercalated green beds which I had not time to reach. I saw only one fragment of selenite or transparent gypsum, and that perhaps may have come from some subsequently formed vein. From the mineralogical characters here given, it is probable that these gypseous beds have undergone some metamorphic action. The strata are much hidden by detritus, but they appeared in most parts to be highly inclined; and in an adjoining lofty pinnacle they could be distinctly seen bending up, and becoming vertical, conformably with the underlying porphyritic conglomerate. In very many parts of the great mountain-face [F], composed of thin gypseous beds, there were innumerable masses, irregularly shaped and not like dikes, yet with well-defined edges, of an imperfectly granular, pale greenish, or yellowish-white rock, essentially composed of feldspar, with a little chlorite or hornblende, epidote, iron-pyrites, and ferruginous powder: I believe that these curious trappean masses have been injected from the not far distant mountain-mass [E] of andesite whilst still fluid, and that owing to the softness of the gypseous strata they have not acquired the ordinary forms of dikes. Subsequently to the injection of these feldspathic rocks, a great dislocation has taken place; and the much shattered gypseous strata here overlie a hillock [G], composed of vertical strata of impure limestone and of black highly calcareous shale including threads of gypsum: these rocks, as we shall presently see, belong to the upper parts of the gypseous series, and hence must here have been thrown down by a vast fault.

Proceeding up the valley-basin of the Yeso, and taking our section sometimes on one hand and sometimes on the other, we come to a great hill of stratified porphyritic conglomerate [H] dipping at 45° to the west; and a few hundred yards farther on, we have a bed between three or four hundred feet thick of gypsum [I] dipping eastward at a very high angle: here then we have a fault and anticlinal axis. On the opposite side of the valley, a vertical mass of red conglomerate, conformably underlying the gypsum, appears gradually to lose its stratification and passes into a mountain of porphyry. The gypsum [I] is covered by a bed [K], at least 1,000 feet in thickness, of a purplish-red, compact, heavy, fine-grained sandstone or mudstone, which fuses easily into a white enamel, and is seen under a lens to contain triturated crystals. This is succeeded by a bed [L], 1,000 feet thick (I believe I understate the thickness) of gypsum, exactly like the beds before described; and this again is capped by another great bed [M] of purplish-red sandstone. All these strata dip eastward; but the inclination becomes less and less, as we leave the first and almost vertical bed [I] of gypsum.

Leaving the basin-plain of Yeso, the road rapidly ascends, passing by mountains composed of the gypseous and associated beds, with their stratification greatly disturbed and therefore not easily intelligible: hence this part of the section has been left uncoloured. Shortly before reaching the great Pequenes ridge, the lowest stratum visible [N] is a red sandstone or mudstone, capped by a vast thickness of black, compact, calcareous, shaly rock [O], which has been thrown into four lofty, though small ridges: looking northward, the strata in these ridges are seen gradually to rise in inclination, becoming in some distant pinnacles absolutely vertical.

The ridge of Pequenes, which divides the waters flowing into the Pacific and Atlantic Oceans, extends in a nearly N.N.W. and S.S.E. line; its strata dip eastward at an angle of between 30° and 45°, but in the higher peaks bending up and becoming almost vertical. Where the road crosses this range, the height is 13,210 feet above the sea-level, and I estimated the neighbouring pinnacles at from fourteen to fifteen thousand feet. The lowest stratum visible in this ridge is a red stratified sandstone [P]; on it are superimposed two great masses [Q and S] of black, hard, compact, even having a conchoidal fracture, calcareous, more or less laminated shale, passing into limestone: this rock contains organic remains, presently to be enumerated. The compacter varieties fuse easily in a white glass; and this I may add is a very general character with all the sedimentary beds in the Cordillera: although this rock when broken is generally quite black, it everywhere weathers into an ash-grey tint. Between these two great masses [Q and S], a bed [R] of gypsum is interposed, about three hundred feet in thickness, and having the same characters as heretofore described. I estimated the total thickness of these three beds [Q, R, S] at nearly three thousand feet; and to this must be added, as will be immediately seen, a great overlying mass of red sandstone.

In descending the eastern slope of this great central range, the strata, which in the upper part dip eastward at about an angle of 40°, become more and more curved, till they are nearly vertical; and a little further onwards there is seen on the further side of a ravine, a thick mass of strata of bright red sandstone [T], with their upper extremities slightly curved, showing that they were once conformably prolonged over the beds [S]: on the southern and opposite side of the road, this red sandstone and the underlying black shaly rocks stand vertical, and in actual juxtaposition. Continuing to descend, we come to a synclinal valley filled with rubbish, beyond which we have the red sandstone [T2] corresponding with [T], and now dipping, as is seen both north and south of the road, at 45° to the west; and under it, the beds [S2, R2, Q2, and I believe P2] in corresponding order and of similar composition, with those on the western flank of the Pequenes range, but dipping westward. Close to the synclinal valley the dip of these strata is 45°, but at the eastern or farther end of the series it increases to 60°. Here the great gypseous formation abruptly terminates, and is succeeded eastward by a pile of more modern strata. Considering how violently these central ranges have been dislocated, and how very numerous dikes are in the exterior and lower parts of the Cordillera, it is remarkable that I did not here notice a single dike. The prevailing rock in this neighbourhood is the black, calcareous, compact shale, whilst in the valley-basin of the Yeso the purplish red sandstone or mudstone predominates,—both being associated with gypseous strata of exactly the same nature. It would be very difficult to ascertain the relative superposition of these several masses, for we shall afterwards see in the Cumbre Pass that the gypseous and intercalated beds are lens-shaped, and that they thin out, even where very thick, and disappear in short horizontal distances: it is quite possible that the black shales and red sandstones may be contemporaneous, but it is more probable that the former compose the uppermost parts of the series.

The fossils above alluded to in the black calcareous shales are few in number, and are in an imperfect condition; they consist, as named for me by M. d’Orbigny, of:—

1. Ammonite, indeterminable, near to *A. recticostatus,* d’Orbigny, “Pal. Franc.” (Neocomian formation).
2. Gryphæa, near to *G. Couloni* (Neocomian formations of France and Neufchâtel).
3. Natica, indeterminable.
4. Cyprina rostrata, d’Orbigny, “Pal. Franc.” (Neocomian formation).
5. Rostellaria angulosa (?), d’Orbigny, “Pal. de l’Amér. Mer.”
6. Terebratula (?).

Some of the fragments of Ammonites were as thick as a man’s arm: the

Gryphæa is much the most abundant shell. These fossils M. d’Orbigny considers as belonging to the Neocomian stage of the Cretaceous system. Dr. Meyen,[11] who ascended the valley of the Rio Volcan, a branch of the Yeso, found a nearly similar, but apparently more calcareous formation, with much gypsum, and no doubt the equivalent of that here described: the beds were vertical, and were prolonged up to the limits of perpetual snow; at the height of 9,000 feet above the sea, they abounded with fossils, consisting, according to Von Buch,[12] of:—

1. Exogyra (Gryphæa) Couloni, absolutely identical with specimens from the Jura and South of France.
2. Trigonia costata, identical with those found in the upper Jurassic beds at Hildesheim.
3. Pecten striatus, identical with those found in the upper Jurassic beds at Hildesheim.
4. Cucullæa, corresponding in form to *C. longirostris,* so frequent in the upper Jurassic beds of Westphalia.
5. Ammonites resembling *A. biplex.*

[11] “Reise um Erde,” etc., Th. I, s. 355.

[12] “Descript. Phys. des Iles Canaries,” p. 471.

Von Buch concludes that this formation is intermediate between the limestone of the Jura and the chalk, and that it is analogous with the uppermost Jurassic beds forming the plains of Switzerland. Hence M. D’Orbigny and Von Buch, under different terms, compare these fossils to those from the same late stage in the secondary formations of Europe.

Some of the fossils which I collected were found a good way down the western slope of the main ridge, and hence must originally have been covered up by a great thickness of the black shaly rock, independently of the now denuded, thick, overlying masses of red sandstone. I neglected at the time to estimate how many hundred or rather thousand feet thick the superincumbent strata must have been: and I will not now attempt to do so. This, however, would have been a highly interesting point, as indicative of a great amount of subsidence, of hich we shall hereafter find in other parts of the Cordillera analogous evidence during this same period. The altitude of the Peuquenes Range, considering its not great antiquity, is very remarkable; many of the fossils were embedded at the height of 13,210 feet, and the same beds are prolonged up to at least from fourteen to fifteen thousand feet above the level of the sea.

The Portillo or Eastern Chain.—The valley of Tenuyan, separating the Peuquenes and Portillo lines, is, as estimated by Dr. Gillies and myself, about twenty miles in width; the lowest part, where the road crosses the river, being 7,500 feet above the sea-level. The pass on the Portillo line is 14,365 feet high (1,100 feet higher than that on the Peuquenes), and the neighbouring pinnacles must, I conceive, rise to nearly 16,000 feet above the sea. The river draining the intermediate valley of Tenuyan, passes through the Portillo line. To return to our section:—shortly after leaving the lower beds [P^2] of the gypseous formation, we come to grand masses of a coarse, red conglomerate [V], totally unlike any strata hitherto seen in the Cordillera. This conglomerate is distinctly stratified, some of the beds being well defined by the greater size of the pebbles: the cement is calcareous and sometimes crystalline, though the mass shows no signs of having been metamorphosed. The included pebbles are either perfectly or only partially rounded: they consist of purplish sandstones, of various porphyries, of brownish limestone, of black calcareous, compact shale precisely like that in situ in the Peuquenes range, and *containing some of the same fossil shells*; also very many pebbles of quartz, some of micaceous schist, and numerous, broken, rounded crystals of a reddish orthitic or potash feldspar (as determined by Professor Miller), and these from their size must have been derived from a coarse-grained rock, probably granite. From this feldspar being orthitic, and even from its external appearance, I venture positively to affirm that it has not been derived from the rocks of the western ranges; but, on the other hand, it may well have come, together with the quartz and metamorphic schists, from the eastern or Portillo line, for this line mainly consists of coarse orthitic granite. The pebbles of the fossiliferous slate and of the purple sandstone, certainly have been derived from the Peuquenes or western ranges.

The road crosses the valley of Tenuyan in a nearly east and west line, and for several miles we have on both hands the conglomerate, everywhere dipping west and forming separate great mountains. The strata, where first met with, after leaving the gypseous formation, are inclined westward at an angle of only 20°, which further on increases to about 45°. The gypseous strata, as we have seen, are also inclined westward: hence, when looking from the eastern side of the valley towards the Peuquenes range, a most deceptive appearance is presented, as if the newer beds of conglomerate dipped directly under the much older beds of the gypseous formation. In the middle of the valley, a bold mountain of unstratified lilac-coloured porphyry (with crystals of hornblende) projects; and further on, a little south of the road, there is another mountain, with its strata inclined at a small angle eastwards, which in its general aspect and colour, resembles the porphyritic conglomerate formation, so rare on this side of the Peuquenes line and so grandly developed throughout the western ranges.

The conglomerate is of great thickness: I do not suppose that the strata forming the separate mountain-masses [V, V, V] have ever been prolonged over each other, but that one mass has been broken up by several, distinct, parallel, uniclinal lines of elevation. Judging therefore of the thickness of the conglomerate, as seen in the separate mountain-masses, I estimated it at least from one thousand five hundred to two thousand feet. The lower beds rest conformably on some singularly coloured, soft strata [W], which I could not reach to examine; and these again rest conformably on a thick mass of micaceous, thinly laminated, siliceous sandstone [X], associated with a little black clay-slate. These lower beds are traversed by several dikes of decomposing porphyry. The laminated sandstone is directly superimposed on the vast masses of granite [Y, Y] which mainly compose the Portillo range. The line of junction between this latter rock, which is of a bright red colour, and the whitish sandstone was beautifully distinct; the sandstone being penetrated by numerous, great, tortuous dikes branching from the granite, and having been converted into a granular quartz rock (singularly like that of the Falkland Islands), containing specks of an ochrey powder, and black crystalline atoms, apparently of imperfect mica. The quartzose strata in one spot were folded into a regular dome.

The granite which composes the magnificent bare pinnacles and the steep western flank of the Portillo chain, is of a brick-red colour, coarsely crystallised, and composed of orthitic or potash feldspar, quartz, and imperfect mica in small quantity, sometimes passing into chlorite. These minerals occasionally assume a laminar or foliated arrangement. The fact of the feldspar being orthitic in this range, is very remarkable, considering how rare, or rather, as I believe, entirely absent, this mineral is throughout the western ranges, in which soda-feldspar, or at least a variety cleaving like albite, is so extremely abundant. In one spot on the western flank, and on the eastern flank near Los Manantiales and near the crest, I noticed some great masses of a whitish granite, parts of it fine- grained, and parts containing large crystals of feldspar; I neglected to collect specimens, so I do not know whether this feldspar is also orthitic, though I am inclined to think so from its general appearance. I saw also some syenite and one mass which resembled andesite, but of which I likewise neglected to collect specimens. From the manner in which the whitish granites formed separate mountain-masses in the midst of the brick-red variety, and from one such mass near the crest being traversed by numerous veins of flesh-coloured and greenish eurite (into which I occasionally observed the brick-red granite insensibly passing), I conclude that the white granites probably belong to an older formation, almost overwhelmed and penetrated by the red granite.

On the crest I saw also, at a short distance, some coloured stratified beds, apparently like those [W] at the western base, but was prevented examining them by a snowstorm: Mr. Caldcleugh,[13] however, collected here specimens of ribboned jasper, magnesian limestone, and other minerals. A little way down the eastern slope a few fragments of quartz and mica-slate are met with; but the great formation of this latter rock [Z], which covers up much of the eastern flank and base of the Portillo range, cannot be conveniently examined until much lower down at a place called Mal Paso. The mica-schist here consists of thick layers of quartz, with intervening folia of finely-scaly mica, often passing into a substance like black glossy clay-slate: in one spot, the layers of the quartz having disappeared, the whole mass became converted into glossy clay-slate. Where the folia were best defined, they were inclined at a high angle westward, that is, towards the range. The line of junction between the dark mica-slate and the coarse red granite was most clearly distinguishable from a vast distance: the granite sent many small veins into the mica-slate, and included some angular fragments of it. As the sandstone on the western base has been converted by the red granite into a granular quartz-rock, so this great formation of mica-schist may possibly have been metamorphosed at the same time and by the same means; but I think it more probable, considering its more perfect metamorphic character and its well-pronounced foliation, that it belongs to an anterior epoch, connected with the white granites: I am the more inclined to this view, from having found at the foot of the range the mica-schist surrounding a hummock [Y²], exclusively composed of white granite. Near Los Arenales, the mountains on all sides are composed of the mica-slate; and looking backwards from this point up to the bare gigantic peaks above, the view was eminently interesting. The colours of the red granite and the black mica-slate are so distinct, that with a bright light these rocks could be readily distinguished even from the Pampas, at a level of at least 9,000 feet below. The red granite, from being divided by parallel joints, has weathered into sharp pinnacles, on some of which, even on some of the loftiest, little caps of mica-schist could be clearly seen: here and there isolated patches of this rock adhered to the mountain-flanks, and these often corresponded in height and position on the opposite sides of the immense valleys. Lower down the schist prevailed more and more, with only a few quite small points of granite projecting through. Looking at the entire eastern face of the Portillo range, the red colour far exceeds in area the black; yet it was scarcely possible to doubt that the granite had once been almost wholly encased by the mica-schist.

[13] "Travels," etc., vol. i, p. 308.

At Los Arenales, low down on the eastern flank, the mica-slate is traversed by several closely adjoining, broad dikes, parallel to each other and to the foliation of the schist. The dikes are formed of three different varieties of rock, of which a pale brown feldspathic porphyry with grains of quartz was much the most abundant. These dikes with their granules of quartz, as well as the mica-schist itself, strikingly resemble the rocks of the Chonos Archipelago. At a height of about twelve hundred feet above the dikes, and perhaps connected with them, there is a range of cliffs formed of successive lava-streams [AA], between three and four hundred feet in thickness, and in places finely columnar. The lava consists of dark-greyish, harsh rocks, intermediate in character between trachyte and basalt, containing glassy feldspar, olivine, and a little mica, and sometimes amygdaloidal with zeolite: the basis is either quite compact, or crenulated with air-vesicles arranged in laminæ. The streams are separated from each other by beds of fragmentary brown scoriæ, firmly cemented together, and including a few well-rounded pebbles of lava. From their general appearance, I suspect that these lava-streams flowed at an ancient period under the pressure of the sea, when the Atlantic covered the Pampas and washed the eastern foot of the Cordillera.[14] On the opposite and northern side of the valley there is another line of lava-cliffs at a corresponding height; the valley between being of considerable breadth, and as nearly as I could estimate 1,500 feet in depth. This field of lava is confined on both sides by the mountains of mica-schist, and slopes down rapidly but irregularly to the edge of the Pampas, where, having a thickness of about two hundred feet, it terminates against a little range of claystone porphyry. The valley in this lower part expands into a bay-like, gentle slope, bordered by the cliffs of lava, which must certainly once have extended across this wide expanse. The inclination of the streams from Los Arenales to the mouth of the valley is so great, that at the time (though ignorant of M. Elie de Beaumont's researches on the extremely small slope over which lava can flow, and yet retain a compact structure and considerable thickness) I concluded that they must subsequently to their flowing have been upheaved and tilted from the mountains; of this conclusion I can now entertain not the smallest doubt.

[14] This conclusion might, perhaps, even have been anticipated, from the general rarity of volcanic action, except near the sea or large bodies of water. Conformably with this rule, at the present day, there are no active volcanoes on this eastern side of the Cordillera; nor are severe earthquakes experienced here.

At the mouth of the valley, within the cliffs of the above lava-field, there are remnants, in the form of separate small hillocks and of lines of low cliffs, of a considerable deposit of compact white tuff (quarried for filtering-stones), composed of broken pumice, volcanic crystals, scales of mica, and fragments of lava. This mass has suffered much denudation; and the hard mica-schist has been deeply worn, since the period of its deposition; and this period must have been subsequent to the denudation of the basaltic lava-streams, as attested by their encircling cliffs standing at a higher level. At the present day, under the existing arid climate, ages might roll past without a square yard of rock of any kind being denuded, except perhaps in the rarely moistened drainage-channel of the valley. Must we then look back to that ancient period, when the waves of the sea beat against the eastern foot of the Cordillera, for a power sufficient to denude extensively, though superficially, this tufaceous deposit, soft although it be?

There remains only to mention some little water-worn hillocks [BB], a few hundred feet in height, and mere mole-hills compared with the gigantic mountains behind them, which rise out of the sloping, shingle-covered margin of the Pampas. The first little range is composed of a brecciated purple porphyritic claystone, with obscurely marked strata dipping at 70° to the S.W.; the other ranges consist of—a pale-coloured feldspathic porphyry,—a purple claystone porphyry with grains of quartz,—and a rock almost exclusively composed of brick-red crystals of feldspar. These outermost small lines of elevation extend in a N.W. by W. and S.E. by S. direction.

Concluding remarks on the Portillo range.—When on the Pampas and looking southward, and whilst travelling northward, I could see for very many leagues the red granite and dark mica-schist forming the crest and eastern flank of the Portillo line. This great range, according to Dr. Gillies, can be traced with little interruption for 140 miles southward to the R. Diamante, where it unites with the western ranges: northward, according to this same author, it terminates where the R. Mendoza debouches from the mountains; but a little further north in the eastern part of the Cumbre section, there are, as we shall hereafter see, some mountain-masses of a brick-red porphyry, the last injected amidst many other porphyries, and having so close an analogy with the coarse red granite of the Portillo line, that I am tempted to believe that they belong to the same axis of injection; if so, the Portillo line is at least 200 miles in length. Its height, even in the lowest gap in the road, is 14,365 feet, and some of the pinnacles apparently attain an elevation of about 16,000 feet above the sea. The geological history of this grand chain appears to me eminently interesting. We may safely conclude, that at a former period the valley of Tenuyan existed as an arm of the sea, about twenty-miles in width, bordered on one hand by a ridge or chain of islets of the black calcareous shales and purple sandstones of the gypseous formation; and on the other hand, by a ridge or chain of islets composed of mica-slate, white granite, and perhaps to a partial extent of red granite. These two chains, whilst thus bordering the old sea-channel, must have been exposed for a vast lapse of time to alluvial and littoral action, during which the rocks were shattered, the fragments rounded, and the strata of conglomerate accumulated to a thickness of at least fifteen hundred or two thousand feet. The red orthitic granite now forms, as we have seen, the main part of the Portillo chain: it is injected in dikes not only into the mica-schist and white granites, but into the laminated sandstone, which it has metamorphosed, and which it has thrown off, together with the conformably overlying coloured beds and stratified conglomerate, at an angle of forty-five degrees. To have thrown off so vast a pile of strata at this angle, is a proof that the main part of the red granite (whether or not portions, as perhaps is probable, previously existed) was injected in a liquified state after the accumulation both of the laminated sandstone and of the conglomerate; this conglomerate, we know, was accumulated, not only after the deposition of the fossiliferous strata of the Peuquenes line, but after their elevation and long-continued denudation: and these fossiliferous strata belong to the early part of the Cretaceous system. Late, therefore, in a geological sense, as must be the age of the main part of the red granite, I can conceive nothing more impressive than the eastern view of this great range, as forcing the mind to grapple with the idea of the thousands of thousands of years requisite for the denudation of the strata which originally encased it,—for that the fluidified granite was once encased, its mineralogical composition and structure, and the bold conical shape of the mountain-masses, yield sufficient evidence. Of the encasing strata we see the last vestiges in the coloured beds on the crest, in the little caps of mica-schist on some of the loftiest pinnacles, and in the isolated patches of this same rock at corresponding heights on the now bare and steep flanks.

