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# DARWIN'S CORAL REEFS, VOLCANIC ISLANDS, SOUTH AMERICA.

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# CHARLES DARWIN'S CORAL REEFS, VOLCANIC ISLANDS AND SOUTH AMERICAN GEOLOGY.

With Introductions by
Prof. J. W. Judd, F.R.S.

EDITED·BY·G·T·BETTANY·M·A

DARWIN.

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# CORAL REEFS, VOLCANIC ISLANDS, SOUTH AMERICAN GEOLOGY.

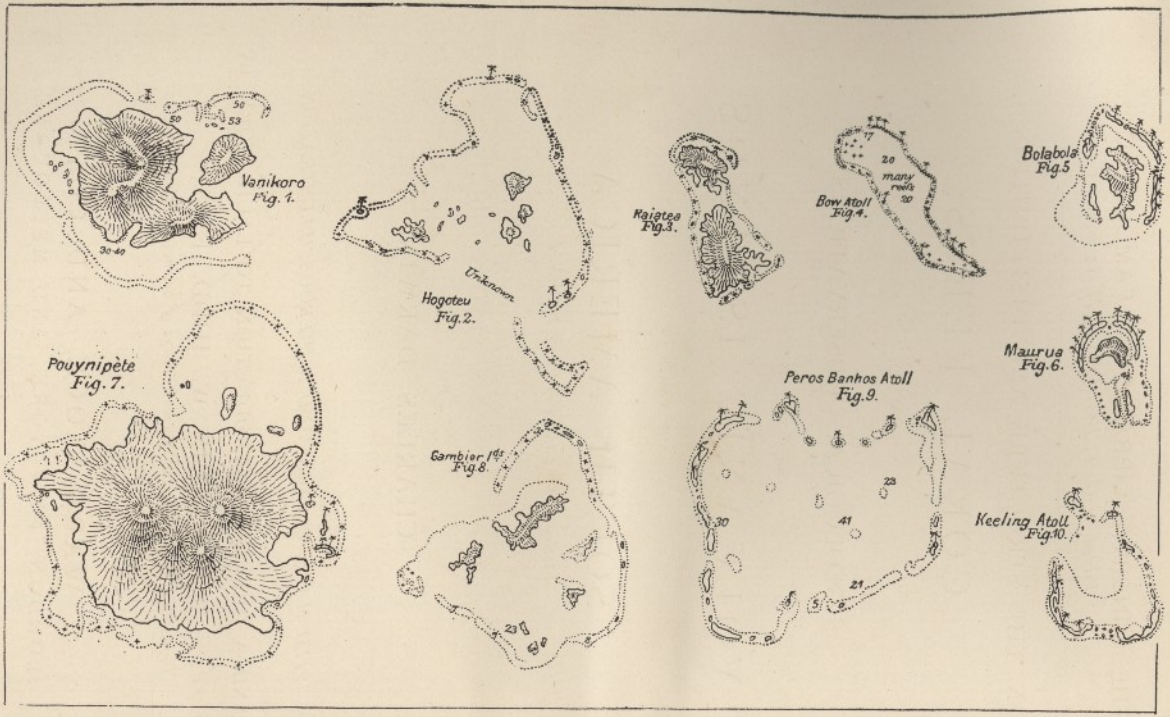


PLATE I.—MAP SHOWING THE RESEMBLANCE IN FORM BETWEEN BARRIER CORAL-REEFS SURROUNDING MOUNTAINOUS ISLANDS, AND ATOLLS OR LAGOON ISLANDS.

THE MINERVA LIBRARY OF FAMOUS BOOKS.
*Edited by G. T. BETTANY, M.A., B.Sc.*

# ON THE STRUCTURE AND DISTRIBUTION OF CORAL REEFS;

ALSO

# GEOLOGICAL OBSERVATIONS

ON THE

# VOLCANIC ISLANDS

AND PARTS OF

# SOUTH AMERICA

*Visited during the Voyage of H.M.S. Beagle.*

BY

CHARLES DARWIN.

*WITH MAPS, PLATES, AND NUMEROUS ILLUSTRATIONS.*

AND A CRITICAL INTRODUCTION TO EACH WORK BY

PROF. JOHN W. JUDD, F.R.S.,

*Professor of Geology in the Normal College of Science, South Kensington.*

WARD, LOCK, AND CO.,
LONDON, NEW YORK, AND MELBOURNE.
1890.

# 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.

# 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 for ever, 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 months' 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 "Dolomut-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.

# 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 ascendency 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 Dufrénoy, 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.

# 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 imper-

fection 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*—is 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, felspar, 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, Daubrée, 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.

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