

DARWIN CHARLES

VOLCANIC
ISLANDS

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Volcanic Islands

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Charles Darwin

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 Palaeozoic 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 scoriae.

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.

(FIGURE 1: MAP 1: PART OF ST. JAGO, ONE OF THE CAPE DE VERDE ISLANDS.)

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 Figure 1 (Map 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.)), 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.

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.

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 debris, 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 *Turritellae*; 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 *Nulliporae*, 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 *Patellae*, 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 *Nulliporae*, 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 lime, 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 arenaceous-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 scoriae. 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, masses of limestone are sometimes fused and crystallised even in common limekilns. (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" volume 15 page 398; Gay-Lussac in "Annales de Chem. et Phys." tome 63 page 219 translated in the "London and Edinburgh Philosophical Magazine" volume 10 page 496.) 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 scoriae, 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.

The fragments of scoriae, 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 scoriae, which have undergone a closely similar change.

THE EXTENT AND HORIZONTALITY OF THE CALCAREOUS STRATUM.

(FIGURE 2: SIGNAL POST HILL. (Section with A low and C high.)

- A. – Ancient volcanic rocks.
- B. – Calcareous stratum.
- C. – Upper basaltic lava.)

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.

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 Figure 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 laminae, 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 scoriae 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 scoriae 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 scoriae 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 tufts; 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 scoriae, 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 scoriae 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 scoriae. 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 scoriae 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 scoriae, – considering, also, the similar occurrence of lime and scoriae 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 scoriae 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. (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.) 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 debris of organic remains, at the bottom of a shallow sea.

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 (Figure 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 (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.), some compact, others highly cellular with inclined beds of loose scoriae, 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 remains of three small points of eruption. These points are composed of glossy scoriae, 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 scoriae 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 scoriae, 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.

The stream of lava, which fills the narrow gorge 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 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.): 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.

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 scoriae, 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. (D'Aubuisson "Traite de Geognosie" tome 2 page 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 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. (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.) 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.

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 latitude 3 degrees 50 minutes 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 facade 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. (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 (page 86 "Memoire 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.) 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.

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 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. (MacCulloch, however, has described and given a plate of ("Geolog. Trans." 1st series volume 4 page 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 have described masses of upraised coral- rock round the greater part of the circumference of the island. (Captain Carmichael, in Hooker's "Bot. Misc." volume 2 page 301. Captain Lloyd has lately, in the "Proceedings of the Geological Society" (volume 3 page 317), described carefully some of these masses. In the "Voyage a 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.") 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 *Astraea* and *Madrepora*, and of fragments of basalt; they were divided into beds dipping seaward, in one case at an angle of 8 degrees, and in the other at 18 degrees; they had a water-worn appearance, and they rose abruptly from a smooth surface, strewed with rolled debris 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.

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 scoriae. 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 ("Voyage aux Terres Australes" tome 1 page 54.) states that they all "se developpent autour d'elle comme une ceinture d'immenses remparts, toutes affectant une pente plus ou moins enclinee vers le rivage de la mer; tandis, au contraire, que vers le centre de l'île elles presentent une coupe abrupte, et souvent taillee a pic. Toutes ces montagnes sont formees de couches paralleles inclinees du centre de l'île 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. (M. Lesson, in his account of this island, in the "Voyage of the 'Coquille'," seems to follow M. Bailly's views.) 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.

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