The lava-streams at the eastern foot of the Portillo are interesting, not so much from the great denudation which they have suffered at a comparatively late period as from the evidence they afford by their inclination taken conjointly with their thickness and compactness, that after the great range had assumed its present general outline, it continued to rise as an axis of elevation. The plains extending from the base of the Cordillera to the Atlantic show that the continent has been upraised in mass to a height of 3,500 feet, and probably to a much greater height, for the smooth shingle-covered margin of the Pampas is prolonged in a gentle unbroken slope far up many of the great valleys. Nor let it be assumed that the Peuquenes and Portillo ranges have undergone only movements of elevation; for we shall hereafter see, that the bottom of the sea subsided several thousand feet during the deposition of strata, occupying the same relative place in the Cordillera, with those of the Peuquenes ridge; moreover, we shall see from the unequivocal evidence of buried upright trees, that at a somewhat later period, during the formation of the Uspallata chain, which corresponds geographically with that of the Portillo, there was another subsidence of many thousand feet: here, indeed, in the valley of Tenuyan, the accumulation of the coarse stratified conglomerate to a thickness of fifteen hundred or two thousand feet, offers strong presumptive evidence of subsidence; for all existing analogies lead to the belief that large pebbles can be transported only in shallow water, liable to be affected by currents and movements of undulation—and if so, the shallow bed of the sea on which the pebbles were first deposited must necessarily have sunk to allow of the accumulation of the superincumbent strata. What a history of changes of level, and of wear and tear, all since the age of the latter secondary formations of Europe, does the structure of this one great mountain-chain reveal!

Passage of the Andes by the Cumbre or Uspallata Pass.

This Pass crosses the Andes about sixty miles north of that just described: the section given in Plate V, Section 1/2, [see map page 440] is on the same scale as before, namely, at one-third of an inch to a mile in distance, and one inch to a mile (or 6,000 feet) in height. Like the last section, it is a mere sketch, and cannot pretend to accuracy, though made under favourable circumstances. We will commence as before, with the western half, of which the main range bears the name of the Cumbre (that is the Ridge), and corresponds to the Peuquenes line in the former section; as does the Uspallata range, though on a much smaller scale, to that of the Portillo. Near the point where the river Aconcagua debouches on the basin plain of the same name, at a height of about two thousand three hundred feet above the sea, we meet with the usual purple and greenish porphyritic claystone conglomerate. Beds of this nature, alternating with numerous compact and amygdaloidal porphyries, which have flowed as submarine lavas, and associated with great mountain-masses of various, injected, non-stratified porphyries, are prolonged the whole distance up to the Cumbre or central ridge. One of the commonest stratified porphyries is of a green colour, highly amygdaloidal with the various minerals described in the preliminary discussion, and including fine tabular crystals of albite. The mountain-range north (often with a little westing) and south. The stratification, wherever I could clearly distinguish it, was inclined westward or towards the Pacific, and, except near the Cumbre, seldom at angles above 25°. Only at one spot on this western side, on a lofty pinnacle not far from the Cumbre, I saw strata apparently belonging to the gypseous formation, and conformably capping a pile of stratified porphyries. Hence, both in composition and in stratification, the structure of the mountains on this western side of the divortium aquarum, is far more simple than in the corresponding part of the Peuquenes section. In the porphyritic claystone conglomerate, the mechanical structure and the planes of stratification have generally been much obscured and even quite obliterated towards the base of the series, whilst in the upper parts, near the summits of the mountains, both are distinctly displayed. In these upper portions the porphyries are generally lighter coloured. In three places [X, Y, Z] masses of andesite are exposed: at [Y], this rock contained some quartz, but the greater part consisted of andesitic porphyry, with only a few well-developed crystals of albite, and forming a great white mass, having the external aspect of granite, capped by much dark unstratified porphyry. In many parts of the mountains, there are dikes of a green colour, and other white ones, which latter probably spring from underlying masses of andesite.

The Cumbre, where the road crosses it, is, according to Mr. Pentland, 12,454 feet above the sea; and the neighbouring peaks, composed of dark purple and whitish porphyries, some obscurely stratified with a westerly dip, and others without a trace of stratification, must exceed 13,000 feet in height. Descending the eastern slope of the Cumbre, the structure becomes very complicated, and generally differs on the two sides of the east and west line of road and section. First we come to a great mass [A] of nearly vertical, singularly contorted strata, composed of highly compact red sandstones, and of often calcareous conglomerates, and penetrated by green, yellow, and reddish dikes; but I shall presently have an opportunity of describing in some detail an analogous pile of strata. These vertical beds are abruptly succeeded by others [B], of apparently nearly the same nature but more metamorphosed, alternating with porphyries and limestones; these dip for a short space westward, but there has been here an extraordinary dislocation, which, on the north side of the road, appears to have determined the excavation of the north and south valley of the R. de las Cuevas. On this northern side of the road, the strata [B] are prolonged till they come in close contact with a jagged lofty mountain [D] of dark-coloured, unstratified, intrusive porphyry, where the beds have been more highly inclined and still more metamorphosed. This mountain of porphyry seems to form a short axis of elevation, for south of the road in its line there is a hill [C] of porphyritic conglomerate with absolutely vertical strata.

We now come to the gypseous formation: I will first describe the structure of the several mountains, and then give in one section a detailed account of the nature of the rocks. On the north side of the road, which here runs in an east and west valley, the mountain of porphyry [D] is succeeded by a hill [E] formed of the upper gypseous strata tilted, at an angle of between 70° and 80° to the west, by a uniclinal axis of elevation which does not run parallel to the other neighbouring ranges, and which is of short length; for on the south side of the valley its prolongation is marked only by a small flexure in a pile of strata inclined by a quite separate axis. A little further on the north and south valley of Horcones enters at right angles our line of section; its western side is bounded by a hill of gypseous strata [F] dipping westward at about 45°, and its eastern side by a mountain of similar strata [G] inclined westward at 70°, and superimposed by an oblique fault on another mass of the same strata [H], also inclined westward, but at an angle of about 30°: the complicated relation of these three masses [F, G, H] is explained by the structure of a great mountain-range lying some way to the north, in which a regular anticlinal axis (represented in the section by dotted lines) is seen, with the strata on its eastern side again bending up and forming a distinct uniclinal axis, of which the beds marked [H] form the lower part. This great uniclinal line is intersected, near the Puente del Inca, by the valley along which the road runs, and the strata composing it will be immediately described. On the south side of the road, in the space corresponding with the mountains [E, F, and G], the strata everywhere dip westward generally at an angle of 30°, occasionally mounting up to 45°, but not in an unbroken line, for there are several vertical faults, forming separate uniclinal masses, all dipping in the same direction,—a form of elevation common in the Cordillera. We thus see that within a narrow space, the gypseous strata have been upheaved and crushed together by a great uniclinal, anticlinal, and one lesser uniclinal line [E] of elevation; and that between these three lines and the Cumbre, in the sandstones, conglomerates and porphyritic formation, there have been at least two or three other great elevatory axes.

The uniclinal axis [I] intersected near the Puente del Inca[15] (of which the strata at [H] form a part) ranges N. by W. and S. by E., forming a chain of mountains, apparently little inferior in height to the Cumbre: the strata, as we have seen, dip at an average angle of 30° to the west. The flanks of the mountains are here quite bare and steep, affording an excellent section; so that I was able to inspect the strata to a thickness of about 4,000 feet, and could clearly distinguish their general nature for 1,000 feet higher, making a total thickness of 5,000 feet, to which must be added about 1,000 feet of the inferior strata seen a little lower down the valley, I will describe this one section in detail, beginning at the bottom.

[15] At this place, there are some hot and cold springs, the warmest having a temperature, according to Lieutenant Brand ("Travels," p. 240), of 91°; they emit much gas. According to Mr. Brande, of the Royal Institution, ten cubical inches contain forty-five grains of solid matter, consisting chiefly of salt, gypsum, carbonate of lime, and oxide of iron. The water is charged with carbonic acid and sulphuretted hydrogen. These springs deposit much tufa in the form of spherical balls. They burst forth, as do those of Cauquenes, and probably those of Villa Vicencio, on a line of elevation.

1st. The lowest mass is the altered clay-slate described in the preliminary discussion, and which in this line of section was here first met with. Lower down the valley, at the R. de las Vacas, I had a better opportunity of examining it; it is there in some parts well characterised, having a distinct, nearly vertical, tortuous cleavage, ranging N.W. and S.E., and intersected by quartz veins: in most parts, however, it is crystalline and feldspathic, and passes into a true greenstone often including grains of quartz. The clay-slate, in its upper half, is frequently brecciated, the embedded angular fragments being of nearly the same nature with the paste.

2nd. Several strata of purplish porphyritic conglomerate, of no very great thickness, rest conformably upon the feldspathic slate. A thick bed of fine, purple, claystone porphyry, obscurely brecciated (but not of metamorphosed sedimentary origin), and capped by porphyritic conglomerate, was the lowest bed actually examined in this section at the Puente del Inca.

3rd. A stratum, eighty feet thick, of hard and very compact impure whitish limestone, weathering bright red, with included layers brecciated and recemented. Obscure marks of shell are distinguishable in it.

4th. A red, quartzose, fine-grained conglomerate, with grains of quartz, and with patches of white earthy feldspar, apparently due to some process of concretionary crystalline action; this bed is more compact and metamorphosed than any of the overlying conglomerates.

5th. A whitish cherty limestone, with nodules of bluish argillaceous limestone.

6th. A white conglomerate, with many particles of quartz, almost blending into the paste.

7th. Highly siliceous, fine-grained white sandstone.

8th and 9th. Red and white beds not examined.

10th. Yellow, fine-grained, thinly stratified, magnesian (judging from its slow dissolution in acids) limestone: it includes some white quartz pebbles, and little cavities, lined with calcareous spar, some retaining the form of shells.

11th. A bed between twenty and thirty feet thick, quite conformable with the underlying ones, composed of a hard basis, tinged lilac-grey porphyritic with *numerous* crystals of whitish feldspar, with black mica and little spots of soft ferruginous matter: evidently a submarine lava.

12th. Yellow magnesian limestone, as before, part-stained purple.

13th. A most singular rock; basis purplish grey, obscurely crystalline, easily fusible into a dark green glass, not hard, thickly speckled with crystals more or less perfect of white carbonate of lime, of red hydrous oxide of iron, of a white and transparent mineral like analcime, and of a green opaque mineral like soap-stone; the basis is moreover amygdaloidal with many spherical balls of white crystallised carbonate of lime, of which some are coated with the red oxide of iron. I have no doubt, from the examination of a superincumbent stratum (19), that this is a submarine lava; though in Northern Chile, some of the metamorphosed sedimentary beds are almost as crystalline, and of as varied composition.

14th. Red sandstone, passing in the upper part into a coarse, hard, red conglomerate, 300 feet thick, having a calcareous cement, and including grains of quartz and broken crystals of feldspar; basis infusible; the pebbles consist of dull purplish porphyries, with some of quartz, from the size of a nut to a man’s head. This is the coarsest conglomerate in this part of the Cordillera: in the middle there was a white layer not examined.

15th. Grand thick bed, of a very hard, yellowish-white rock, with a crystalline feldspathic base, including large crystals of white feldspar, many little cavities mostly full of soft ferruginous matter, and numerous hexagonal plates of black mica. The upper part of this great bed is slightly cellular; the lower part compact: the thickness varied a little in different parts. Manifestly a submarine lava; and is allied to bed 11.

16th and 17th. Dull purplish, calcareous, fine-grained, compact sandstones, which pass into coarse white conglomerates with numerous particles of quartz.

18th. Several alternations of red conglomerate, purplish sandstone, and submarine lava, like that singular rock forming bed 13.

19th. A very heavy, compact, greenish-black stone, with a fine-grained obviously crystalline basis, containing a few specks of white calcareous spar, many specks of the crystallised hydrous red oxide of iron, and some specks of a green mineral; there are veins and nests filled with epidote: certainly a submarine lava.

20th. Many thin strata of compact, fine-grained, pale purple sandstone.

21st. Gypsum in a nearly pure state, about three hundred feet in thickness: this bed, in its concretions of anhydrite and layers of small blackish crystals of carbonate of lime, exactly resembles the great gypseous beds in the Peuquenes range.

22nd. Pale purple and reddish sandstone, as in bed 20: about three hundred feet in thickness.

23rd. A thick mass composed of layers, often as thin as paper and convoluted, of pure gypsum with others very impure, of a purplish colour.

24th. Pure gypsum, thick mass.

25th. Red sandstones, of great thickness.

26th. Pure gypsum, of great thickness.

27th. Alternating layers of pure and impure gypsum, of great thickness.

I was not able to ascend to these few last great strata, which compose the neighbouring loftiest pinnacles. The thickness, from the lowest to the uppermost bed of gypsum, cannot be less than 2,000 feet: the beds beneath I estimated at 3,000 feet, and this does not include either the lower parts of the porphyritic conglomerate, or the altered clay-slate; I conceive the total thickness must be about six thousand feet. I distinctly observed that not only the gypsum, but the alternating sandstones and conglomerates were lens-shaped, and repeatedly thinned out and replaced each other: thus in the distance of about a mile, a bed 300 feet thick of sandstone between two beds of gypsum, thinned out to nothing and disappeared. The lower part of this section differs remarkably,—in the much greater diversity of its mineralogical composition,—in the abundance of calcareous matter,—in the greater coarseness of some of the conglomerates,—and in the numerous particles and well-rounded pebbles, sometimes of large size, of quartz,— from any other section hitherto described in Chile. From these peculiarities and from the lens-form of the strata, it is probable that this great pile of strata was accumulated on a shallow and very uneven bottom, near some pre-existing land formed of various porphyries and quartz-rock. The formation of porphyritic claystone conglomerate does not in this section attain nearly its ordinary thickness; this may be PARTLY attributed to the metamorphic action having been here much less energetic than usual, though the lower beds have been affected to a certain degree. If it had been as energetic as in most other parts of Chile, many of the beds of sandstone and conglomerate, containing rounded masses of porphyry, would doubtless have been converted into porphyritic conglomerate; and these would have alternated with, and even blended into, crystalline and porphyritic strata without a trace of mechanical structure,—namely, into those which, in the present state of the section, we see are unquestionably submarine lavas.

The beds of gypsum, together with the red alternating sandstones and conglomerates, present so perfect and curious a resemblance with those seen in our former section in the basin-valley of Yeso, that I cannot doubt the identity of the two formations: I may add, that a little westward of the P. del Inca, a mass of gypsum passed into a fine-grained, hard, brown sandstone, which contained some layers of black, calcareous, compact, shaly rock, precisely like that seen in such vast masses on the Peuquenes range.

Near the Puente del Inca, numerous fragments of limestone, containing some fossil remains, were scattered on the ground: these fragments so perfectly resemble the limestone of bed No. 3, in which I saw impressions of shells, that I have no doubt they have fallen from it.

The yellow magnesian limestone of bed No. 10, which also includes traces of shells, has a different appearance. These fossils (as named by M. d’Orbigny) consist of:—

Gryphæa, near to *G. Couloni* (Neocomian formation).

Arca, perhaps *A. Gabrielis,* d’Orbigny, “Pal. Franc.” (Neocomian formation).

Mr. Pentland made a collection of shells from this same spot, and Von Buch[16] considers them as consisting of:—

Trigonia, resembling in form *T. costata.*

Pholadomya, like one found by M. Dufresnoy near Alencon.

Isocardi excentrica, Voltz., identical with that from the Jura.

[16] “Description Phys. des Iles Can.,” p. 472.

Two of these shells, namely, the Gryphæa and Trigonia, appear to be identical with species collected by Meyen and myself on the Peuquenes range; and in the opinion of Von Buch and M. d’Orbigny, the two formations belong to the same age. I must here add, that Professor E. Forbes, who has examined my specimens from this place and from the Peuquenes range, has likewise a strong impression that they indicate the Cretaceous period, and probably an early epoch in it: so that all the palæontologists who have seen these fossils nearly coincide in opinion regarding their age. The limestone, however, with these fossils here lies at the very base of the formation, just above the porphyritic conglomerate, and certainly several thousand feet lower in the series, than the equivalent, fossiliferous, black, shaly rocks high up on the Peuquenes range.

It is well worthy of remark that these shells, or at least those of which I saw impressions in the limestone (bed No. 3), must have been covered up, on the *least* computation, by 4,000 feet of strata: now we know from Professor E. Forbes's researches, that the sea at greater depths than 600 feet becomes exceedingly barren of organic beings,—a result quite in accordance with what little I have seen of deep-sea soundings. Hence, after this limestone with its shells was deposited, the bottom of the sea where the main line of the Cordillera now stands, must have subsided some thousand feet to allow of the deposition of the superincumbent submarine strata. Without supposing a movement of this kind, it would, moreover, be impossible to understand the accumulation of the several lower strata of *coarse,* well-rounded conglomerates, which it is scarcely possible to believe were spread out in profoundly deep water, and which, especially those containing pebbles of quartz, could hardly have been rounded in submarine craters and afterwards ejected from them, as I believe to have been the case with much of the porphyritic conglomerate formation. I may add that, in Professor Forbes's opinion, the above-enumerated species of mollusca probably did not live at a much greater depth than twenty fathoms, that is only 120 feet.

To return to our section down the valley; standing on the great N. by W. and S. by E. uniclinal axis of the Puente del Inca, of which a section has just been given, and looking north-east, greater tabular masses of gypseous formation (KK) could be seen in the distance, very slightly inclined towards the east. Lower down the valley, the mountains are almost exclusively composed of porphyries, many of them of intrusive origin and non-stratified, others stratified, but with the stratification seldom distinguishable except in the upper parts. Disregarding local disturbances, the beds are either horizontal or inclined at a small angle eastwards: hence, when standing on the plain of Uspallata and looking to the west or backwards, the Cordillera appear composed of huge, square, nearly horizontal, tabular masses: so wide a space, with such lofty mountains so equably elevated, is rarely met with within the Cordillera. In this line of section, the interval between the Puente del Inca and the neighbourhood of the Cumbre, includes all the chief axes of dislocation.

The altered clay-slate formation, already described, is seen in several parts of the valley as far down as Las Vacas, underlying the porphyritic conglomerate. At the Casa de Pujios [L], there is a hummock of (andesitic?) granite; and the stratification of the surrounding mountains here changes from W. by S. to S.W. Again, near the R. Vacas there is a larger formation of (andesitic?) granite [M], which sends a meshwork of veins into the superincumbent clay-slate, and which locally throws off the strata, on one side to N.W. and on the other to S.E. but not at a high angle: at the junction, the clay-slate is altered into fine-grained greenstone. This granitic axis is intersected by a green dike, which I mention, because I do not remember having elsewhere seen dikes in this lowest and latest intrusive rock. From the R. Vacas to the plain of Uspallata, the valley runs N.E., so that I have had to contract my section; it runs exclusively through porphyritic rocks. As far as the Pass of Jaula, the claystone conglomerate formation, in most parts highly porphyritic, and crossed by numerous dikes of greenstone porphyry, attains a great thickness: there is also much intrusive porphyry. From the Jaula to the plain, the stratification has been in most places obliterated, except near the tops of some of the mountains; and the metamorphic action has been extremely great. In this space, the number and bulk of the intrusive masses of differently coloured porphyries, injected one into another and intersected by dikes, is truly extraordinary. I saw one mountain of whitish porphyry, from which two huge dikes, thinning out, branched *downwards* into an adjoining blackish porphyry. Another hill of white porphyry, which had burst through dark-coloured strata, was itself injected by a purple, brecciated, and recemented porphyry, both being crossed by a green dike, and both having been upheaved and injected by a granitic dome. One brick-red porphyry, which above the Jaula forms an isolated mass in the midst of the porphyritic conglomerate formation, and lower down the valley a magnificent group of peaked mountains, differs remarkably from all the other porphyries. It consists of a red feldspathic base, including some rather large crystals of red feldspar, numerous large angular grains of quartz, and little bits of a soft green mineral answering in most of its characters to soapstone. The crystals of red feldspar resemble in external appearance those of orthite, though, from being partially decomposed, I was unable to measure them; and they certainly are quite unlike the variety, so abundantly met with in almost all the other rocks of this line of section, and which, wherever I tried it, cleaved like albite. This brick-red porphyry appears to have burst through all the other porphyries, and numerous red dikes traversing the neighbouring mountains have proceeded from it: in some few places, however, it was intersected by white dikes. From this posteriority of intrusive origin,—from the close general resemblance between this red porphyry and the red granite of the Portillo line, the only difference being that the feldspar here is less perfectly granular, and that soapstone replaces the mica, which is there imperfect and passes into chlorite,—and from the Portillo line a little southward of this point appearing to blend (according to Dr. Gillies) into the western ranges,—I am strongly urged to believe (as formerly remarked) that the grand mountain-masses composed of this brick-red porphyry belong to the same axis of injection with the granite of the Portillo line; if so, the injection of this porphyry probably took place, as long subsequently to the several axes of elevation in the gypseous formation near the Cumbre, as the injection of the Portillo granite has been shown to have been subsequent to the elevation of the gypseous strata composing the Peuquenes range; and this interval, we have seen, must have been a very long one.

The Plain of Uspallata has been briefly described in Chapter 3; it resembles the basin-plains of Chile; it is ten or fifteen miles wide, and is said to extend for 180 miles northward; its surface is nearly six thousand feet above the sea; it is composed, to a thickness of some hundred feet of loosely aggregated, stratified shingle, which is prolonged with a gently sloping surface up the valleys in the mountains on both sides. One section in this plain [Z] is interesting, from the unusual[17] circumstance of alternating layers of almost loose red and white sand with lines of pebbles (from the size of a nut to that of an apple), and beds of gravel, being inclined at an angle of 45°, and in some spots even at a higher angle. These beds are dislocated by small faults: and are capped by a thick mass of horizontally stratified gravel, evidently of subaqueous origin. Having been accustomed to observe the irregularities of beds accumulated under currents, I feel sure that the inclination here has not been thus produced. The pebbles consist chiefly of the brick-red porphyry just described and of white granite, both probably derived from the ranges to the west, and of altered clay-slate and of certain porphyries, apparently belonging to the rocks of the Uspallata chain. This plain corresponds geographically with the valley of Tenuyan between the Portillo and Peuquenes ranges; but in that valley the shingle, which likewise has been derived both from the eastern and western ranges, has been cemented into a hard conglomerate, and has been throughout tilted at a considerable inclination; the gravel there apparently attains a much greater thickness, and is probably of higher antiquity.

[17] I find that Mr. Smith of Jordan Hill has described (*Edinburgh New Phil. Journ.,* vol. xxv, p. 392) beds of sand and gravel, near Edinburgh, tilted at an angle of 60°, and dislocated by miniature faults.

The Uspallata range.—The road by the Villa Vicencio Pass does not strike directly across the range, but runs for some leagues northward along its western base: and I must briefly describe the rocks here seen, before continuing with the coloured east and west section. At the mouth of the valley of Canota, and at several points northwards, there is an extensive formation of a glossy and harsh, and of a feldspathic clay-slate, including strata of grauwacke, and having a tortuous, nearly vertical cleavage, traversed by numerous metalliferous veins and others of quartz. The clay-slate is in many parts capped by a thick mass of fragments of the same rock, firmly recemented; and both together have been injected and broken up by very numerous hillocks, ranging north and south, of lilac, white, dark and salmon-coloured porphyries: one steep, now denuded, hillock of porphyry had its face as distinctly impressed with the angles of a fragmentary mass of the slate, with some of the points still remaining embedded, as sealing-wax could be by a seal. At the mouth of this same valley of Canota, in a fine escarpment having the strata dipping from 50° to 60° to the N.E.,[18] the clay-slate formation is seen to be covered by—(1st) a purple, claystone porphyry resting unconformably in some parts on the solid slate, and in others on a thick fragmentary mass; (2nd), a conformable stratum of compact blackish rock, having a spheroidal structure, full of minute acicular crystals of glassy feldspar, with red spots of oxide of iron; (3rd), a great stratum of purplish-red claystone porphyry, abounding with crystals of opaque feldspar, and laminated with thin, parallel, often short, layers, and likewise with great irregular patches of white, earthy, semi-crystalline feldspar; this rock (which I noticed in other neighbouring places) perfectly resembles a curious variety described at Port Desire, and occasionally occurs in the great porphyritic conglomerate formation of Chile; (4th), a thin stratum of greenish white, indurated tuff, fusible and containing broken crystals and particles of porphyries; (5th), a grand mass, imperfectly columnar and divided into three parallel and closely joined strata, of cream-coloured claystone porphyry; (6th), a thick stratum of lilac-coloured porphyry, which I could see was capped by another bed of the cream-coloured variety; I was unable to examine the still higher parts of the escarpment. These conformably stratified porphyries, though none are either vesicular are amygdaloidal, have evidently flowed as submarine lavas: some of them are separated from each other by seams of indurated tuff, which, however, are quite insignificant in thickness compared with the porphyries. This whole pile resembles, but not very closely, some of the less brecciated parts of the great porphyritic conglomerate formation of Chile; but it does not probably belong to the same age, as the porphyries here rest unconformably on the altered feldspathic clay-slate, whereas the porphyritic conglomerate formation alternates with and rests conformably on it. These porphyries, moreover, with the exception of the one blackish stratum, and of the one indurated, white tufaceous bed, differ from the beds composing the Uspallata range in the line of the Villa Vicencio Pass.

> [18] Nearly opposite to this escarpment, there is another corresponding one, with the strata dipping not to the exactly opposite point, or S.W., but to S.S.W.: consequently the two escarpments trend towards each other, and some miles southward they become actually united: this is a form of elevation which I have not elsewhere seen.

I will now give, first, a sketch of the structure of the range, as represented in the section, and will then describe its composition and interesting history. At its western foot, a hillock [N] is seen to rise out of the plain, with its strata dipping at 70° to the west, fronted by strata [O] inclined at 45° to the east, thus forming a little north and south anticlinal axis. Some other little hillocks of similar composition, with their strata highly inclined, range N.E. and S.W., obliquely to the main Uspallata line. The cause of these dislocations, which, though on a small scale, have been violent and complicated, is seen to lie in hummocks of lilac, purple and red porphyries, which have been injected in a liquified state through and into the underlying clay-slate formation. Several dykes were exposed here, but in no other part, that I saw of this range. As the strata consist of black, white, greenish and brown-coloured rocks, and as the intrusive porphyries are so brightly tinted, a most extraordinary view was presented, like a coloured geological drawing. On the gently inclined main western slope [PP], above the little anticlinal ridges just mentioned, the strata dip at an average angle of 25° to the west; the inclination in some places being only 19°, in some few others as much as 45°. The masses having these different inclinations, are separated from each other by parallel vertical faults [as represented at Pa], often giving rise to separate, parallel, uniclinal ridges. The summit of the main range is broad and undulatory, with the stratification undulatory and irregular: in a few places granitic and porphyritic masses [Q] protrude, which, from the small effect they have locally produced in deranging the strata, probably form the upper points of a regular, great underlying dome. These denuded granitic points, I estimated at about nine thousand feet in height above the sea. On the eastern slope, the strata in the upper part are regularly inclined at about 25° to the east, so that the summit of this chain, neglecting small irregularities, forms a broad anticlinal axis. Lower down, however, near Los Hornillos [R], there is a well-marked synclinal axis, beyond which the strata are inclined at nearly the same angle, namely from 20° to 30°, inwards or westward. Owing to the amount of denudation which this chain has suffered, the outline of the gently inclined eastern flank scarcely offers the slightest indication of this synclinal axis. The stratified beds, which we have hitherto followed across the range, a little further down are seen to lie, I believe unconformably, on a broad mountainous band of clay-slate and grauwacke. The strata and laminæ of this latter formation, on the extreme eastern flank, are generally nearly vertical; further inwards they become inclined from 45° to 80° to the west: near Villa Vicencio [S] there is apparently an anticlinal axis, but the structure of this outer part of the clay-slate formation is so obscure, that I have not marked the planes of stratification in the section. On the margin of the Pampas, some low, much dislocated spurs of this same formation, project in a north-easterly line, in the same oblique manner as do the ridges on the western foot, and as is so frequently the case with those at the base of the main Cordillera.

I will now describe the nature of the beds, beginning at the base on the eastern side. First, for the clay-slate formation: the slate is generally hard and bluish, with the laminæ coated by minute micaceous scales; it alternates many times with a coarse-grained, greenish grauwacke, containing rounded fragments of quartz and bits of slate in a slightly calcareous basis. The slate in the upper part generally becomes purplish, and the cleavage so irregular that the whole consists of mere splinters. Transverse veins of quartz are numerous. At the Calera, some leagues distant, there is a dark crystalline limestone, apparently included in this formation. With the exception of the grauwacke being here more abundant, and the clay-slate less altered, this formation closely resembles that unconformably underlying the porphyries at the western foot of this same range; and likewise that alternating with the porphyritic conglomerate in the main Cordillera. This formation is a considerable one, and extends several leagues southward to near Mendoza: the mountains composed of it rise to a height of about two thousand feet above the edge of the Pampas, or about seven thousand feet above the sea.[19]

> [19] I infer this from the height of V. Vicencio, which was ascertained by Mr. Miers to be 5,328 feet above the sea.

Secondly: the most usual bed on the clay-slate is a coarse, white, slightly calcareous conglomerate, of no great thickness, including broken crystals of feldspar, grains of quartz, and numerous pebbles of brecciated claystone porphyry, but without any pebbles of the underlying clay-slate. I nowhere saw the actual junction between this bed and the clay-slate, though I spent a whole day in endeavouring to discover their relations. In some places I distinctly saw the white conglomerate and overlying beds inclined at from 25° to 30° to the west, and at the bottom of the same mountain, the clay-slate and grauwacke inclined to the same point, but at an angle from 70° to 80°: in one instance, the clay-slate dipped not only at a different angle, but to a different point from the overlying formation. In these cases the two formations certainly appeared quite unconformable: moreover, I found in the clay-slate one great, vertical, dike-like fissure, filled up with an indurated whitish tuff, quite similar to some of the upper beds presently to be described; and this shows that the clay-slate must have been consolidated and dislocated before their deposition. On the other hand, the stratification of the slate and grauwacke,[20] in some cases gradually and entirely disappeared in approaching the overlying white conglomerate; in other cases the stratification of the two formations became strictly conformable; and again in other cases, there was some tolerably well characterised clay-slate lying above the conglomerate. The most probable conclusion appears to be, that after the clay-slate formation had been dislocated and tilted, but whilst under the sea, a fresh and more recent deposition of clay-slate took place, on which the white conglomerate was conformably deposited, with here and there a thin intercalated bed of clay-slate. On this view the white conglomerates and the presently to be described tuffs and lavas are really unconformable to the main part of the clay-slate; and this, as we have seen, certainly is the case with the clay-stone lavas in the valley of Canota, at the western and opposite base of the range.

> [20] The coarse, mechanical structure of many grauwackes has always appeared to me a difficulty; for the texture of the associated clay-slate and the nature of the embedded organic remains where present, indicate that the whole has been a deep-water deposit. Whence have the sometimes included angular fragments of clay-slate, and the rounded masses of quartz and other rocks, been derived? Many deep-water limestones, it is well known, have been brecciated, and then firmly recemented.

Thirdly: on the white conglomerate, strata several hundred feet in thickness are superimposed, varying much in nature in short distances: the commonest variety is a white, much indurated tuff, sometimes slightly calcareous, with ferruginous spots and water-lines, often passing into whitish or purplish compact, fine-grained grit or sandstones; other varieties become semi-porcellanic, and tinted faint green or blue; others pass into an indurated shale: most of these varieties are easily fusible.

Fourthly: a bed, about one hundred feet thick of a compact, partially columnar, pale-grey, feldspathic lava, stained with iron, including very numerous crystals of opaque feldspar, and with some crystallised and disseminated calcareous matter. The tufaceous stratum on which this feldspathic lava rests is much hardened, stained purple, and has a spherico-concretionary structure; it here contains a good many pebbles of claystone porphyry.

Fifthly: thin beds, 400 feet in thickness, varying much in nature, consisting of white and ferruginous tuffs, in some parts having a concretionary structure, in others containing rounded grains and a few pebbles of quartz; also passing into hard gritstones and into greenish mudstones: there is, also, much of a bluish-grey and green semi-porcellanic stone.

Sixthly: a volcanic stratum, 250 feet in thickness, of so varying a nature that I do not believe a score of specimens would show all the varieties; much is highly amygdaloidal, much compact; there are greenish, blackish, purplish, and grey varieties, rarely including crystals of green augite and minute acicular ones of feldspar, but often crystals and amygdaloidal masses of white, red, and black carbonate of lime. Some of the blackish varieties of this rock have a conchoidal fracture and resemble basalt; others have an irregular fracture. Some of the grey and purplish varieties are thickly speckled with green earth and with white crystalline carbonate of lime; others are largely amygdaloidal with green earth and calcareous spar. Again, other earthy varieties, of greenish, purplish and grey tints, contain much iron, and are almost half composed of amygdaloidal balls of dark brown bole, of a whitish indurated feldspathic matter, of bright green earth, of agate, and of black and white crystallised carbonate of lime. All these varieties are easily fusible. Viewed from a distance, the line of junction with the underlying semi-porcellanic strata was distinct; but when examined closely, it was impossible to point out within a foot where the lava ended and where the sedimentary mass began: the rock at the time of junction was in most places hard, of a bright green colour, and abounded with irregular amygdaloidal masses of ferruginous and pure calcareous spar, and of agate.

Seventhly: strata, eighty feet in thickness, of various indurated tuffs, as before; many of the varieties have a fine basis including rather coarse extraneous particles; some of them are compact and semi-porcellanic, and include vegetable impressions.

Eighthly: a bed, about fifty feet thick, of greenish-grey, compact, feldspathic lava, with numerous small crystals of opaque feldspar, black augite, and oxide of iron. The junction with the bed on which it rested, was ill defined; balls and masses of the feldspathic rock being enclosed in much altered tuff.

Ninthly: indurated tuffs, as before.

Tenthly: a conformable layer, less than two feet in thickness, of pitchstone, generally brecciated, and traversed by veins of agate and of carbonate of lime: parts are composed of apparently concretionary fragments of a more perfect variety, arranged in horizontal lines in a less perfectly characterised variety. I have much difficulty in believing that this thin layer of pitchstone flowed as lava.

Eleventhly: sedimentary and tufaceous beds as before, passing into sandstone, including some conglomerate: the pebbles in the latter are of claystone porphyry, well rounded, and some as large as cricket-balls.

Twelfthly: a bed of compact, sonorous, feldspathic lava, like that of bed No. 8, divided by numerous joints into large angular blocks.

Thirteenthly: sedimentary beds as before.

Fourteenthly: a thick bed of greenish or greyish black, compact basalt (fusing into a black enamel), with small crystals, occasionally distinguishable, of feldspar and augite: the junction with the underlying sedimentary bed, differently from that in most of the foregoing streams, here was quite distinct:—the lava and tufaceous matter preserving their perfect characters within two inches of each other. This rock closely resembles certain parts of that varied and singular lava-stream No. 6; it likewise resembles, as we shall immediately see, many of the great upper beds on the western flank and on the summit of this range.

The pile of strata here described attains a great thickness; and above the last-mentioned volcanic stratum, there were several other great tufaceous beds alternating with submarine lavas, which I had not time to examine; but a corresponding series, several thousand feet in thickness, is well exhibited on the crest and western flank of the range. Most of the lava-streams on the western side are of a jet-black colour and basaltic nature; they are either compact and fine-grained, including minute crystals of augite and feldspar, or they are coarse-grained and abound with rather large coppery-brown crystals of an augitic mineral.[21] Another variety was of a dull-red colour, having a claystone brecciated basis, including specks of oxide of iron and of calcareous spar, and amygdaloidal with green earth: there were apparently several other varieties. These submarine lavas often exhibit a spheroidal, and sometimes an imperfect columnar structure: their upper junctions are much more clearly defined than their lower junctions; but the latter are not so much blended into the underlying sedimentary beds as is the case in the eastern flank. On the crest and western flank of the range, the streams, viewed as a whole, are mostly basaltic; whilst those on the eastern side, which stand lower in the series, are, as we have seen, mostly feldspathic.

[21] Very easily fusible into a jet-black bead, attracted by the magnet: the crystals are too much tarnished to be measured by the goniometer.

The sedimentary strata alternating with the lavas on the crest and western side, are of an almost infinitely varying nature; but a large proportion of them closely resemble those already described on the eastern flank: there are white and brown, indurated, easily fusible tuffs,—some passing into pale blue and green semi-porcellanic rocks,—others into brownish and purplish sandstones and gritstones, often including grains of quartz,—others into mudstone containing broken crystals and particles of rock, and occasionally single large pebbles. There was one stratum of a bright red, coarse, volcanic gritstone; another of conglomerate; another of a black, indurated, carbonaceous shale marked with imperfect vegetable impressions; this latter bed, which was thin, rested on a submarine lava, and followed all the considerable inequalities of its upper surface. Mr. Miers states that coal has been found in this range. Lastly, there was a bed (like No. 10 on the eastern flank) evidently of sedimentary origin, and remarkable from closely approaching in character to an imperfect pitchstone, and from including extremely thin layers of perfect pitchstone, as well as nodules and irregular fragments (but not resembling extraneous fragments) of this same rock arranged in horizontal lines: I conceive that this bed, which is only a few feet in thickness, must have assumed its present state through metamorphic and concretionary action. Most of these sedimentary strata are much indurated, and no doubt have been partially metamorphosed: many of them are extraordinarily heavy and compact; others have agate and crystalline carbonate of lime disseminated throughout them. Some of the beds exhibit a singular concretionary arrangement, with the curves determined by the lines of fissure. There are many veins of agate and calcareous spar, and innumerable ones of iron and other metals, which have blackened and curiously affected the strata to considerable distances on both sides.

Many of these tufaceous beds resemble, with the exception of being more indurated, the upper beds of the Great Patagonian tertiary formation, especially those variously coloured layers high up the River Santa Cruz, and in a remarkable degree the tufaceous formation at the northern end of Chiloe. I was so much struck with this resemblance, that I particularly looked out for silicified wood, and found it under the following extraordinary circumstances. High up on this western flank,[22] at a height estimated at 7,000 feet above the sea, in a broken escarpment of thin strata, composed of compact green gritstone passing into a fine mudstone, and alternating with layers of coarser, brownish, very heavy mudstone, including broken crystals and particles of rock almost blended together, I counted the stumps of fifty-two trees. They projected between two and five feet above the ground, and stood at exactly right angles to the strata, which were here inclined at an angle of about 25° to the west. Eleven of these trees were silicified and well preserved; Mr. R. Brown has been so kind as to examine the wood when sliced and polished; he says it is coniferous, partaking of the characters of the Araucarian tribe, with some curious points of affinity with the Yew. The bark round the trunks must have been circularly furrowed with irregular lines, for the mudstone round them is thus plainly marked. One cast consisted of dark argillaceous limestone; and forty of them of coarsely crystallised carbonate of lime, with cavities lined by quartz crystals: these latter white calcareous columns do not retain any internal structure, but their external form plainly shows their origin. All the stumps have nearly the same diameter, varying from one foot to eighteen inches; some of them stand within a yard of each other; they are grouped in a clump within a space of about sixty yards across, with a few scattered round at the distance of 150 yards. They all stand at about the same level. The longest stump stood seven feet out of the ground: the roots, if they are still preserved, are buried and concealed. No one layer of the mudstone appeared much darker than the others, as if it had formerly existed as soil, nor could this be expected, for the same agents which replaced with silex and lime the wood of the trees, would naturally have removed all vegetable matter from the soil. Besides the fifty-two upright trees, there were a few fragments, like broken branches, horizontally embedded. The surrounding strata are crossed by veins of carbonate of lime, agate, and oxide of iron; and a poor gold vein has been worked not far from the trees.

[22] For the information of any future traveller, I will describe the spot in detail. Proceeding eastward from the Agua del Zorro, and afterwards leaving on the north side of the road a rancho attached to some old goldmines, you pass through a gully with low but steep rocks on each hand: the road then bends, and the ascent becomes steeper. A few hundred yards farther on, a stone's throw on the south side of the road, the white calcareous stumps may be seen. The spot is about half a mile east of the Agua del Zorro.

The green and brown mudstone beds including the trees, are conformably covered by much indurated, compact, white or ferruginous tuffs, which pass upwards into a fine-grained, purplish sedimentary rock: these strata, which, together, are from four to five hundred feet in thickness, rest on a thick bed of submarine lava, and are conformably covered by another great mass of fine-grained basalt,[23] which I estimated at 1,000 feet in thickness, and which probably has been formed by more than one stream. Above this mass I could clearly distinguish five conformable alternations, each several hundred feet in thickness, of stratified sedimentary rocks and lavas, such as have been previously described. Certainly the upright trees have been buried under several thousand feet in thickness of matter, accumulated under the sea. As the trees obviously must once have grown on dry land, what an enormous amount of subsidence is thus indicated! Nevertheless, had it not been for the trees there was no appearance which would have led any one even to have conjectured that these strata had subsided. As the land, moreover, on which the trees grew, is formed of subaqueous deposits, of nearly if not quite equal thickness with the superincumbent strata, and as these deposits are regularly stratified and fine-grained, not like the matter thrown up on a sea-beach, a previous upward movement, aided no doubt by the great accumulation of lavas and sediment, is also indicated.[24]

[23] This rock is quite black, and fuses into a black bead, attracted strongly by the magnet; it breaks with a conchoidal fracture; the included crystals of augite are distinguishable by the naked eye, but are not perfect enough to be measured: there are many minute acicular crystals of glassy feldspar.

[24] At first I imagined, that the strata with the trees might have been accumulated in a lake: but this seems highly improbable; for, first, a very deep lake was necessary to receive the matter below the trees, then it must have been drained for their growth, and afterwards re-formed and made profoundly deep, so as to receive a subsequent accumulation of matter *several thousand* feet in thickness. And all this must have taken place necessarily before the formation of the Uspallata range, and therefore on the margin of the wide level expanse of the Pampas! Hence I conclude, that it is infinitely more probable that the strata were accumulated under the sea: the vast amount of denudation, moreover, which this range has suffered, as shown by the wide valleys, by the exposure of the very trees and by other appearances, could have been effected, I conceive, only by the long-continued action of the sea; and this shows that the range was either upheaved from under the sea, or subsequently let down into it. From the natural manner in which the stumps (fifty-two in number) are *grouped in a clump*, and from their all standing vertically to the strata, it is superfluous to speculate on the chance of the trees having been drifted from adjoining land, and deposited upright: I may, however, mention that the late Dr. Malcolmson assured me, that he once met in the Indian Ocean, fifty miles from land, several cocoa-nut trees floating upright, owing to their roots being loaded with earth.

In nearly the middle of the range, there are some hills [Q], before alluded to, formed of a kind of granite externally resembling andesite, and consisting of a white, imperfectly granular, feldspathic basis, including some perfect crystals apparently of albite (but I was unable to measure them), much black mica, epidote in veins, and very little or no quartz. Numerous small veins branch from this rock into the surrounding strata; and it is a singular fact that these veins, though composed of the same kind of feldspar and small scales of mica as in the solid rock, abound with innumerable minute *rounded* grains of quartz: in the veins or dikes also, branching from the great granitic axis in the peninsula of Tres Montes, I observed that quartz was more abundant in them than in the main rock: I have heard of other analogous cases: can we account for this fact, by the long-continued vicinity of quartz[25] when cooling, and by its having been thus more easily sucked into fissures than the other constituent minerals of granite? The strata encasing the flanks of these granitic or andesite masses, and forming a thick cap on one of their summits, appear originally to have been of the same tufaceous nature with the beds already described, but they are now changed into porcellanic, jaspery, and crystalline rocks, and into others of a white colour with a harsh texture, and having a siliceous aspect, though really of a feldspathic nature and fusible. Both the granitic intrusive masses and the encasing strata are penetrated by innumerable metallic veins, mostly ferruginous and auriferous, but some containing copper-pyrites and a few silver: near the veins, the rocks are blackened as if blasted by gunpowder. The strata are only slightly dislocated close round these hills, and hence, perhaps, it may be inferred that the granitic masses form only the projecting points of a broad continuous axis-dome, which has given to the upper parts of this range its anticlinal structure.

[25] See a paper by M. Elie de Beaumont, "Soc. Philomath.," May 1839 ("L'Institut.," 1839, p. 161.)

Concluding remarks on the Uspallata range.—I will not attempt to estimate the total thickness of the pile of strata forming this range, but it must amount to many thousand feet. The sedimentary and tufaceous beds have throughout a general similarity, though with infinite variations. The submarine lavas in the lower part of the series are mostly feldspathic, whilst in the upper part, on the summit and western flank, they are mostly basaltic. We are thus reminded of the relative position in most recent volcanic districts of the trachytic and basaltic lavas,—the latter from their greater weight having sunk to a lower level in the earth's crust, and having consequently been erupted at a later period over the lighter and upper lavas of the trachytic series.[26] Both the basaltic and feldspathic submarine streams are very compact; none being vesicular, and only a few amygdaloidal: the effects which some of them, especially those low in the series, have produced on the tufaceous beds over which they have flowed is highly curious. Independently of this local metamorphic action, all the strata undoubtedly display an indurated and altered character; and all the rocks of this range—the lavas, the alternating sediments, the intrusive granite and porphyries, and the underlying clay-slate—are intersected by metalliferous veins. The lava-strata can often be seen extending for great distances, conformably with the under and overlying beds; and it was obvious that they thickened towards the west. Hence the points of eruption must have been situated westward of the present range, in the direction of the main Cordillera: as, however, the flanks of the Cordillera are entirely composed of various porphyries, chiefly claystone and greenstone, some intrusive, and others belonging to the porphyritic conglomerate formation, but all quite unlike these submarine lava-streams, we must in all probability look to the plain of Uspallata for the now deeply buried points of eruption.

[26] See on this subject, "Volcanic Islands," etc., by the Author.

Comparing our section of the Uspallata range with that of the Cumbre, we see, with the exception of the underlying clay-slate, and perhaps of the intrusive rocks of the axes, a striking dissimilarity in the strata composing them. The great porphyritic conglomerate formation has not extended as far as this range; nor have we here any of the gypseous strata, the magnesian and other limestones, the red sandstones, the siliceous beds with pebbles of quartz, and comparatively little of the conglomerates, all of which form such vast masses over the basal series in the main Cordillera. On the other hand, in the Cordillera, we do not find those endless varieties of indurated tuffs, with their numerous veins and concretionary arrangement, and those grit and mud stones, and singular semi-porcellanic rocks, so abundant in the Uspallata range. The submarine lavas, also, differ considerably; the feldspathic streams of the Cordillera contain much mica, which is absent in those of the Uspallata range: in this latter range we have seen on how grand a scale, basaltic lava has been poured forth, of which there is not a trace in the Cordillera. This dissimilarity is the more striking, considering that these two parallel chains are separated by a plain only between ten and fifteen miles in width; and that the Uspallata lavas, as well as no doubt the alternating tufaceous beds, have proceeded from the west, from points apparently between the two ranges. To imagine that these two piles of strata were contemporaneously deposited in two closely adjoining, very deep, submarine areas, separated from each other by a lofty ridge, where a plain now extends, would be a gratuitous hypothesis. And had they been contemporaneously deposited, without any such dividing ridge, surely some of the gypseous and other sedimentary matter forming such immensely thick masses in the Cordillera, would have extended this short distance eastwards; and surely some of the Uspallata tuffs and basalts also accumulated to so great a thickness, would have extended a little westward. Hence I conclude, that it is far from probable that these two series are not contemporaneous; but that the strata of one of the chains were deposited, and even the chain itself uplifted, before the formation of the other:—which chain, then, is the oldest? Considering that in the Uspallata range the lowest strata on the western flank lie unconformably on the clay-slate, as probably is the case with those on the eastern flank, whereas in the Cordillera all the overlying strata lie conformably on this formation:—considering that in the Uspallata range some of the beds, both low down and high up in the series, are marked with vegetable impressions, showing the continued existence of neighbouring land;—considering the close general resemblance between the deposits of this range and those of tertiary origin in several parts of the continent;—and lastly, even considering the lesser height and outlying position of the Uspallata range,—I conclude that the strata composing it are in all probability of subsequent origin, and that they were accumulated at a period when a deep sea studded with submarine volcanoes washed the eastern base of the already partially elevated Cordillera.

This conclusion is of much importance, for we have seen that in the Cordillera, during the deposition of the Neocomian strata, the bed of the sea must have subsided many thousand feet: we now learn that at a later period an adjoining area first received a great accumulation of strata, and was upheaved into land on which coniferous trees grew, and that this area then subsided several thousand feet to receive the superincumbent submarine strata, afterwards being broken up, denuded, and elevated in mass to its present height. I am strengthened in this conclusion of there having been two distinct, great periods of subsidence, by reflecting on the thick mass of coarse stratified conglomerate in the valley of Tenuyan, between the Peuquenes and Portillo lines; for the accumulation of this mass seems to me, as previously remarked, almost necessarily to have required a prolonged subsidence; and this subsidence, from the pebbles in the conglomerate having been to a great extent derived from the gypseous or Neocomian strata of the Peuquenes line, we know must have been quite distinct from, and subsequent to, that sinking movement which probably accompanied the deposition of the Peuquenes strata, and which certainly accompanied the deposition of the equivalent beds near the Puente del Inca, in this line of section.

The Uspallata chain corresponds in geographical position, though on a small scale, with the Portillo line; and its clay-slate formation is probably the equivalent of the mica-schist of the Portillo, there metamorphosed by the old white granites and syenites. The coloured beds under the conglomerate in the valley of Tenuyan, of which traces are seen on the crest of the Portillo, and even the conglomerate itself, may perhaps be synchronous with the tufaceous beds and submarine lavas of the Uspallata range; an open sea and volcanic action in the latter case, and a confined channel between two bordering chains of islets in the former case, having been sufficient to account for the mineralogical dissimilarity of the two series. From this correspondence between the Uspallata and Portillo ranges, perhaps in age and certainly in geographical position, one is tempted to consider the one range as the prolongation of the other; but their axes are formed of totally different intrusive rocks; and we have traced the apparent continuation of the red granite of the Portillo in the red porphyries diverging into the main Cordillera. Whether the axis of the Uspallata range was injected before, or as perhaps is more probable, after that of the Portillo line, I will not pretend to decide; but it is well to remember that the highly inclined lava-streams on the eastern flank of the Portillo line, prove that its angular upheavement was not a single and sudden event; and therefore that the anticlinal elevation of the Uspallata range may have been contemporaneous with some of the later angular movements by which the gigantic Portillo range gained its present height above the adjoining plain.

Chapter VIII

NORTHERN CHILE.—CONCLUSION.

Section from Illapel to Combarbala; gypseous formation with silicified wood.—Panuncillo.—Coquimbo; mines of Arqueros; section up valley; fossils.—Guasco, fossils of.—Copiapo, section up valley; Las Amolanas, silicified wood.—Conglomerates, nature of former land, fossils, thickness of strata, great subsidence.—Valley of Despoblado, fossils, tufaceous deposit, complicated dislocations of.—Relations between ancient orifices of eruption and subsequent axes of injection.—Iquique, Peru, fossils of, salt-deposits.—Metalliferous veins.—Summary on the porphyritic conglomerate and gypseous formations.—Great subsidence with partial elevations during the cretaceo-oolitic period.—On the elevation and structure of the Cordillera.—Recapitulation on the tertiary series.—Relation between movements of subsidence and volcanic action.—Pampean formation.—Recent elevatory movements. Long-continued volcanic action in the Cordillera.—Conclusion.

Valparaiso to Coquimbo. I have already described the general nature of the rocks in the low country north of Valparaiso, consisting of granites, syenites, greenstones, and altered feldspathic clay-slate. Near Coquimbo there is much hornblendic rock and various dusky-coloured porphyries. I will describe only one section in this district, namely, from near Illapel in a N.E. line to the mines of Los Hornos, and thence in a north by east direction to Combarbala, at the foot of the main Cordillera.

Near Illapel, after passing for some distance over granite, andesite, and andesitic porphyry, we come to a greenish stratified feldspathic rock, which I believe is altered clay-slate, conformably capped by porphyries and porphyritic conglomerate of great thickness, dipping at an average angle of 20° to N.E. by N. The uppermost beds consist of conglomerates and sandstone only a little metamorphosed, and conformably covered by a gypseous formation of very great thickness, but much denuded. This gypseous formation, where first met with, lies in a broad valley or basin, a little southward of the mines of Los Hornos: the lower half alone contains gypsum, not in great masses as in the Cordillera, but in innumerable thin layers, seldom more than an inch or two in thickness. The gypsum is either opaque or transparent, and is associated with carbonate of lime. The layers alternate with numerous varying ones of a calcareous clay-shale (with strong aluminous odour, adhering to the tongue, easily fusible into a pale green glass), more or less indurated, either earthy and cream-coloured, or greenish and hard. The more indurated varieties have a compact, homogeneous, almost crystalline fracture, and contain granules of crystallised oxide of iron. Some of the varieties almost resemble honestones. There is also a little black, hardly fusible, siliceo-calcareous clay-slate, like some of the varieties alternating with gypsum on the Peuquenes range.

The upper half of this gypseous formation is mainly formed of the same calcareous clay-shale rock, but without any gypsum, and varying extremely in nature: it passes from a soft, coarse, earthy, ferruginous state, including particles of quartz, into compact claystones with crystallised oxide of iron,—into porcellanic layers, alternating with seams of calcareous matter,—and into green porcelain-jasper, excessively hard, but easily fusible. Strata of this nature alternate with much black and brown siliceo-calcareous slate, remarkable from the wonderful number of huge embedded logs of silicified wood. This wood, according to Mr. R. Brown, is (judging from several specimens) all coniferous. Some of the layers of the black siliceous slate contained irregular angular fragments of imperfect pitchstone, which I believe, as in the Uspallata range, has originated in a metamorphic process. There was one bed of a marly tufaceous nature, and of little specific gravity. Veins of agate and calcareous spar are numerous. The whole of this gypseous formation, especially the upper half, has been injected, metamorphosed, and locally contorted by numerous hillocks of intrusive porphyries crowded together in an extraordinary manner. These hillocks consist of purple claystone and of various other porphyries, and of much white feldspathic greenstone passing into andesite; this latter variety included in one case crystals of orthitic and albitic feldspar touching each other, and others of hornblende, chlorite, and epidote. The strata surrounding these intrusive hillocks at the mines of Los Hornos, are intersected by many veins of copper-pyrites, associated with much micaceous iron-ore, and by some of gold: in the neighbourhood of these veins the rocks are blackened and much altered. The gypsum near the intrusive masses is always opaque. One of these hillocks of porphyry was capped by some stratified porphyritic conglomerate, which must have been brought up from below, through the whole immense thickness of the overlying gypseous formation. The lower beds of the gypseous formation resemble the corresponding and probably contemporaneous strata of the main Cordillera; whilst the upper beds in several respects resemble those of the Uspallata chain, and possibly may be contemporaneous with them; for I have endeavoured to show that the Uspallata beds were accumulated subsequently to the gypseous or Neocomian formations of the Cordillera.

This pile of strata dips at an angle of about 20 degrees to N.E. by N., close up to the foot of the Cuesta de Los Hornos, a crooked range of mountains formed of intrusive rocks of the same nature with the above described hillocks. Only in one or two places, on this south-eastern side of the range, I noticed a narrow fringe of the upper gypseous strata brushed up and inclined south-eastward from it. On its north-eastern flank, and likewise on a few of the summits, the stratified porphyritic conglomerate is inclined N.E.: so that, if we disregard the very narrow anticlinal fringe of gypseous strata at its S.E. foot, this range forms a second uniclinal axis of elevation. Proceeding in a north-by-east direction to the village of Combarbala, we come to a third escarpment of the porphyritic conglomerate, dipping eastwards, and forming the outer range of the main Cordillera. The lower beds were here more jaspery than usual, and they included some white cherty strata and red sandstones, alternating with purple claystone porphyry. Higher up in the Cordillera there appeared to be a line of andesitic rocks; and beyond them, a fourth escarpment of the porphyritic conglomerate, again dipping eastwards or inwards. The overlying gypseous strata, if they ever existed here, have been entirely removed.

Copper mines of Panuncillo.—From Combarbala to Coquimbo, I traversed the country in a zigzag direction, crossing and recrossing the porphyritic conglomerate and finding in the granitic districts an unusual number of mountain-masses composed of various intrusive, porphyritic rocks, many of them andesitic. One common variety was greenish-black, with large crystals of blackish albite. At Panuncillo a short N.N.W. and S.S.E. ridge, with a nucleus formed of greenstone and of a slate-coloured porphyry including crystals of glassy feldspar, deserves notice, from the very singular nature of the almost vertical strata composing it. These consist chiefly of a finer and coarser granular mixture, not very compact, of white carbonate of lime, of protoxide of iron and of yellowish garnets (ascertained by Professor Miller), each grain being an almost perfect crystal. Some of the varieties consist exclusively of granules of the calcareous spar; and some contain grains of copper ore, and, I believe, of quartz. These strata alternate with a bluish, compact, fusible, feldspathic rock. Much of the above granular mixture has, also, a pseudo-brecciated structure, in which fragments are obscurely arranged in planes parallel to those of the stratification, and are conspicuous on the weathered surfaces. The fragments are angular or rounded, small or large, and consist of bluish or reddish compact feldspathic matter, in which a few acicular crystals of feldspar can sometimes be seen. The fragments often blend at their edges into the surrounding granular mass, and seem due to a kind of concretionary action.

These singular rocks are traversed by many copper veins, and appear to rest conformably on the granular mixture (in parts as fine-grained as a sandstone) of quartz, mica, hornblende, and feldspar; and this on fine-grained, common gneiss; and this on a laminated mass, composed of pinkish *orthitic* feldspar, including a few specks of hornblende; and lastly, this on granite, which together with andesitic rocks, form the surrounding district.

Coquimbo: Mining district of Arqueros.—At Coquimbo the porphyritic conglomerate formation approaches nearer to the Pacific than in any other part of Chile visited by me, being separated from the coast by a tract only a few miles broad of the usual plutonic rocks, with the addition of a porphyry having a red euritic base. In proceeding to the mines of Arqueros, the strata of porphyritic conglomerate are at first nearly horizontal, an unusual circumstance, and afterwards they dip gently to S.S.E. After having ascended to a considerable height, we come to an undulatory district in which the famous silver mines are situated; my examination was chiefly confined to those of S. Rosa. Most of the rocks in this district are stratified, dipping in various directions, and many of them are of so singular a nature, that at the risk of being tedious I must briefly describe them. The commonest variety is a dull-red, compact, finely brecciated stone, containing much iron and innumerable white crystallised particles of carbonate of lime, and minute extraneous fragments. Another variety is almost equally common near S. Rosa; it has a bright green, scanty basis, including distinct crystals and patches of white carbonate of lime, and grains of red, semi-micaceous oxide of iron; in parts the basis becomes dark green, and assumes an obscure crystalline arrangement, and occasionally in parts it becomes soft and slightly translucent like soapstone. These red and green rocks are often quite distinct, and often pass into each other; the passage being sometimes affected by a fine brecciated structure, particles of the red and green matter being mingled together. Some of the varieties appear gradually to become porphyritic with feldspar; and all of them are easily fusible into pale or dark-coloured beads, strongly attracted by the magnet. I should perhaps have mistaken several of these stratified rocks for submarine lavas, like some of those described at the Puente del Inca, had I not examined, a few leagues eastward of this point, a fine series of analogous but less metamorphosed, sedimentary beds belonging to the gypseous formation, and probably derived from a volcanic source.

This formation is intersected by numerous metalliferous veins, running, though irregularly, N.W. and S.E., and generally at right angles to the many dikes. The veins consist of native silver, of muriate of silver, an amalgam of silver, cobalt, antimony, and arsenic,[1] generally embedded in sulphate of barytes. I was assured by Mr. Lambert, that native copper without a trace of silver has been found in the same vein with native silver without a trace of copper. At the mines of Aristeas, the silver veins are said to be unproductive as soon as they pass into the green strata, whereas at S. Rosa, only two or three miles distant, the reverse happens; and at the time of my visit, the miners were working through a red stratum, in the hope of the vein becoming productive in the underlying green sedimentary mass. I have a specimen of one of these green rocks, with the usual granules of white calcareous spar and red oxide of iron, abounding with disseminated particles of glittering native and muriate of silver, yet taken at the distance of one yard from any vein,—a circumstance, as I was assured, of very rare occurrence.

[1] See the Report on M. Domeyko’s account of those mines, in the “Comptes Rendus,” tome xiv, p. 560.

Section eastward, up the Valley of Coquimbo.—After passing for a few miles over the coast granitic series, we come to the porphyritic conglomerate, with its usual characters, and with some of the beds distinctly displaying their mechanical origin. The strata, where first met with, are, as before stated, only slightly inclined; but near the Hacienda of Pluclaro, we come to an anticlinal axis, with the beds much dislocated and shifted by a great fault, of which not a trace is externally seen in the outline of the hill. I believe that this anticlinal axis can be traced northwards, into the district of Arqueros, where a conspicuous hill called Cerro Blanco, formed of a harsh, cream-coloured euritic rock, including a few crystals of reddish feldspar, and associated with some purplish claystone porphyry, seems to fall on a line of elevation. In descending from the Arqueros district, I crossed on the northern border of the valley, strata inclined eastward from the Pluclaro axis: on the porphyritic conglomerate there rested a mass, some hundred feet thick, of brown argillaceous limestone, in parts crystalline, and in parts almost composed of *Hippurites Chilensis,* d’Orbigny; above this came a black calcareous shale, and on it a red conglomerate. In the brown limestone, with the Hippurites, there was an impression of a Pecten and a coral, and great numbers of a large Gryphæa, very like, and, according to Professor E. Forbes, probably identical with *G. Orientalis,* Forbes MS.,—a cretaceous species (probably upper greensand) from Verdachellum, in Southern India. These fossils seem to occupy nearly the same position with those at the Puente del Inca,—namely, at the top of the porphyritic conglomerate, and at the base of the gypseous formation.

A little above the Hacienda of Pluclaro, I made a detour on the northern side of the valley, to examine the superincumbent gypseous strata, which I estimated at 6,000 feet in thickness. The uppermost beds of the porphyritic conglomerate, on which the gypseous strata conformably rest, are variously coloured, with one very singular and beautiful stratum composed of purple pebbles of various kinds of porphyry, embedded in white calcareous spar, including cavities lined with bright-green crystallised epidote. The whole pile of strata belonging to both formations is inclined, apparently from the above-mentioned axis of Pluclaro, at an angle of between 20 and 30 degrees to the east. I will here give a section of the principal beds met with in crossing the entire thickness of the gypseous strata.

Firstly: above the porphyritic conglomerate formation, there is a fine-grained, red, crystalline sandstone.

Secondly: a thick mass of smooth-grained, calcareo-aluminous, shaly rock, often marked with dendritic manganese, and having, where most compact, the external appearance of honestone. It is easily fusible. I shall for the future, for convenience' sake, call this variety pseudo-honestone. Some of the varieties are quite black when freshly broken, but all weather into a yellowish-ash coloured, soft, earthy substance, precisely as is the case with the compact shaly rocks of the Peuquenes range. This stratum is of the same general nature with many of the beds near Los Hornos in the Illapel section. In this second bed, or in the underlying red sandstone (for the surface was partially concealed by detritus), there was a thick mass of gypsum, having the same mineralogical characters with the great beds described in our sections across the Cordillera.

Thirdly: a thick stratum of fine-grained, red, sedimentary matter, easily fusible into a white glass, like the basis of claystone porphyry; but in parts jaspery, in parts brecciated, and including crystalline specks of carbonate of lime. In some of the jaspery layers, and in some of the black siliceous slaty bands, there were irregular seams of imperfect pitchstone, undoubtedly of metamorphic origin, and other seams of brown, crystalline limestone. Here, also, were masses, externally resembling ill-preserved silicified wood.

Fourthly and fifthly: calcareous pseudo-honestone; and a thick stratum concealed by detritus.

Sixthly: a thinly stratified mass of bright green, compact, smooth-grained, calcareo-argillaceous stone, easily fusible, and emitting a strong aluminous odour: the whole has a highly angulo-concretionary structure; and it resembles, to a certain extent, some of the upper tufaceo-infusorial deposits of the Patagonian tertiary formation. It is in its nature allied to our pseudo-honestone, and it includes well characterised layers of that variety; and other layers of a pale green, harder, and brecciated variety; and others of red sedimentary matter, like that of bed Three. Some pebbles of porphyries are embedded in the upper part.

Seventhly: red sedimentary matter or sandstone like that of bed One, several hundred feet in thickness, and including jaspery layers, often having a finely brecciated structure.

Eighthly: white, much indurated, almost crystalline tuff, several hundred feet in thickness, including rounded grains of quartz and particles of green matter like that of bed Six. Parts pass into a very pale green, semi-porcellanic stone.

Ninthly: red or brown coarse conglomerate, three or four hundred feet thick, formed chiefly of pebbles of porphyries, with volcanic particles, in an arenaceous, non-calcareous, fusible basis: the upper two feet are arenaceous without any pebbles.

Tenthly: the last and uppermost stratum here exhibited, is a compact, slate-coloured porphyry, with numerous elongated crystals of glassy feldspar, from one hundred and fifty to two hundred feet in thickness; it lies strictly conformably on the underlying conglomerate, and is undoubtedly a submarine lava.

This great pile of strata has been broken up in several places by intrusive hillocks of purple claystone porphyry, and by dikes of porphyritic greenstone: it is said that a few poor metalliferous veins have been discovered here. From the fusible nature and general appearance of the finer-grained strata, they probably owe their origin (like the allied beds of the Uspallata range, and of the Upper Patagonian tertiary formations), to gentle volcanic eruptions, and to the abrasion of volcanic rocks. Comparing these beds with those in the mining district of Arqueros, we see at both places rocks easily fusible, of the same peculiar bright green and red colours, containing calcareous matter, often having a finely brecciated structure, often passing into each other, and often alternating together: hence I cannot doubt that the only difference between them, lies in the Arqueros beds having been more metamorphosed (in conformity with their more dislocated and injected condition), and consequently in the calcareous matter, oxide of iron and green colouring matter, having been segregated under a more crystalline form.

The strata are inclined, as before stated, from 20° to 30° eastward, towards an irregular north and south chain of andesitic porphyry and of porphyritic greenstone, where they are abruptly cut off. In the valley of

Coquimbo, near to the H. of Gualliguaca, similar plutonic rocks are met with, apparently a southern prolongation of the above chain; and eastward of it we have an escarpment of the porphyritic conglomerate, with the strata inclined at a small angle eastward, which makes the third escarpment, including that nearest the coast. Proceeding up the valley we come to another north and south line of granite, andesite, and blackish porphyry, which seem to lie in an irregular trough of the porphyritic conglomerate. Again, on the south side of the R. Claro, there are some irregular granitic hills, which have thrown off the strata of porphyritic conglomerate to the N.W. by W.; but the stratification here has been much disturbed. I did not proceed any farther up the valley, and this point is about two-thirds of the distance between the Pacific and the main Cordillera.

I will describe only one other section, namely, on the north side of the R. Claro, which is interesting from containing fossils: the strata are much dislocated by faults and dikes, and are inclined to the north, towards a mountain of andesite and porphyry, into which they appear to become almost blended. As the beds approach this mountain, their inclination increases up to an angle of 70°, and in the upper part, the rocks become highly metamorphosed. The lowest bed visible in this section, is a purplish hard sandstone. Secondly, a bed two or three hundred feet thick, of a white siliceous sandstone, with a calcareous cement, containing seams of slaty sandstone, and of hard yellowish-brown (dolomitic?) limestone; numerous, well-rounded, little pebbles of quartz are included in the sandstone. Thirdly, a dark coloured limestone with some quartz pebbles, from fifty to sixty feet in thickness, containing numerous silicified shells, presently to be enumerated. Fourthly, very compact, calcareous, jaspery sandstone, passing into (fifthly) a great bed, several hundred feet thick, of conglomerate, composed of pebbles of white, red, and purple porphyries, of sandstone and quartz, cemented by calcareous matter. I observed that some of the finer parts of this conglomerate were much indurated within a foot of a dike eight feet in width, and were rendered of a paler colour with the calcareous matter segregated into white crystallised particles; some parts were stained green from the colouring matter of the dike. Sixthly, a thick mass, obscurely stratified, of a red sedimentary stone or sandstone, full of crystalline calcareous matter, imperfect crystals of oxide of iron, and I believe of feldspar, and therefore closely resembling some of the highly metamorphosed beds at Arqueros: this bed was capped by, and appeared to pass in its upper part into, rocks similarly coloured, containing calcareous matter, and abounding with minute crystals, mostly elongated and glassy, of reddish albite. Seventhly, a conformable stratum of fine reddish porphyry with large crystals of (albitic?) feldspar; probably a submarine lava. Eighthly, another conformable bed of green porphyry, with specks of green earth and cream-coloured crystals of feldspar. I believe that there are other superincumbent crystalline strata and submarine lavas, but I had not time to examine them.

The upper beds in this section probably correspond with parts of the great gypseous formation; and the lower beds of red sandstone conglomerate and fossiliferous limestone no doubt are the equivalents of the Hippurite stratum, seen in descending from Arqueros to Pluclaro, which there lies conformably upon the porphyritic conglomerate formation. The fossils found in the third bed, consist of:—

Pecten Dufreynoyi, d'Orbigny, "Voyage, Part Pal."

This species, which occurs here in vast numbers, according to M. D'Orbigny, resembles certain cretaceous forms.

Ostrea hemispherica, d'Orbigny, "Voyage" etc.

Also resembles, according to the same author, cretaceous forms.

Terebratula ænigma, d'Orbigny, "Voyage" etc. (Pl. XXII, Figs. 10-12.)

Is allied, according to M. d'Orbigny, to T. concinna from the Forest Marble. A series of this species, collected in several localities hereafter to be referred to, has been laid before Professor Forbes; and he informs me that many of the specimens are almost undistinguishable from our oolitic T. tetrædra, and that the varieties amongst them are such as are found in that variable species. Generally speaking, the American specimens of T. ænigma may be distinguished from the British T. tetrædra, by the surface having the ribs sharp and well-defined to the beak, whilst in the British species they become obsolete and smoothed down; but this difference is not constant. Professor Forbes adds, that, possibly, internal characters may exist, which would distinguish the American species from its European allies.

Spirifer linguiferoides, E. Forbes.

Professor Forbes states that this species is very near to S. linguifera of Phillips (a carboniferous limestone fossil), but probably distinct. M. d'Orbigny considers it as perhaps indicating the Jurassic period.

Ammonites, imperfect impression of.

M. Domeyko has sent to France a collection of fossils, which, I presume, from the description given, must have come from the neighbourhood of Arqueros; they consist of:—

Pecten Dufreynoyi, d’Orbigny, “Voyage” Part Pal.
Ostrea hemispherica, d’Orbigny, “Voyage” Part Pal.
Turritella Andii, d’Orbigny, “Voyage” Part Pal. (Pleurotomaria Humboldtii of Von Buch).
Hippurites Chilensis, d’Orbigny, “Voyage” Part Pal.

The specimens of this Hippurite, as well as those I collected in my descent from Arqueros, are very imperfect; but in M. d’Orbigny’s opinion they resemble, as does the Turritella Andii, cretaceous (upper greensand) forms.

Nautilus Domeykus, d’Orbigny, “Voyage” Part Pal.
Terebratula ænigma, d’Orbigny, “Voyage” Part Pal.
Terebratula ignaciana, d’Orbigny, “Voyage” Part Pal.

This latter species was found by M. Domeyko in the same block of limestone with the T. ænigma. According to M. d’Orbigny, it comes near to T. ornithocephala from the Lias. A series of this species collected at Guasco, has been examined by Professor E. Forbes, and he states that it is difficult to distinguish between some of the specimens and the T. hastata from the mountain limestone; and that it is equally difficult to draw a line between them and some Marlstone Terebratulæ. Without a knowledge of the internal structure, it is impossible at present to decide on their identity with analogous European forms.

The remarks given on the several foregoing shells, show that, in M. d’Orbigny’s opinion, the Pecten, Ostrea, Turritella, and Hippurite indicate the cretaceous period; and the Gryphæa appears to Professor Forbes to be identical with a species, associated in Southern India with unquestionably cretaceous forms. On the other hand, the two Terebratulæ and the Spirifer point, in the opinion both of M. d’Orbigny and Professor Forbes, to the oolitic series. Hence M. d’Orbigny, not having himself examined this country, has concluded that there are here two distinct formations; but the Spirifer and T. ænigma were certainly included in the same bed with the Pecten and Ostrea, whence I extracted them; and the geologist M. Domeyko sent home the two Terebratulæ with the other-named shells, from the same locality, without specifying that they came from different beds. Again, as we shall presently see, in a collection of shells given me from Guasco, the same species, and others presenting analogous differences, are mingled together, and are in the same condition; and lastly, in three places in the valley of Copiapo, I found some of these same species similarly grouped. Hence there cannot be any doubt, highly curious though the fact be, that these several fossils, namely, the Hippurites, Gryphæa, Ostrea, Pecten, Turritella, Nautilus, two Terebratulæ, and Spirifer all belong to the same formation, which would appear to form a passage between the oolitic and cretaceous systems of Europe. Although aware how unusual the term must sound, I shall, for convenience’ sake, call this formation cretaceo-oolitic. Comparing the sections in this valley of Coquimbo with those in the Cordillera described in the last chapter, and bearing in mind the character of the beds in the intermediate district of Los Hornos, there is certainly a close general mineralogical resemblance between them, both in the underlying porphyritic conglomerate, and in the overlying gypseous formation. Considering this resemblance, and that the fossils from the Puente del Inca at the base of the gypseous formation, and throughout the greater part of its entire thickness on the Peuquenes range, indicate the Neocomian period,—that is, the dawn of the cretaceous system, or, as some have believed, a passage between this latter and the oolitic series—I conclude that probably the gypseous and associated beds in all the sections hitherto described, belong to the same great formation, which I have denominated—cretaceo-oolitic. I may add, before leaving Coquimbo, that M. Gay found in the neighbouring Cordillera, at the height of 14,000 feet above the sea, a fossiliferous formation, including a Trigonia and Pholadomya;[2]—both of which genera occur at the Puente del Inca.

[2] D’Orbigny, “Voyage,” Part Géolog., p. 242.

Coquimbo to Guasco.—The rocks near the coast, and some way inland, do not differ from those described northwards of Valparaiso: we have much greenstone, syenite, feldspathic and jaspery slate, and grauwackes having a basis like that of claystone; there are some large tracts of granite, in which the constituent minerals are sometimes arranged in folia, thus composing an imperfect gneiss. There are two large districts of mica-schists, passing into glossy clay-slate, and resembling the great formation in the Chonos Archipelago. In the valley of Guasco, an escarpment of porphyritic conglomerate is first seen high up the valley, about two leagues eastward of the town of Ballenar. I heard of a great gypseous formation in the Cordillera; and a collection of shells made there was given me. These shells are all in the same condition, and appear to have come from the same bed: they consist of:—

Turritella Andii, d’Orbigny, “Voyage,” Part Pal.
Pecten Dufreynoyi, d’Orbigny, “Voyage,” Part Pal.
Terebatula ignaciana, d’Orbigny, “Voyage,” Part Pal.

The relations of these species have been given under the head of Coquimbo.

Terebratula ænigma, d’Orbigny, “Voyage,” Part Pal.

This shell M. d’Orbigny does not consider identical with his T. ænigma, but near to T. obsoleta. Professor Forbes thinks that it is certainly a variety of T. ænigma: we shall meet with this variety again at Copiapo.

Spirifer Chilensis, E. Forbes.

Professor Forbes remarks that this fossil resembles several carboniferous limestone Spirifers; and that it is also related to some liassic species, as S. Wolcotii.

If these shells had been examined independently of the other collections, they would probably have been considered, from the characters of the two Terebratulæ, and from the Spirifer, as oolitic; but considering that the first species, and according to Professor Forbes, the four first, are identical with those from Coquimbo, the two formations no doubt are the same, and may, as I have said, be provisionally called cretaceo-oolitic.

Valley of Copiapo.—The journey from Guasco to Copiapo, owing to the utterly desert nature of the country, was necessarily so hurried, that I do not consider my notes worth giving. In the valley of Copiapo some of the sections are very interesting. From the sea to the town of Copiapo, a distance estimated at thirty miles, the mountains are composed of greenstone, granite, andesite, and blackish porphyry, together with some dusky-green feldspathic rocks, which I believe to be altered clay-slate: these mountains are crossed by many brown-coloured dikes, running north and south. Above the town, the main valley runs in a south-east and even more southerly course towards the Cordillera, where it is divided into three great ravines, by the northern one of which, called Jolquera, I penetrated for a short distance. The section, Fig. 3 in Plate V, gives an eye-sketch of the structure and composition of the mountains on both sides of this valley: a straight east and west line from the town to the Cordillera is perhaps not more than thirty miles, but along the valley the distance is much greater. Wherever the valley trended very southerly, I have endeavoured to contract the section into its true proportion. This valley, I may add, rises much more gently than any other valley which I saw in Chile.

To commence with our section, for a short distance above the town we have hills of the granitic series, together with some of that rock [A], which I suspect to be altered clay-slate, but which Professor G. Rose, judging from specimens collected by Meyen at P. Negro, states is serpentine passing into greenstone. We then come suddenly to the great gypseous formation [B], without having passed over, differently from, in all the sections hitherto described, any of the porphyritic conglomerate. The strata are at first either horizontal or gently inclined westward; then highly inclined in various directions, and contorted by underlying masses of intrusive rocks; and lastly, they have a regular eastward dip, and form a tolerably well pronounced north and south line of hills. This formation consists of thin strata, with innumerable alternations, of black, calcareous slate-rock, of calcareo-aluminous stones like those at Coquimbo, which I have called pseudo-honestones of green jaspery layers, and of pale-purplish, calcareous, soft rotten-stone, including seams and veins of gypsum. These strata are conformably overlaid by a great thickness of thinly stratified, compact limestone with included crystals of carbonate of lime. At a place called Tierra Amarilla, at the foot of a mountain thus composed there is a broad vein, or perhaps stratum, of a beautiful and curious crystallised mixture, composed, according to Professor G. Rose,[3] of sulphate of iron under two forms, and of the sulphates of copper and alumina: the section is so obscure that I could not make out whether this vein or stratum occurred in the gypseous formation, or more probably in some underlying masses [A], which I believe are altered clay-slate.

[3] Meyen’s “Reise,” etc., Th. I, s. 394.

Second axis of elevation.—After the gypseous masses [B], we come to a line of hills of unstratified porphyry [C], which on their eastern side blend into strata of great thickness of porphyritic conglomerate, dipping eastward. This latter formation, however, here has not been nearly so much metamorphosed as in most parts of Central Chile; it is composed of beds of true purple claystone porphyry, repeatedly alternating with thick beds of purplish-red conglomerate with the well-rounded, large pebbles of various porphyries, not blended together. *Third axis of elevation.*—Near the ravine of Los Hornitos, there is a well-marked line of elevation, extending for many miles in a N.N.E. and S.S.W. direction, with the strata dipping in most parts (as in the second axis) only in one direction, namely, eastward at an average angle of between 30° and 40°. Close to the mouth of the valley, however, there is, as represented in the section, a steep and high mountain [D], composed of various green and brown intrusive porphyries enveloped with strata, apparently belonging to the upper parts of the porphyritic conglomerate, and dipping both eastward and westward. I will describe the section seen on the eastern side of this mountain [D], beginning at the base with the lowest bed visible in the porphyritic conglomerate, and proceeding upwards through the gypseous formation. Bed 1 consists of reddish and brownish porphyry varying in character, and in many parts highly amygdaloidal with carbonate of lime, and with bright green and brown bole. Its upper surface is throughout clearly defined, but the lower surface is in most parts indistinct, and towards the summit of the mountain [D] quite blended into the intrusive porphyries. Bed 2, a pale lilac, hard but not heavy stone, slightly laminated, including small extraneous fragments, and imperfect as well as some perfect and glassy crystals of feldspar; from one hundred and fifty to two hundred feet in thickness. When examining it in situ, I thought it was certainly a true porphyry, but my specimens now lead me to suspect that it possibly may be a metamorphosed tuff. From its colour it could be traced for a long distance, overlying in one part, quite conformably to the porphyry of bed 1, and in another not distant part, a very thick mass of conglomerate, composed of pebbles of a porphyry chiefly like that of bed 1: this fact shows how the nature of the bottom formerly varied in short horizontal distances. Bed 3, white, much indurated tuff, containing minute pebbles, broken crystals, and scales of mica, varies much in thickness. This bed is remarkable from containing many globular and pear-shaped, externally rusty balls, from the size of an apple to a man’s head, of very tough, slate-coloured porphyry, with imperfect crystals of feldspar: in shape these balls do not resemble pebbles, *and i believe that they are subaqueous volcanic bombs*; they differ from *subaerial* bombs only in not being vesicular. Bed 4; a dull purplish-red, hard conglomerate, with crystallised particles and veins of carbonate of lime, from three hundred to four hundred feet in thickness. The pebbles are of claystone porphyries of many varieties; they are tolerably well rounded, and vary in size from a large apple to a man’s head. This bed includes three layers of coarse, black, calcareous, somewhat slaty rock: the upper part passes into a compact red sandstone.

In a formation so highly variable in mineralogical nature, any division not founded on fossil remains, must be extremely arbitrary: nevertheless, the beds below the last conglomerate may, in accordance with all the sections hitherto described, be considered as belonging to the porphyritic conglomerate, and those above it to the gypseous formation, marked [E] in the section. The part of the valley in which the following beds are seen is near Potrero Seco. Bed 5, compact, fine-grained, pale greenish-grey, non-calcareous, indurated mudstone, easily fusible into a pale green and white glass. Bed 6, purplish, coarse-grained, hard sandstone, with broken crystals of feldspar and crystallised particles of carbonate of lime; it possesses a slightly nodular structure. Bed 7, blackish-grey, much indurated, calcareous mudstone, with extraneous particles of unequal size; the whole being in parts finely brecciated. In this mass there is a stratum, twenty feet in thickness, of impure gypsum. Bed 8, a greenish mudstone, with several layers of gypsum. Bed 9, a highly indurated, easily fusible, white tuff, thickly mottled with ferruginous matter, and including some white semi-porcellanic layers, which are interlaced with ferruginous veins. This stone closely resembles some of the commonest varieties in the Uspallata chain. Bed 10, a thick bed of rather bright green, indurated mudstone or tuff, with a concretionary nodular structure so strongly developed that the whole mass consists of balls. I will not attempt to estimate the thickness of the strata in the gypseous formation hitherto described, but it must certainly be very many hundred feet. Bed 11 is at least 800 feet in thickness: it consists of thin layers of whitish, greenish, or more commonly brown, fine-grained, indurated tuffs, which crumble into angular fragments: some of the layers are semi-porcellanic, many of them highly ferruginous, and some are almost composed of carbonate of lime and iron with drusy cavities lined with quartzf-crystals. Bed 12, dull purplish or greenish or dark-grey, very compact and much indurated mudstone: estimated at 1,500 feet in thickness: in some parts this rock assumes the character of an imperfect coarse clay-slate; but viewed under a lens, the basis always has a mottled appearance, with the edges of the minute component particles blending together. Parts are calcareous, and there are numerous veins of highly crystalline carbonate of lime charged with iron. The mass has a nodular structure, and is divided by only a few planes of stratification: there are, however, two layers, each about eighteen inches thick, of a dark brown, finer-grained stone, having a conchoidal, semi-porcellanic fracture, which can be followed with the eye for some miles across the country.

I believe this last great bed is covered by other nearly similar alternations; but the section is here obscured by a tilt from the next porphyritic chain, presently to be described. I have given this section in detail, as being illustrative of the general character of the mountains in this neighbourhood; but it must not be supposed that any one stratum long preserves the same character. At a distance of between only two and three miles the green mudstones and white indurated tuffs are to a great extent replaced by red sandstone and black calcareous shaly rocks, alternating together. The white indurated tuff, bed 11, here contains little or no gypsum, whereas on the northern and opposite side of the valley, it is of much greater thickness and abounds with layers of gypsum, some of them alternating with thin seams of crystalline carbonate of lime. The uppermost, dark-coloured, hard mudstone, bed 12, is in this neighbourhood the most constant stratum. The whole series differs to a considerable extent, especially in its upper part, from that met with at [BB], in the lower part of the valley; nevertheless, I do not doubt that they are equivalents. *Fourth axis of elevation (Valley of Copiapo).*—This axis is formed of a chain of mountains [F], of which the central masses (near La Punta) consist of andesite containing green hornblende and coppery mica, and the outer masses of greenish and black porphyries, together with some fine lilac-coloured claystone porphyry; all these porphyries being injected and broken up by small hummocks of andesite. The central great mass of this latter rock, is covered on the eastern side by a black, fine-grained, highly micaceous slate, which, together with the succeeding mountains of porphyry, are traversed by numerous white dikes, branching from the andesite, and some of them extending in straight lines, to a distance of at least two miles. The mountains of porphyry eastward of the micaceous schist soon, but gradually, assume (as observed in so many other cases) a stratified structure, and can then be recognised as a part of the porphyritic conglomerate formation. These strata [G] are inclined at a high angle to the S.E., and form a mass from fifteen hundred to two thousand feet in thickness. The gypseous masses to the west already described, dip directly towards this axis, with the strata only in a few places (one of which is represented in the section) thrown from it: hence this fourth axis is mainly uniclinal towards the S.E., and just like our third axis, only locally anticlinal.

The above strata of porphyritic conglomerate [G] with their south-eastward dip, come abruptly up against beds of the gypseous formation [H], which are gently, but irregularly, inclined westward: so that there is here a synclinal axis and great fault. Further up the valley, here running nearly north and south, the gypseous formation is prolonged for some distance; but the stratification is unintelligible, the whole being broken up by faults, dikes, and metalliferous veins. The strata consist chiefly of red calcareous sandstones, with numerous veins in the place of layers, of gypsum; the sandstone is associated with some black calcareous slate-rock, and with green pseudo-honestones, passing into porcelain-jasper. Still further up the valley, near Las Amolanas [I], the gypseous strata become more regular, dipping at an angle of between 30 and 40 degrees to W.S.W., and conformably overlying, near the mouth of the ravine of Jolquera, strata [K] of porphyritic conglomerate. The whole series has been tilted by a partially concealed axis [L], of granite, andesite, and a granitic mixture of white feldspar, quartz, and oxide of iron.

Fifth axis of elevation (Valley of Copiapo, near Las Amolanas).—I will describe in some detail the beds [I] seen here, which, as just stated, dip to W.S.W., at an angle of from 30° to 40°. I had not time to examine the underlying porphyritic conglomerate, of which the lowest beds, as seen at the mouth of the Jolquera, are highly compact, with crystals of red oxide of iron; and I am not prepared to say whether they are chiefly of volcanic or metamorphic origin. On these beds there rests a coarse purplish conglomerate, very little metamorphosed, composed of pebbles of porphyry, but remarkable from containing one pebble of granite;—of which fact no instance has occurred in the sections hitherto described.

Above this conglomerate, there is a black siliceous claystone, and above it numerous alternations of dark-purplish and green porphyries, which may be considered as the uppermost limit of the porphyritic conglomerate formation.

Above these porphyries comes a coarse, arenaceous conglomerate, the lower half white and the upper half of a pink colour, composed chiefly of pebbles of various porphyries, but with some of red sandstone and jaspery rocks. In some of the more arenaceous parts of the conglomerate, there was an oblique or current lamination; a circumstance which I did not elsewhere observe. Above this conglomerate, there is a vast thickness of thinly stratified, pale-yellowish, siliceous sandstone, passing into a granular quartz-rock, used for grindstones (hence the name of the place *Las Amolanas*), and certainly belonging to the gypseous formation, as does probably the immediately underlying conglomerate. In this yellowish sandstone there are layers of white and pale-red siliceous conglomerate; other layers with small, well-rounded pebbles of white quartz, like the bed at the R. Claro at Coquimbo; others of a greenish, fine-grained, less siliceous stone, somewhat resembling the pseudo-honestones lower down the valley; and lastly, others of a black calcareous shale-rock. In one of the layers of conglomerate, there was embedded a fragment of mica-slate, of which this is the first instance; hence perhaps, it is from a formation of mica-slate, that the numerous small pebbles of quartz, both here and at Coquimbo, have been derived. Not only does the siliceous sandstone include layers of the black, thinly stratified, not fissile, calcareous shale-rock, but in one place the whole mass, especially the upper part, was, in a marvellously short horizontal distance, after frequent alternations, replaced by it. When this occurred, a mountain-mass, several thousand feet in thickness was thus composed; the black calcareous shale-rock, however, always included some layers of the pale-yellowish siliceous sandstone, of the red conglomerate, and of the greenish jaspery and pseudo-honestone varieties. It likewise included three or four widely separated layers of a brown limestone, abounding with shells immediately to be described. This pile of strata was in parts traversed by many veins of gypsum. The calcareous shale-rock, though when freshly broken quite black, weathers into an ash- colour: in which respect and in general appearance, it perfectly resembles those great fossiliferous beds of the Peuquenes range, alternating with gypsum and red sandstone, described in the last chapter.

The shells out of the layers of brown limestone, included in the black calcareous shale-rock, which latter, as just stated, replaces the white siliceous sandstone, consist of:—

Pecten Dufreynoyi, d’Orbigny, “Voyage,” Part Pal.
Turritella Andii, d’Orbigny, “Voyage,” Part Pal.

Astarte Darwinii, E. Forbes.
Gryphæa Darwinii, E. Forbes.

An intermediate form between G. gigantea and G. incurva.

Gryphæa nov. spec.?, E. Forbes.
Perna Americana, E. Forbes.
Avicula, nov. spec.

Considered by Mr. G. B. Sowerby as the A. echinata, by M. d’Orbigny as certainly a new and distinct species, having a Jurassic aspect. The specimen has been unfortunately lost.

Terebratula ænigma, d’Orbigny, (var. of do. E. Forbes.)

This is the same variety, with that from Guasco, considered by M. D’Orbigny to be a distinct species from his T. ænigma, and related to T. obsoleta.

Plagiostoma and Ammonites, fragments of.

The lower layers of the limestone contained thousands of the Gryphæa; and the upper ones as many of the Turritella, with the Gryphæa (nov. species) and Serpulæ adhering to them; in all the layers, the Terebratula and fragments of the Pecten were included. It was evident, from the manner in which species were grouped together, that they had lived where now embedded. Before making any further remarks, I may state, that higher up this same valley we shall again meet with a similar association of shells; and in the great Despoblado Valley, which branches off near the town from that of Copiapo, the Pecten Dufreynoyi, some Gryphites (I believe G. Darwinii), and the *true* Terebratula ænigma of d’Orbigny were found together in an equivalent formation, as will be hereafter seen. A specimen also, I may add, of the true T. ænigma, was given me from the neighbourhood of the famous silver mines of Chanuncillo, a little south of the valley of the Copiapo, and these mines, from their position, I have no doubt, lie within the great gypseous formation: the rocks close to one of the silver veins, judging from fragments shown me, resemble those singular metamorphosed deposits from the mining district of Arqueros near Coquimbo.

I will reiterate the evidence on the association of these several shells in the several localities.

Coquimbo.

In the same bed, Rio Claro:
Pecten Dufreynoyi.
Ostrea hemispherica.
Terebratula ænigma.
Spirifer linguiferoides.

Same bed, near Arqueros:
Hippurites Chilensis.
Gryphæa orientalis.

Collected by M. Domeyko from the same locality, apparently near Arqueros:
Terebratula ænigma and Terebratula ignaciana, in same block of limestone.
Pecten Dufreynoyi.
Ostrea hemispherica.
Hippurites Chilensis.
Turritella Andii.
Nautilus Domeykus.

Guasco.

In a collection from the Cordillera, given me: the specimens all in the same condition:
Pecten Dufreynoyi.
Turritella Andii.
Terebratula ignaciana.
Terebratula ænigma, *var.*
Spirifer Chilensis.

Copiapo.

Mingled together in alternating beds in the main valley of Copiapo near Las Amolanas, and likewise higher up the valley:
Pecten Dufreynoyi.
Turritella Andii.
Terebratula ænigma, *var.*, as at Guasco.
Astarte Darwinii.
Gryphæa Darwinii.
Gryphæa nov. species?
Perna Americana.
Avicula, nov. species.

Main valley of Copiapo, apparently same formation with that of Amolanas:
Terebratula ænigma (true).

In the same bed, high up the great lateral valley of the Despoblado, in the ravine of Maricongo:
Terebratula ænigma (true).
Pecten Dufreynoyi.
Gryphæa Darwinii?

Considering this table, I think it is impossible to doubt that all these fossils belong to the same formation. If, however, the species from Las Amolanas, in the Valley of Copiapo, had, as in the case of those from Guasco, been separately examined, they would probably have been ranked as oolitic; for, although no Spirifers were found here, all the other species, with the exception of the Pecten, Turritella, and Astarte, have a more ancient aspect than cretaceous forms. On the other hand, taking into account the evidence derived from the cretaceous character of these three shells, and of the Hippurites, Gryphæa orientalis, and Ostrea, from Coquimbo, we are driven back to the provisional name already used of cretaceo-oolitic. From geological evidence, I believe this formation to be the equivalent of the Neocomian beds of the Cordillera of Central Chile.

To return to our section near Las Amolanas:—Above the yellow siliceous sandstone, or the equivalent calcareous slate-rock, with its bands of fossil-shells, according as the one or other prevails, there is a pile of strata, which cannot be less than from two to three thousand feet in thickness, in main part composed of a coarse, bright red conglomerate, with many intercalated beds of red sandstone, and some of green and other coloured porcelain-jaspery layers. The included pebbles are well-rounded, varying from the size of an egg to that of a cricket-ball, with a few larger; and they consist chiefly of porphyries. The basis of the conglomerate, as well as some of the alternating thin beds, are formed of a red, rather harsh, easily fusible sandstone, with crystalline calcareous particles. This whole great pile is remarkable from the thousands of huge, embedded, silicified trunks of trees, one of which was eight feet long, and another eighteen feet in circumference: how marvellous it is, that every vessel in so thick a mass of wood should have been converted into silex! I brought home many specimens, and all of them, according to Mr. R. Brown, present a coniferous structure.

Above this great conglomerate, we have from two to three hundred feet in thickness of red sandstone; and above this, a stratum of black calcareous slate-rock, like that which alternates with and replaces the underlying yellowish-white, siliceous sandstone. Close to the junction between this upper black slate-rock and the upper red sandstone, I found the Gryphæa Darwinii, the Turritella Andii, and vast numbers of a bivalve, too imperfect to be recognised. Hence we see that, as far as the evidence of these two shells serves—and the Turritella is an eminently characteristic species—the whole thickness of this vast pile of strata belongs to the same age. Again, above the last-mentioned upper red sandstone, there were several alternations of the black, calcareous slate-rock; but I was unable to ascend to them. All these uppermost strata, like the lower ones, vary extremely in character in short horizontal distances. The gypseous formation, as here seen, has a coarser, more mechanical texture, and contains much more siliceous matter than the corresponding beds lower down the valley. Its total thickness, together with the upper beds of the porphyritic conglomerate, I estimated at least at 8,000 feet; and only a small portion of the porphyritic conglomerate, which on the eastern flank of the fourth axis of elevation appeared to be from fifteen hundred to two thousand feet thick, is here included. As corroborative of the great thickness of the gypseous formation, I may mention that in the Despoblado Valley (which branches from the main valley a little above the town of Copiapo) I found a corresponding pile of red and white sandstones, and of dark, calcareous, semi-jaspery mudstones, rising from a nearly level surface and thrown into an absolutely vertical position; so that, by pacing, I ascertained their thickness to be nearly two thousand seven hundred feet; taking this as a standard of comparison, I estimated the thickness of the strata *above* the porphyritic conglomerate at 7,000 feet.

The fossils before enumerated, from the limestone-layers in the whitish siliceous sandstone, are now covered, on the least computation, by strata from 5,000 to 6,000 feet in thickness. Professor E. Forbes thinks that these shells probably lived at a depth of from about 30 to 40 fathoms, that is from 180 to 240 feet; anyhow, it is impossible that they could have lived at the depth of from 5,000 to 6,000 feet. Hence in this case, as in that of the Puente del Inca, we may safely conclude that the bottom of the sea on which the shells lived, subsided, so as to receive the superincumbent submarine strata: and this subsidence must have taken place during the existence of these shells; for, as I have shown, some of them occur high up as well as low down in the series. That the bottom of the sea subsided, is in harmony with the presence of the layers of coarse, well-rounded pebbles included throughout this whole pile of strata, as well as of the great upper mass of conglomerate from 2,000 to 3,000 feet thick; for coarse gravel could hardly have been formed or spread out at the profound depths indicated by the thickness of the strata. The subsidence, also, must have been slow to have allowed of this often-recurrent spreading out of the pebbles. Moreover, we shall presently see that the surfaces of some of the streams of porphyritic lava beneath the gypseous formation, are so highly amygdaloidal that it is scarcely possible to believe that they flowed under the vast pressure of a deep ocean. The conclusion of a great subsidence during the existence of these cretaceo-oolitic fossils, may, I believe, be extended to the district of Coquimbo, although owing to the fossiliferous beds there not being directly covered by the upper gypseous strata, which in the section north of the valley are about 6,000 feet in thickness, I did not there insist on this conclusion.

The pebbles in the above conglomerates, both in the upper and lower beds, are all well rounded, and, though chiefly composed of various porphyries, there are some of red sandstone and of a jaspery stone, both like the rocks intercalated in layers in this same gypseous formation; there was one pebble of mica-slate and some of quartz, together with many particles of quartz. In these respects there is a wide difference between the gypseous conglomerates and those of the porphyritic-conglomerate formation, in which latter, angular and rounded fragments, almost exclusively composed of porphyries, are mingled together, and which, as already often remarked, probably were ejected from craters deep under the sea. From these facts I conclude, that during the formation of the conglomerates, land existed in the neighbourhood, on the shores of which the innumerable pebbles were rounded and thence dispersed, and on which the coniferous forests flourished—for it is improbable that so many thousand logs of wood should have drifted from any great distance. This land, probably islands, must have been mainly formed of porphyries, with some mica-slate, whence the quartz was derived, and with some red sandstone and jaspery rocks. This latter fact is important, as it shows that in this district, even previously to the deposition of the lower gypseous or cretaceo-oolitic beds, strata of an analogous nature had elsewhere, no doubt in the more central ranges of the Cordillera, been elevated; thus recalling to our minds the relations of the Cumbre and Uspallata chains. Having already referred to the great lateral valley of the Despoblado, I may mention that above the 2,700 feet of red and white sandstone and dark mudstone, there is a vast mass of coarse, hard, red conglomerate, some thousand feet in thickness, which contains much silicified wood, and evidently corresponds with the great upper conglomerate at Las Amolanas: here, however, the conglomerate consists almost exclusively of pebbles of granite, and of disintegrated crystals of reddish feldspar and quartz firmly recemented together. In this case, we may conclude that the land whence the pebbles were derived, and on which the now silicified trees once flourished, was formed of granite.

The mountains near Las Amolanas, composed of the cretaceo-oolitic strata, are interlaced with dikes like a spider’s web, to an extent which I have never seen equalled, except in the denuded interior of a volcanic crater: north and south lines, however, predominate. These dikes are composed of green, white, and blackish rocks, all porphyritic with feldspar, and often with large crystals of hornblende. The white varieties approach closely in character to andesite, which composes as we have seen, the injected axes of so many of the lines of elevation. Some of the green varieties are finely laminated, parallel to the walls of the dikes.

Sixth axis of elevation (Valley of Copiapo).—This axis consists of a broad mountainous mass [O] of andesite, composed of albite, brown mica, and chlorite, passing into andesitic granite, with quartz: on its western side it has thrown off, at a considerable angle, a thick mass of stratified porphyries, including much epidote [NN], and remarkable only from being divided into very thin beds, as highly amygdaloidal on their surfaces as subaerial lava-streams are often vesicular. This porphyritic formation is conformably covered, as seen some way up the ravine of Jolquera, by a mere remnant of the lower part of the cretaceo-oolitic formation [MM], which in one part encases, as represented in the coloured section, the foot of the andesitic axis [L], of the already described fifth line, and in another part entirely conceals it: in this latter case, the gypseous or cretaceo-oolitic strata falsely appeared to dip under the porphyritic conglomerate of the fifth axis. The lowest bed of the gypseous formation, as seen here [M], is of yellowish siliceous sandstone, precisely like that of Amolanas, interlaced in parts with veins of gypsum, and including layers of the black, calcareous, non-fissile slate-rock: the *Turritella Andii, Pecten Dufreynoyi, Terebratula ænigma, var.,* and some Gryphites were embedded in these layers. The sandstone varies in thickness from only twenty to eighty feet; and this variation is caused by the inequalities in the upper surface of an underlying stream of purple claystone porphyry. Hence the above fossils here lie at the very base of the gypseous or cretaceo-oolitic formation, and hence they were probably once covered up by strata about seven thousand feet in thickness: it is, however, possible, though from the nature of all the other sections in this district not probable, that the porphyritic claystone lava may in this case have invaded a higher level in the series. Above the sandstone there is a considerable mass of much indurated, purplish-black, calcareous claystone, allied in nature to the often-mentioned black calcareous slate-rock.

Eastward of the broad andesitic axis of this sixth line, and penetrated by many dikes from it, there is a great formation [P] of mica-schist, with its usual variations, and passing in one part into a ferruginous quartz-rock. The folia are curved and highly inclined, generally dipping eastward. It is probable that this mica-schist is an old formation, connected with the granitic rocks and metamorphic schists near the coast; and that the one fragment of mica-slate, and the pebbles of quartz low down in the gypseous formation at Las Amolanas, have been derived from it. The mica-schist is succeeded by stratified porphyritic conglomerate [Q] of great thickness, dipping eastward with a high inclination: I have included this latter mountain-mass in the same anticlinal axis with the porphyritic streams [NN]; but I am far from sure that the two masses may not have been independently upheaved.

Seventh axis of elevation.—Proceeding up the ravine, we come to another mass [R] of andesite; and beyond this, we again have a very thick, stratified porphyritic formation [S], dipping at a small angle eastward, and forming the basal part of the main Cordillera. I did not ascend the ravine any higher; but here, near Castano, I examined several sections, of which I will not give the details, only observing, that the porphyritic beds, or submarine lavas, preponderate greatly in bulk over the alternating sedimentary layers, which have been but little metamorphosed: these latter consist of fine-grained red tuffs and of whitish volcanic grit-stones, together with much of a singular, compact rock, having an almost crystalline basis, finely brecciated with red and green fragments, and occasionally including a few large pebbles. The porphyritic lavas are highly amygdaloidal, both on their upper and lower surfaces; they consist chiefly of claystone porphyry, but with one common variety, like some of the streams at the Puente del Inca, having a grey mottled basis, abounding with crystals of red hydrous oxide of iron, green ones apparently of epidote, and a few glassy ones of feldspar. This pile of strata differs considerably from the basal strata of the Cordillera in Central Chile, and may possibly belong to the upper and gypseous series: I saw, however, in the bed of the valley, one fragment of porphyritic breccia-conglomerate, exactly like those great masses met with in the more southern parts of Chile.

Finally, I must observe, that though I have described between the town of Copiapo and the western flank of the main Cordillera seven or eight axes of elevation, extending nearly north and south, it must not be supposed that they all run continuously for great distances. As was stated to be the case in our sections across the Cordillera of Central Chile, so here most of the lines of elevation, with the exception of the first, third, and fifth, are very short. The stratification is everywhere disturbed and intricate; nowhere have I seen more numerous faults and dikes. The whole district, from the sea to the Cordillera, is more or less metalliferous; and I heard of gold, silver, copper, lead, mercury, and iron veins. The metamorphic action, even in the lower strata, has certainly been far less here than in Central Chile.

Valley of the Despoblado.—This great barren valley, which has already been alluded to, enters the main valley of Copiapo a little above the town: it runs at first northerly, then N.E., and more easterly into the Cordillera; I followed its dreary course to the foot of the first main ridge. I will not give a detailed section, because it would be essentially similar to that already given, and because the stratification is exceedingly complicated. After leaving the plutonic hills near the town, I met first, as in the main valley, with the gypseous formation, having the same diversified character as before, and soon afterwards with masses of porphyritic conglomerate, about one thousand feet in thickness. In the lower part of this formation there were very thick beds composed of fragments of claystone porphyries, both angular and rounded, with the smaller ones partially blended together and the basis rendered porphyritic; these beds separated distinct streams, from sixty to eighty feet in thickness, of claystone lavas. Near Paipote, also, there was much true porphyritic breccia-conglomerate: nevertheless, few of these masses were metamorphosed to the same degree with the corresponding formation in Central Chile. I did not meet in this valley with any true andesite, but only with imperfect andesitic porphyry, including large crystals of hornblende: numerous as have been the varieties of intrusive porphyries already mentioned, there were here mountains composed of a new kind, having a compact, smooth, cream-coloured basis, including only a few crystals of feldspar, and mottled with dendritic spots of oxide of iron. There were also some mountains of a porphyry with a brick-red basis, containing irregular, often lens-shaped, patches of compact feldspar, and crystals of feldspar, which latter to my surprise I find to be orthite.

At the foot of the first ridge of the main Cordillera, in the ravine of Maricongo, and at an elevation which, from the extreme coldness and appearance of the vegetation, I estimated at about ten thousand feet, I found beds of white sandstone and of limestone including the Pecten Dufreynoyi, Terebratula ænigma, and some Gryphites. This ridge throws the water on the one hand into the Pacific, and on the other, as I was informed, into a great gravel-covered, basin-like plain, including a salt-lake, and without any drainage-exit. In crossing the Cordillera by this Pass, it is said that three principal ridges must be traversed, instead of two, or only one as in Central Chile.

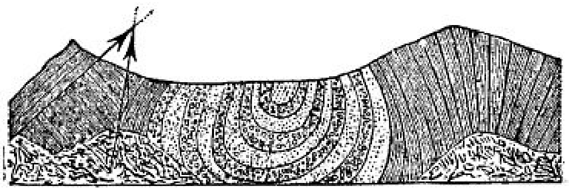
The crest of this first main ridge and the surrounding mountains, with the exception of a few lofty pinnacles, are capped by a great thickness of a horizontally stratified, tufaceous deposit. The lowest bed is of a pale purple colour, hard, fine-grained, and full of broken crystals of feldspar and scales of mica. The middle bed is coarser, and less hard, and hence weathers into very sharp pinnacles; it includes very small fragments of granite, and innumerable ones of all sizes of grey vesicular trachyte, some of which were distinctly rounded. The uppermost bed is about two hundred feet in thickness, of a darker colour and apparently hard: but I had not time to ascend to it. These three horizontal beds may be seen for the distance of many leagues, especially westward or in the direction of the Pacific, capping the summits of the mountains, and standing on the opposite sides of the immense valleys at exactly corresponding heights. If united they would form a plain, inclined very slightly towards the Pacific; the beds become thinner in this direction, and the tuff (judging from one point to which I ascended, some way down the valley) finer-grained and of less specific gravity, though still compact and sonorous under the hammer. The gently inclined, almost horizontal stratification, the presence of some rounded pebbles, and the compactness of the lowest bed, though rendering it probable, would not have convinced me that this mass had been of subaqueous origin, for it is known that volcanic ashes falling on land and moistened by rain often become hard and stratified; but beds thus originating, and owing their consolidation to atmospheric moisture, would have covered almost equally every neighbouring summit, high and low, and would not have left those above a certain exact level absolutely bare; this circumstance seems to me to prove that the volcanic ejections were arrested at their present, widely extended, equable level, and there consolidated by some other means than simple atmospheric moisture; and this no doubt must have been a sheet of water. A lake at this great height, and without a barrier on any one side, is out of the question; consequently we must conclude that the tufaceous matter was anciently deposited beneath the sea. It was certainly deposited before the excavation of the valleys, or at least before their final enlargement;[4] and I may add, that Mr. Lambert, a gentleman well acquainted with this country, informs me, that in ascending the ravine of Santandres (which branches off from the Despoblado) he met with streams of lava and much erupted matter capping all the hills of granite and porphyry, with the exception of some projecting points; he also remarked that the valleys had been excavated subsequently to these eruptions.

[4] I have endeavoured to show in my "Journal," etc. (2nd edit.), p. 355, that this arid valley was left by the retreating sea, as the land slowly rose, in the state in which we now see it.

This volcanic formation, which I am informed by Mr. Lambert extends far northward, is of interest, as typifying what has taken place on a grander scale on the corresponding western side of the Cordillera of Peru. Under another point of view, however, it possesses a far higher interest, as confirming that conclusion drawn from the structure of the fringes of stratified shingle which are prolonged from the plains at the foot of the Cordillera far up the valleys,—namely, that this great range has been elevated in mass to a height of between eight and nine thousand feet;[5] and now, judging from this tufaceous deposit, we may conclude that the horizontal elevation has been in the district of Copiapo about ten thousand feet.

[5] I may here mention that on the south side of the main valley of Copiapo, near Potrero Seco, the mountains are capped by a thick mass of horizontally stratified shingle, at a height which I estimated at between fifteen hundred and two thousand feet above the bed of the valley. This shingle, I believe, forms the edge of a wide plain, which stretches southwards between two mountain ranges.

No. 40



In the valley of the Despoblado, the stratification, as before remarked has been much disturbed, and in some points to a greater degree than I have anywhere else seen. I will give two cases: a very thick mass of thinly stratified red sandstone, including beds of conglomerate, has been crushed together (as represented in figure no. 24) into a yoke or urnformed trough, so that the strata on both sides have been folded inwards: on the right hand the properly underlying porphyritic claystone conglomerate is seen overlying the sandstone, but it soon becomes vertical, and then is inclined towards the trough, so that the beds radiate like the spokes of a wheel: on the left hand, the inverted porphyritic conglomerate also assumes a dip towards the trough, not gradually, as on the right hand, but by means of a vertical fault and synclinal break; and a little still further on towards the left, there is a second great oblique fault (both shown by the arrow-lines), with the strata dipping to a directly opposite point; these mountains are intersected by infinitely numerous dikes, some of which can be seen to rise from hummocks of greenstone, and can be traced for thousands of feet. In the second case, two low ridges trend together and unite at the head of a little wedge-shaped valley: throughout the right-hand ridge, the strata dip at 45° to the east; in the left-hand ridge, we have the very same strata and at first with exactly the same dip; but in following this ridge up the valley, the strata are seen very regularly to become more and more inclined until they stand vertical, they then gradually fall over (the basset edges forming symmetrical serpentine lines along the crest), till at the very head of the valley they are reversed at an angle of 45°: so that at this point the beds have been turned through an angle of 135°; and here there is a kind of anticlinal axis, with the strata on both sides dipping to opposite points at an angle of 45°, but those on the left hand upside down.

On the eruptive sources of the porphyritic claystone and greenstone lavas.—In Central Chile, from the extreme metamorphic action, it is in most parts difficult to distinguish between the streams of porphyritic lava and the porphyritic breccia-conglomerate, but here, at Copiapo, they are generally perfectly distinct, and in the Despoblado, I saw for the first time, two great strata of purple claystone porphyry, after having been for a considerable space closely united together, one above the other, become separated by a mass of fragmentary matter, and then both thin out;—the lower one more rapidly than the upper and greater stream. Considering the number and thickness of the streams of porphyritic lava, and the great thickness of the beds of breccia-conglomerate, there can be little doubt that the sources of eruption must originally have been numerous: nevertheless, it is now most difficult even to conjecture the precise point of any one of the ancient submarine craters. I have repeatedly observed mountains of porphyries, more or less distinctly stratified towards their summits or on their flanks, without a trace of stratification in their central and basal parts: in most cases, I believe this is simply due either to the obliterating effects of metamorphic action, or to such parts having been mainly formed of intrusive porphyries, or to both causes conjoined; in some instances, however, it appeared to me very probable that the great central unstratified masses of porphyry were the now partially denuded nuclei of the old submarine volcanoes, and that the stratified parts marked the points whence the streams flowed. In one case alone, and it was in this Valley of the Despoblado, I was able actually to trace a thick stratum of purplish porphyry, which for a space of some miles conformably overlay the usual alternating beds of breccia-conglomerates and claystone lavas, until it became united with, and blended into, a mountainous mass of various unstratified porphyries.

The difficulty of tracing the streams of porphyries to their ancient and doubtless numerous eruptive sources, may be partly explained by the very general disturbance which the Cordillera in most parts has suffered; but I strongly suspect that there is a more specific cause, namely, *that the original points of eruption tend to become the points of injection.* This in itself does not seem improbable; for where the earth’s crust has once yielded, it would be liable to yield again, though the liquified intrusive matter might not be any longer enabled to reach the submarine surface and flow as lava. I have been led to this conclusion, from having so frequently observed that, where part of an unstratified mountain-mass resembled in mineralogical character the adjoining streams or strata, there were several other kinds of intrusive porphyries and andesitic rocks injected into the same point. As these intrusive mountain-masses form most of the axes-lines in the Cordillera, whether anticlinal, uniclinal, or synclinal, and as the main valleys have generally been hollowed out along these lines, the intrusive masses have generally suffered much denudation. Hence they are apt to stand in some degree isolated, and to be situated at the points where the valleys abruptly bend, or where the main tributaries enter. On this view of there being a tendency in the old points of eruption to become the points of subsequent injection and disturbance, and consequently of denudation, it ceases to be surprising that the streams of lava in the porphyritic claystone conglomerate formation, and in other analogous cases, should most rarely be traceable to their actual sources.

Iquique, Southern Peru.—Differently from what we have seen throughout Chile, the coast here is formed not by the granitic series, but by an escarpment of the porphyritic conglomerate formation, between two and three thousand feet in height.[6] I had time only for a very short examination; the chief part of the escarpment appears to be composed of various reddish and purple, sometimes laminated, porphyries, resembling those of Chile; and I saw some of the porphyritic breccia-conglomerate; the stratification appeared but little inclined. The uppermost part, judging from the rocks near the famous silver mine of Huantajaya,[7]consists of laminated, impure, argillaceous, purplish-grey limestone, associated, I believe, with some purple sandstone. In the limestone shells are found: the three following species were given me:—

Lucina Americana, E. Forbes.
Terebratula inca, E. Forbes.
Terebratula ænigma, D'Orbigny.

[6] The lowest point, where the road crosses the coast-escarpment, is 1,900 feet by the barometer above the level of the sea.

[7] Mr. Bollaert has described ("Geolog. Proceedings," vol. ii, p. 598, a singular mass of stratified detritus, gravel, and sand, eighty-one yards in thickness, overlying the limestone, and abounding with loose masses of silver ore. The miners believe that they can attribute these masses to their proper veins.

This latter species we have seen associated with the fossils of which lists have been given in this chapter, in two places in the valley of Coquimbo, and in the ravine of Maricongo at Copiapo. Considering this fact, and the superposition of these beds on the porphyritic conglomerate formation; and, as we shall immediately see, from their containing much gypsum, and from their otherwise close general resemblance in mineralogical nature with the strata described in the valley of Copiapo, I have little doubt that these fossiliferous beds of Iquique belong to the great cretaceo-oolitic formation of Northern Chile. Iquique is situated seven degrees latitude north of Copiapo; and I may here mention, that an Ammonites, nov. species, and an Astarte, nov. species, were given me from the Cerro Pasco, about ten degrees of latitude north of Iquique, and M. D'Orbigny thinks that they probably indicate a Neocomian formation. Again, fifteen degrees of latitude northward, in Colombia, there is a grand fossiliferous deposit, now well known from the labours of Von Buch, Lea, d'Orbigny, and Forbes, which belongs to the earlier stages of the cretaceous system. Hence, bearing in mind the character of the few fossils from Tierra del Fuego, there is some evidence that a great portion of the stratified deposits of the whole vast range of the South American Cordillera belongs to about the same geological epoch.

Proceeding from the coast escarpment inwards, I crossed, in a space of about thirty miles, an elevated undulatory district, with the beds dipping in various directions. The rocks are of many kinds,—white laminated, sometimes siliceous sandstone,—purple and red sandstone, sometimes so highly calcareous as to have a crystalline fracture,—argillaceous limestone,—black calcareous slate-rock, like that so often described at Copiapo and other places,—thinly laminated, fine-grained, greenish, indurated, sedimentary, fusible rocks, approaching in character to the so-called pseudo-honestone of Chile, including thin contemporaneous veins of gypsum,—and lastly, much calcareous, laminated porcelain jasper, of a green colour, with red spots, and of extremely easy fusibility: I noticed one conformable stratum of a freckled-brown, feldspathic lava. I may here mention that I heard of great beds of gypsum in the Cordillera. The only novel point in this formation, is the presence of innumerable thin layers of rock-salt, alternating with the laminated and hard, but sometimes earthy, yellowish, or bright red and ferruginous sandstones. The thickest layer of salt was only two inches, and it thinned out at both ends. On one of these saliferous masses I noticed a stratum about twelve feet thick, of dark-brown, hard brecciated, easily fusible rock, containing grains of quartz and of black oxide of iron, together with numerous imperfect fragments of shells. The problem of the origin of salt is so obscure, that every fact, even geographical position, is worth recording.[8] With the exception of these saliferous beds, most of the rocks as already remarked, present a striking general resemblance with the upper parts of the gypseous or cretaceo-oolitic formation of Chile.

[8] It is well known that stratified salt is found in several places on the shores of Peru. The island of San Lorenzo, off Lima, is

composed of a pile of thin strata, about eight hundred feet in thickness, composed of yellowish and purplish, hard siliceous, or earthy sandstones, alternating with thin layers of shale, which in places passes into a greenish, semi-porcellanic, fusible rock. There are some thin beds of reddish mudstone, and soft ferruginous rotten-stones, with layers of gypsum. In nearly all these varieties, especially in the softer sandstones, there are numerous thin seams of rock-salt: I was informed that one layer has been found two inches in thickness. The manner in which the minutest fissures of the dislocated beds have been penetrated by the salt, apparently by subsequent infiltration, is very curious. On the south side of the island, layers of coal and of impure limestone have been discovered. Hence we here have salt, gypsum, and coal associated together. The strata include veins of quartz, carbonate of lime, and iron pyrites; they have been dislocated by an injected mass of greenish-brown feldspathic trap.

Not only is salt abundant on the extreme western limits of the district between the Cordillera and the Pacific, but, according to Helms, it is found in the outlying low hills on the eastern flank of the Cordillera. These facts appear to me opposed to the theory, that rock-salt is due to the sinking of water, charged with salt, in mediterranean spaces of the ocean. The general character of the geology of these countries would rather lead to the opinion, that its origin is in some way connected with volcanic heat at the bottom of the sea: see on this subject Sir R. Murchison's "Anniversary Address to Geolog. Soc., 1843," p. 65.)

Metalliferous Veins.

I have only a few remarks to make on this subject: in nine mining districts, some of them of considerable extent, which I visited in *Central* Chile, I found the *principal* veins running from between [N. and N.W.] to [S. and S.E.];[9] at the C. de los Hornos (further northward), it is N.N.W. and S.S.E.; at Panuncillo, it is N.N.W. and S.S.E.; and, lastly, at Arqueros, the direction is N.W. and S.E.): in some other places, however, their courses appeared quite irregular, as is said to be generally the case in the whole valley of Copiapo: at Tambillos, south of Coquimbo, I saw one large copper vein extending east and west. It is worthy of notice, that the foliation of the gneiss and mica-slate, where such rocks occur, certainly tend to run like the metalliferous veins, though often irregularly, in a direction a little westward of north. At Yaquil, I observed that the principal auriferous veins ran nearly parallel to the grain or imperfect cleavage of the surrounding *granitic* rocks. With respect to the distribution of the different metals, copper, gold, and iron are generally associated together, and are most frequently found (but with many exceptions, as we shall presently see) in the rocks of the lower series, between the Cordillera and the Pacific, namely, in granite, syenite, altered feldspathic clay-slate, gneiss, and as near Guasco mica-schist. The copper-ores consist of sulphurets, oxides, and carbonates, sometimes with laminæ of native metal: I was assured that in some cases (as at Panuncillo S.E. of Coquimbo), the upper part of the same vein contains oxides, and the lower part sulphurets of copper.[10] Gold occurs in its native form; it is believed that, in many cases, the upper part of the vein is the most productive part: this fact probably is connected with the abundance of this metal in the stratified detritus of Chile, which must have been chiefly derived from the degradation of the upper portions of the rocks. These superficial beds of well-rounded gravel and sand, containing gold, appeared to me to have been formed under the sea close to the beach, during the slow elevation of the land: Schmidtmeyer[11] remarks that in Chile gold is sought for in shelving banks at the height of some feet on the sides of the streams, and not in their beds, as would have been the case had this metal been deposited by common alluvial action. Very frequently the copper-ores, including some gold, are associated with abundant micaceous specular iron. Gold is often found in iron-pyrites: at two gold mines at Yaquil (near Nancagua), I was informed by the proprietor that in one the gold was always associated with copper-pyrites, and in the other with iron-pyrites: in this latter case, it is said that if the vein ceases to contain iron-pyrites, it is yet worth while to continue the search, but if the iron-pyrites, when it reappears, is not auriferous, it is better at once to give up working the vein. Although I believe copper and gold are most frequently found in the lower granitic and metamorphic schistose series, yet these metals occur both in the porphyritic conglomerate formation (as on the flanks of the Bell of Quillota and at Jajuel), and in the superincumbent strata. At Jajuel I was informed that the copper-ore, with some gold, is found only in the greenstones and altered feldspathic clay-slate, which alternate with the purple porphyritic conglomerate. Several gold veins and some of copper-ore are worked in several parts of the Uspallata range, both in the metamorphosed strata, which have been shown to have been of probably subsequent origin to the Neocomian or gypseous formation of the main Cordillera, and in the intrusive andesitic rocks of that range. At Los Hornos (N.E. of Illapel), likewise, there are numerous veins of copper-pyrites and of gold, both in the strata of the gypseous formation and in the injected hills of andesite and various porphyries.

[9] These mining districts are Yaquil near Nancagua, where the direction of the chief veins, to which only in all cases I refer, is north and south; in the Uspallata range, the prevailing line is N.N.W. and S.S.E.; in the C. de Prado, it is N.N.W. and S.S.E.; near Illapel, it is N. by W. and S. by E.; at Los Hornos the direction varies from between [N. and N.W.] to [S. and S.E.].

[10] The same fact has been observed by Mr. Taylor in Cuba: *London Phil. Journ.,* vol. xi, p. 21.

[11] "Travels in Chile," p. 29.

Silver, in the form of a chloride, sulphuret, or an amalgam, or in its native state, and associated with lead and other metals, and at Arqueros with pure native copper, occurs chiefly in the upper great gypseous or cretaceo-oolitic formation which forms probably the richest mass in Chile. We may instance the mining districts of Arqueros near Coquimbo, and of nearly the whole valley of Copiapo, and of Iquique (where the principal veins run N.E. by E. and S.W. by W.), in Peru. Hence comes Molina's remark, that silver is born in the cold and solitary deserts of the Upper Cordillera. There are, however, exceptions to this rule: at Paral (S.E. of Coquimbo) silver is found in the porphyritic conglomerate formation; as I suspect is likewise the case at S. Pedro de Nolasko in the Peuquenes Pass. Rich argentiferous lead is found in the clay-slate of the Uspallata range; and I saw an old silver-mine in a hill of syenite at the foot of the Bell of Quillota: I was also assured that silver has been found in the andesitic and porphyritic region between the town of Copiapo and the Pacific. I have stated in a previous part of this chapter, that in two neighbouring mines at Arqueros the veins in one were productive when they traversed the singular green sedimentary beds, and unproductive when crossing the reddish beds; whereas at the other mine exactly the reverse takes place; I have also described the singular and rare case of numerous particles of native silver and of the chloride being disseminated in the green rock at the distance of a yard from the vein. Mercury occurs with silver both at Arqueros and at Copiapo: at the base of C. de los Hornos (S.E. of Coquimbo, a different place from Los Hornos, before mentioned) I saw in a syenitic rock numerous quartzose veins, containing a little cinnabar in nests: there were here other parallel veins of copper and of a ferrugino-auriferous ore. I believe tin has never been found in Chile.

From information given me by Mr. Nixon of Yaquil,[12] and by others, it appears that in Chile those veins are generally most permanently productive, which, consisting of various minerals (sometimes differing but slightly from the surrounding rocks), include parallel strings *rich* in metals; such a vein is called a *veta real.* More commonly the mines are worked only where one, two, or more thin veins or strings running in a different direction, intersect a *poor* "veta real:" it is unanimously believed that at such points of intersection (*cruceros*), the quantity of metal is much greater than that contained in other parts of the intersecting veins. In some *cruceros* or points of intersection, the metals extend even beyond the walls of the main, broad, stony vein. It is said that the greater the angle of intersection, the greater the produce; and that nearly parallel strings attract each other; in the Uspallata range, I observed that numerous thin auri-ferruginous veins repeatedly ran into knots, and then branched out again. I have already described the remarkable manner in which rocks of the Uspallata range are indurated and blackened (as if by a blast of gunpowder) to a considerable distance from the metallic veins.

[12] At the Durazno mine, the gold is associated with copper-pyrites, and the veins contain large prisms of plumbago. Crystallised carbonate of lime is one of the commonest minerals in the matrix of the Chilean veins.

Finally, I may observe, that the presence of metallic veins seems obviously connected with the presence of intrusive rocks, and with the degree of metamorphic action which the different districts of Chile have undergone.[13] Such metamorphosed areas are generally accompanied by numerous dikes and injected masses of andesite and various porphyries: I have in several places traced the metalliferous veins from the intrusive masses into the encasing strata. Knowing that the porphyritic conglomerate formation consists of alternate streams of submarine lavas and of the debris of anciently erupted rocks, and that the strata of the upper gypseous formation sometimes include submarine lavas, and are composed of tuffs, mudstones, and mineral substances, probably due to volcanic exhalations,—the richness of these strata is highly remarkable when compared with the erupted beds, often of submarine origin, but *not metamorphosed,* which compose the numerous islands in the Pacific, Indian, and Atlantic Oceans; for in these islands metals are entirely absent, and their nature even unknown to the aborigines.

[13] Sir R. Murchison and his fellow travellers have given some striking facts on this subject in their account of the Ural Mountains ("Geolog. Proc.," vol. iii, p. 748.

Summary of the Geological History of the Chilean Cordillera, and of the Southern Parts of South America.

We have seen that the shores of the Pacific, for a space of 1,200 miles from Tres Montes to Copiapo, and I believe for a very much greater distance, are composed, with the exception of the tertiary basins, of metamorphic schists, plutonic rocks, and more or less altered clay-slate. On the floor of the ocean thus constituted, vast streams of various purplish claystone and greenstone porphyries were poured forth, together with great alternating piles of angular and rounded fragments of similar rocks ejected from the submarine craters. From the compactness of the streams and fragments, it is probable that, with the exception of some districts in Northern Chile, the eruptions took place in profoundly deep water. The orifices of eruption appear to have been studded over a breadth, with some outliers, of from fifty to one hundred miles: and closely enough together, both north and south, and east and west, for the ejected matter to form a continuous mass, which in Central Chile is more than a mile in thickness. I traced this mould-like mass, for only 450 miles; but judging from what I saw at Iquique, from specimens, and from published accounts, it appears to have a manifold greater length. In the basal parts of the series, and especially towards the flanks of the range, mud, since converted into a feldspathic slaty rock, and sometimes into greenstone, was occasionally deposited between the beds of erupted matter: with this exception the uniformity of the porphyritic rocks is very remarkable. At the period when the claystone and greenstone porphyries nearly or quite ceased being erupted, that great pile of strata which, from often abounding with gypsum, I have generally called the gypseous formation was deposited, and feldspathic lavas, together with other singular volcanic rocks, were occasionally poured forth: I am far from pretending that any distinct line of demarcation can be drawn between this formation and the underlying porphyries and porphyritic conglomerate, but in a mass of such great thickness, and between beds of such widely different mineralogical nature, some division was necessary. At about the commencement of the gypseous period, the bottom of the sea here seems first to have been peopled by shells, not many in kind, but abounding in individuals. At the P. del Inca the fossils are embedded near the base of the formation; in the Peuquenes range, at different levels, halfway up, and even higher in the series; hence, in these sections, the whole pile of strata belongs to the same period: the same remark is applicable to the beds at Copiapo, which attain a thickness of between seven and eight thousand feet. The fossil shells in the Cordillera of Central Chile, in the opinion of all the palæontologists who have examined them, belong to the earlier stages of the cretaceous system; whilst in Northern Chile there is a most singular mixture of cretaceous and oolitic forms: from the geological relations, however, of these two districts, I cannot but think that they all belong to nearly the same epoch, which I have provisionally called cretaceo-oolitic.

The strata in this formation, composed of black calcareous shaly-rocks of red and white, and sometimes siliceous sandstone, of coarse conglomerates, limestones, tuffs, dark mudstones, and those singular fine-grained rocks which I have called pseudo-honestones, vast beds of gypsum, and many other jaspery and scarcely describable varieties, vary and replace each other in short horizontal distances, to an extent, I believe, unequalled even in any tertiary basin. Most of these substances are easily fusible, and have apparently been derived either from volcanoes still in quiet action, or from the attrition of volcanic products. If we picture to ourselves the bottom of the sea, rendered uneven in an extreme degree, with numerous craters, some few occasionally in eruption, but the greater number in the state of solfataras, discharging calcareous, siliceous, ferruginous matters, and gypsum or sulphuric acid to an amount surpassing, perhaps, even the existing sulphureous volcanoes of Java,[14] we shall probably understand the circumstances under which this singular pile of varying strata was accumulated. The shells appear to have lived at the quiescent periods when only limestone or calcareo-argillaceous matter was depositing. From Dr. Gillies' account, this gypseous or cretaceo-oolitic formation extends as far south as the Pass of Planchon, and I followed it northward at intervals for 500 miles: judging from the character of the beds with the *Terebratula ænigma,* at Iquique, it extends from four to five hundred miles further: and perhaps even for ten degrees of latitude north of Iquique to the Cerro Pasco, not far from Lima: again, we know that a cretaceous formation, abounding with fossils, is largely developed north of the equator, in Colombia: in Tierra del Fuego, at about this same period, a wide district of clay-slate was deposited, which in its mineralogical characters and external features, might be compared to the Silurian regions of North Wales. The gypseous formation, like that of the porphyritic breccia-conglomerate on which it rests, is of inconsiderable breadth; though of greater breadth in Northern than in Central Chile.

[14] Von Buch's "Descript. Physique des Iles Canaries," p. 428.

As the fossil shells in this formation are covered, in the Peuquenes ridge, by a great thickness of strata; at the Puente del Inca, by at least five thousand feet; at Coquimbo, though the superposition there is less plainly seen, by about six thousand feet; and at Copiapo, certainly by five or six thousand, and probably by seven thousand feet (the same species there recurring in the upper and lower parts of the series), we may feel confident that the bottom of the sea subsided during this cretaceo-oolitic period, so as to allow of the accumulation of the superincumbent submarine strata. This conclusion is confirmed by, or perhaps rather explains, the presence of the many beds at many levels of coarse conglomerate, the well-rounded pebbles in which we cannot believe were transported in very deep water. Even the underlying porphyries at Copiapo. with their highly amygdaloidal surfaces, do not appear to have flowed under great pressure. The great sinking movement thus plainly indicated, must have extended in a north and south line for at least four hundred miles, and probably was co-extensive with the gypseous formation.

The beds of conglomerate just referred to, and the extraordinarily numerous silicified trunks of fir-trees at Los Hornos, perhaps at Coquimbo and at two distant points in the valley of Copiapo, indicate that land existed at this period in the neighbourhood. This land, or islands, in the northern part of the district of Copiapo, must have been almost exclusively composed, judging from the nature of the pebbles of granite: in the southern parts of Copiapo, it must have been mainly formed of claystone porphyries, with some mica-schist, and with much sandstone and jaspery rocks exactly like the rocks in the gypseous formation, and no doubt belonging to its basal series. In several other places also, during the accumulation of the gypseous formation, its basal parts and the underlying porphyritic conglomerate must likewise have been already partially upheaved and exposed to wear and tear; near the Puente del Inca and at Coquimbo, there must have existed masses of mica-schist or some such rock, whence were derived the many small pebbles of opaque quartz. It follows from these facts, that in some parts of the Cordillera the upper beds of the gypseous formation must lie unconformably on the lower beds; and the whole gypseous formation, in parts, unconformably on the porphyritic conglomerate; although I saw no such cases, yet in many places the gypseous formation is entirely absent; and this, although no doubt generally caused by quite subsequent denudation, may in others be due to the underlying porphyritic conglomerate having been locally upheaved before the deposition of the gypseous strata, and thus having become the source of the pebbles of porphyry embedded in them. In the porphyritic conglomerate formation, in its lower and middle parts, there is very rarely any evidence, with the exception of the small quartz pebbles at Jajuel near Aconcagua, and of the single pebble of granite at Copiapo, of the existence of neighbouring land: in the upper parts, however, and especially in the district of Copiapo, the number of thoroughly well-rounded pebbles of compact porphyries make me believe, that, as during the prolonged accumulation of the gypseous formation the lower beds had already been locally upheaved and exposed to wear and tear, so it was with the porphyritic conglomerate. Hence in following thus far the geological history of the Cordillera, it may be inferred that the bed of a deep and open, or nearly open, ocean was filled up by porphyritic eruptions, aided probably by some general and some local elevations, to that comparatively shallow level at which the cretaceo-oolitic shells first lived. At this period, the submarine craters yielded at intervals a prodigious supply of gypsum and other mineral exhalations, and occasionally, in certain places poured forth lavas, chiefly of a feldspathic nature: at this period, islands clothed with fir-trees and composed of porphyries, primary rocks, and the lower gypseous strata had already been locally upheaved, and exposed to the action of the waves;—the general movement, however, at this time having been over a very wide area, one of slow subsidence, prolonged till the bed of the sea sank several thousand feet.

In Central Chile, after the deposition of a great thickness of the gypseous strata, and after their upheaval, by which the Cumbre and adjoining ranges were formed, a vast pile of tufaceous matter and submarine lava was accumulated, where the Uspallata chain now stands; also after the deposition and upheaval of the equivalent gypseous strata of the Peuquenes range, the great thick mass of conglomerate in the valley of Tenuyan was accumulated: during the deposition of the Uspallata strata, we know absolutely, from the buried vertical trees, that there was a subsidence of some thousand feet; and we may infer from the nature of the conglomerate in the valley of Tenuyan, that a similar and perhaps contemporaneous movement there took place. We have, then, evidence of a second great period of subsidence; and, as in the case of the subsidence which accompanied the accumulation of the cretaceo-oolitic strata, so this latter subsidence appears to have been complicated by alternate or local elevatory movement— for the vertical trees, buried in the midst of the Uspallata strata, must have grown on dry land, formed by the upheaval of the lower submarine beds. Presently I shall have to recapitulate the facts, showing that at a still later period, namely, at nearly the commencement of the old tertiary deposits of Patagonia and of Chile, the continent stood at nearly its present level, and then, for the third time, slowly subsided to the amount of several hundred feet, and was afterwards slowly re-uplifted to its present level.

The highest peaks of the Cordillera appear to consist of active or more commonly dormant volcanoes,—such as Tupungato, Maypu, and Aconcagua, which latter stands 23,000 feet above the level of the sea, and many others. The next highest peaks are formed of the gypseous and porphyritic strata, thrown into vertical or highly inclined positions. Besides the elevation thus gained by angular displacements, I infer, without any hesitation—from the stratified gravel-fringes which gently slope up the valleys of the Cordillera from the gravel-capped plains at their base, which latter are connected with the plains, still covered with recent shells on the coast—that this great range has been upheaved in mass by a slow movement, to an amount of at least 8,000 feet. In the Despoblado Valley, north of Copiapo, the horizontal elevation, judging from the compact, stratified tufaceous deposit, capping the distant mountains at corresponding heights, was about ten thousand feet. It is very possible, or rather probable, that this elevation in mass may not have been strictly horizontal, but more energetic under the Cordillera, than towards the coast on either side; nevertheless, movements of this kind may be conveniently distinguished from those by which strata have been abruptly broken and upturned. When viewing the Cordillera, before having read Mr. Hopkins's profound "Researches on Physical Geology," the conviction was impressed on me, that the angular dislocations, however violent, were quite subordinate in importance to the great upward movement in mass, and that they had been caused by the edges of the wide fissures, which necessarily resulted from the tension of the elevated area, having yielded to the inward rush of fluidified rock, and having thus been upturned.

The ridges formed by the angularly upheaved strata are seldom of great length: in the central parts of the Cordillera they are generally parallel to each other, and run in north and south lines; but towards the flanks they often extend more or less obliquely. The angular displacement has been much more violent in the central than in the exterior *main* lines; but it has likewise been violent in some of the *minor* lines on the extreme flanks. The violence has been very unequal on the same short lines; the crust having apparently tended to yield on certain points along the lines of fissures. These points, I have endeavoured to show, were probably first foci of eruption, and afterwards of injected masses of porphyry and andesite.[15] The close similarity of the andesitic granites and porphyries, throughout Chile, Tierra del Fuego, and even in Peru, is very remarkable. The prevalence of feldspar cleaving like albite, is common not only to the andesites, but (as I infer from the high authority of Professor G. Rose, as well as from my own measurements) to the various claystone and greenstone porphyries, and to the trachytic lavas of the Cordillera. The andesitic rocks have in most cases been the last injected ones, and they probably form a continuous dome under this great range: they stand in intimate relationship with the modern lavas; and they seem to have been the immediate agent in metamorphosing the porphyritic conglomerate formation, and often likewise the gypseous strata, to the extraordinary extent to which they have suffered.

[15] Sir R. Murchison and his companions state ("Geolog. Proc.," vol. iii, p. 747), that no true granite appears in the higher Ural Mountains; but that syenitic greenstone—a rock closely analogous to our andesite—is far the most abundant of the intrusive masses.

With respect to the age at which the several parallel ridges composing the Cordillera were upthrown, I have little evidence. Many of them may have been contemporaneously elevated and injected in the same manner[16] as in volcanic archipelagoes lavas are contemporaneously ejected on the parallel lines of fissure. But the pebbles apparently derived from the wear and tear of the porphyritic conglomerate formation, which are occasionally present in the upper parts of this same formation, and are often present in the gypseous formation, together with the pebbles from the basal parts of the latter formation in its upper strata, render it almost certain that portions, we may infer ridges, of these two formations were successively upheaved. In the case of the gigantic Portillo range, we may feel almost certain that a preexisting granitic line was upraised (not by a single blow, as shown by the highly inclined basaltic streams in the valley on its eastern flank) at a period long subsequent to the upheavement of the parallel Peuquenes range.[17] Again, subsequently to the upheavement of the Cumbre chain, that of Uspallata was formed and elevated; and afterwards, I may add, in the plain of Uspallata, beds of sand and gravel were violently upthrown. The manner in which the various kinds of porphyries and andesites have been injected one into the other, and in which the infinitely numerous dikes of various composition intersect each other, plainly show that the stratified crust has been stretched and yielded many times over the same points. With respect to the age of the axes of elevation between the Pacific and the Cordillera, I know little: but there are some lines which must—namely, those running north and south in Chiloe, those eight or nine east and west, parallel, far-extended, most symmetrical uniclinal lines at P. Rumena, and the short N.W.-S.E. and N.E.-S.W. lines at Concepcion—have been upheaved long after the formation of the Cordillera. Even during the earthquake of 1835, when the linear north and south islet of St. Mary was uplifted several feet above the surrounding area, we perhaps see one feeble step in the formation of a subordinate mountain-axis. In some cases, moreover, for instance, near the baths of Cauquenes, I was forcibly struck with the small size of the breaches cut through the exterior mountain-ranges, compared with the size of the same valleys higher up where entering the Cordillera; and this circumstance appeared to me scarcely explicable, except on the idea of the exterior lines having been subsequently upthrown, and therefore having been exposed to a less amount of denudation. From the manner in which the fringes of gravel are prolonged in unbroken slopes up the valleys of the Cordillera, I infer that most of the greater dislocations took place during the earlier parts of the great elevation in mass: I have, however, elsewhere given a case, and M. de Tschudi[18] has given another, of a ridge thrown up in Peru across the bed of a river, and consequently after the final elevation of the country above the level of the sea.

[16] "Volcanic Islands," etc.)

[17] I have endeavoured to show in my "Journal" (2nd edit., p. 321), that the singular fact of the river, which drains the valley between these two ranges, passing through the Portillo and higher line, is explained by its slow and subsequent elevation. There are many analogous cases in the drainage of rivers: see *Edinburgh New Phil. Journal,* vol. xxviii, pp. 33 and 44.

[18] "Reise in Peru," Band 2, s. 8: Author's "Journal," 2nd edit., p. 359.

Ascending to the older tertiary formations, I will not again recapitulate the remarks already given at the end of the Fifth Chapter,—on their great extent, especially along the shores of the Atlantic—on their antiquity, perhaps corresponding with that of the eocene deposits of Europe,—on the almost entire dissimilarity, though the formations are apparently contemporaneous, of the fossils from the eastern and western coasts, as is likewise the case, even in a still more marked degree, with the shells now living in these opposite though approximate seas,—on the climate of this period not having been more tropical than what might have been expected from the latitudes of the places under which the deposits occur; a circumstance rendered well worthy of notice, from the contrast with what is known to have been the case during the older tertiary periods of Europe, and likewise from the fact of the southern hemisphere having suffered at a much later period, apparently at the same time with the northern hemisphere, a colder or more equable temperature, as shown by the zones formerly affected by ice-action. Nor will I recapitulate the proofs of the bottom of the sea, both on the eastern and western coast, having subsided seven or eight hundred feet during this tertiary period; the movement having apparently been co-extensive, or nearly co-extensive, with the deposits of this age. Nor will I again give the facts and reasoning on which the proposition was founded, that when the bed of the sea is either stationary or rising, circumstances are far less favourable than when its level is sinking, to the accumulation of conchiferous deposits of sufficient thickness, extension, and hardness to resist, when upheaved, the ordinary vast amount of denudation. We have seen that the highly remarkable fact of the absence of any *extensive* formations containing recent shells, either on the eastern or western coasts of the continent,—though these coasts now abound with living mollusca,—though they are, and apparently have always been, as favourable for the deposition of sediment as they were when the tertiary formations were copiously deposited,—and though they have been upheaved to an amount quite sufficient to bring up strata from the depths the most fertile for animal life—can be explained in accordance with the above proposition. As a deduction, it was also attempted to be shown, first, that the want of close sequence in the fossils of successive formations, and of successive stages in the same formation, would follow from the improbability of the same area continuing slowly to subside from one whole period to another, or even during a single entire period; and secondly, that certain epochs having been favourable at distant points, in the same quarter of the world for the synchronous accumulation of fossiliferous strata, would follow from movements of subsidence having apparently, like those of elevation, contemporaneously affected very large areas.

There is another point which deserves some notice, namely, the analogy between the upper parts of the Patagonian tertiary formation, as well as of the upper possibly contemporaneous beds at Chiloe and Concepcion, with the great gypseous formation of Cordillera; for in both formations, the rocks, in their fusible nature, in their containing gypsum, and in many other characters, show a connection, either intimate or remote, with volcanic action; and as the strata in both were accumulated during subsidence, it appears at first natural to connect this sinking movement with a state of high activity in the neighbouring volcanoes. During the cretaceo-oolitic period this certainly appears to have been the case at the Puente del Inca, judging from the number of intercalated lava-streams in the lower 3,000 feet of strata; but generally, the volcanic orifices seem at this time to have existed as submarine solfataras, and were certainly quiescent compared with their state during the accumulation of the porphyritic conglomerate formation. During the deposition of the tertiary strata we know that at S. Cruz, deluges of basaltic lava were poured forth; but as these lie in the upper part of the series, it is possible that the subsidence may at that time have ceased: at Chiloe, I was unable to ascertain to what part of the series the pile of lavas belonged. The Uspallata tuffs and great streams of submarine lavas, were probably intermediate in age between the cretaceo-oolitic and older tertiary formations, and we know from the buried trees that there was a great subsidence during their accumulation; but even in this case, the subsidence may not have been strictly contemporaneous with the great volcanic eruptions, for we must believe in at least one intercalated period of elevation, during which the ground was upraised on which the now buried trees grew. I have been led to make these remarks, and to throw some doubt on the strict contemporaneousness of high volcanic activity and movements of subsidence, from the conviction impressed on my mind by the study of coral formations,[19] that these two actions do not generally go on synchronously;—on the contrary, that in volcanic districts, subsidence ceases as soon as the orifices burst forth into renewed action, and only recommences when they again have become dormant.

[19] “The Structure, etc., of Coral Reefs.”

At a later period, the Pampean mud, of estuary origin, was deposited over a wide area,—in one district conformably on the underlying old tertiary strata, and in another district unconformably on them, after their upheaval and denudation. During and before the accumulation, however, of these old tertiary strata, and, therefore, at a very remote period, sediment, strikingly resembling that of the Pampas, was deposited; showing during how long a time in this case the same agencies were at work in the same area. The deposition of the Pampean estuary mud was accompanied, at least in the southern parts of the Pampas, by an elevatory movement, so that the M. Hermoso beds probably were accumulated after the upheaval of those round the S. Ventana; and those at P. Alta after the upheaval of the M. Hermoso strata; but there is some reason to suspect that one period of subsidence intervened, during which mud was deposited over the coarse sand of the Barrancas de S. Gregorio, and on the higher parts of Banda Oriental. The mammiferous animals characteristic of this formation, many of which differ as much from the present inhabitants of South America, as do the eocene mammals of Europe from the present ones of that quarter of the globe, certainly co-existed at B. Blanca with twenty species of mollusca, one balanus, and two corals, all now living in the adjoining sea: this is likewise the case in Patagonia with the Macrauchenia, which co-existed with eight shells, still the commonest kinds on that coast. I will not repeat what I have elsewhere said, on the place of habitation, food, wide range, and extinction of the numerous gigantic mammifers, which at this late period inhabited the two Americas.

The nature and grouping of the shells embedded in the old tertiary formations of Patagonia and Chile show us, that the continent at that period must have stood only a few fathoms below its present level, and that afterwards it subsided over a wide area, seven or eight hundred feet. The manner in which it has since been rebrought up to its actual level, was described in detail in the First and Second Chapters. It was there shown that recent shells are found on the shores of the Atlantic, from Tierra del Fuego northward for a space of at least 1,180 nautical miles, and at the height of about 100 feet in La Plata, and of 400 feet in Patagonia. The elevatory movements on this side of the continent have been slow; and the coast of Patagonia, up to the height in one part of 950 feet and in another of 1,200 feet, is modelled into eight great, step-like, gravel-capped plains, extending for hundreds of miles with the same heights; this fact shows that the periods of denudation (which, judging from the amount of matter removed, must have been long continued) and of elevation were synchronous over surprisingly great lengths of coasts. On the shores of the Pacific, upraised shells of recent species, generally, though not always, in the same proportional numbers as in the adjoining sea, have actually been found over a north and south space of 2,075 miles, and there is reason to believe that they occur over a space of 2,480 miles. The elevation on this western side of the continent has not been equable; at Valparaiso, within the period during which upraised shells have remained undecayed on the surface, it has been 1,300 feet, whilst at Coquimbo, 200 miles northward, it has been within this same period only 252 feet. At Lima, the land has been uplifted at least 80 feet since Indian man inhabited that district; but the level within historical times apparently has subsided. At Coquimbo, in a height of 364 feet, the elevation has been interrupted by five periods of comparative rest. At several places the land has been lately, or still is, rising both insensibly and by sudden starts of a few feet during earthquake-shocks; this shows that these two kinds of upward movement are intimately connected together. For a space of 775 miles, upraised recent shells are found on the two opposite sides of the continent; and in the southern half of this space, it may be safely inferred from the slope of the land up to the Cordillera, and from the shells found in the central part of Tierra del Fuego, and high up the River Santa Cruz, that the entire breadth of the continent has been uplifted. From the general occurrence on both coasts of successive lines of escarpments, of sand-dunes and marks of erosion, we must conclude that the elevatory movement has been normally interrupted by periods, when the land either was stationary, or when it rose at so slow a rate as not to resist the average denuding power of the waves, or when it subsided. In the case of the present high sea-cliffs of Patagonia and in other analogous instances, we have seen that the difficulty in understanding how strata can be removed at those depths under the sea, at which the currents and oscillations of the water are depositing a smooth surface of mud, sand, and sifted pebbles, leads to the suspicion that the formation or denudation of such cliffs has been accompanied by a sinking movement.

In South America, everything has taken place on a grand scale, and all geological phenomena are still in active operation. We know how violent at the present day the earthquakes are, we have seen how great an area is now rising, and the plains of tertiary origin are of vast dimensions; an almost straight line can be drawn from Tierra del Fuego for 1,600 miles northward, and probably for a much greater distance, which shall intersect no formation older than the Patagonian deposits; so equable has been the upheaval of the beds, that throughout this long line, not a fault in the stratification or abrupt dislocation was anywhere observable. Looking to the basal, metamorphic, and plutonic rocks of the continent, the areas formed of them are likewise vast; and their planes of cleavage and foliation strike over surprisingly great spaces in uniform directions. The Cordillera, with its pinnacles here and there rising upwards of twenty thousand feet above the level of the sea, ranges in an unbroken line from Tierra del Fuego, apparently to the Arctic circle. This grand range has suffered both the most violent dislocations, and slow, though grand, upward and downward movements in mass; I know not whether the spectacle of its immense valleys, with mountain-masses of once liquified and intrusive rocks now bared and intersected, or whether the view of those plains, composed of shingle and sediment hence derived, which stretch to the borders of the Atlantic Ocean, is best adapted to excite our astonishment at the amount of wear and tear which these mountains have undergone.

The Cordillera from Tierra del Fuego to Mexico, is penetrated by volcanic orifices, and those now in action are connected in great trains. The intimate relation between their recent eruptions and the slow elevation of the continent in mass,[20] appears to me highly important, for no explanation of the one phenomenon can be considered as satisfactory which is not applicable to the other. The permanence of the volcanic action on this chain of mountains is, also, a striking fact; first, we have the deluges of submarine lavas alternating with the porphyritic conglomerate strata, then occasionally feldspathic streams and abundant mineral exhalations during the gypseous or cretaceo-oolitic period: then the eruptions of the Uspallata range, and at an ancient but unknown period, when the sea came up to the eastern foot of the Cordillera, streams of basaltic lava at the foot of the Portillo range; then the old tertiary eruptions; and lastly, there are here and there amongst the mountains, much worn and apparently very ancient volcanic formations without any craters; there are, also, craters quite extinct, and others in the condition of solfataras, and others occasionally or habitually in fierce action. Hence it would appear that the Cordillera has been, probably with some quiescent periods, a source of volcanic matter from an epoch anterior to our cretaceo-oolitic formation to the present day; and now the earthquakes, daily recurrent on some part of the western coast, give little hope that the subterranean energy is expended.

[20] On the Connection of certain Volcanic Phenomena in South America: "Geolog. Transact.," vol. v, p. 609.

Recurring to the evidence by which it was shown that some at least of the parallel ridges, which together compose the Cordillera, were successively and slowly upthrown at widely different periods; and that the whole range certainly once, and almost certainly twice, subsided some thousand feet, and being then brought up by a slow movement in mass, again, during the old tertiary formations, subsided several hundred feet, and again was brought up to its present level by a slow and often interrupted movement; we see how opposed is this complicated history of changes slowly effected, to the views of those geologists who believe that this great mountain-chain was formed in late times by a single blow. I have endeavoured elsewhere to show,[21] that the excessively disturbed condition of the strata in the Cordillera, so far from indicating single periods of extreme violence, presents insuperable difficulties, except on the admission that the masses of once liquified rocks of the axes were repeatedly injected with intervals sufficiently long for their successive cooling and consolidation. Finally, if we look to the analogies drawn from the changes now in progress in the earth's crust, whether to the manner in which volcanic matter is erupted, or to the manner in which the land is historically known to have risen and sunk: or again, if we look to the vast amount of denudation which every part of the Cordillera has obviously suffered, the changes through which it has been brought into its present condition, will appear neither to have been too slowly effected, nor to have been too complicated.

[21] "Geolog. Transact.," vol. v, p. 626.

NOTE.—As, both in France and England, translations of a passage in Professor Ehrenberg's Memoir, often referred to in the Fourth Chapter of this volume, have appeared, implying that Professor Ehrenberg believes, from the character of the infusoria, that the Pampean formation was deposited by a sea-debacle rushing over the land, I may state, on the authority of a letter to me, that these translations are incorrect.

The following is the passage in question:—“Durch Beachtung der mikroscopischen Formen hat sich nun feststellen lassen, das die Mastodonten-Lager am La Plata und die Knochen-Lager am Monte Hermoso, who wie die der Riesen-Gürtelthiere in den Dünenhügeln bei Bahia Blanca, beides in Patagonien, unveränderte brakische Süsswasserbildungen sind, die einst wohl sämmtlich zum obersten Fluthgebiethe des Meeres im tieferen Festlande gehörten.”—*Monatsberichten der königl. Akad., etc.,* zu Berlin vom April 1845.

INDEX
TO CORAL-REEFS.

The names in italics are all names of places, and refer exclusively to the Appendix: in well-defined archipelagoes, or groups of islands, the name of each separate island is not given.

INDEX TO VOLCANIC ISLANDS.

INDEX TO SOUTH AMERICAN GEOLOGY.

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