THE

VOYAGE OF H.M.S. CHALLENGER.

PHYSICS AND CHEMISTRY.

REPORT on the ROCK SPECIMENS collected on Oceanic Islands during the Voyage of H.M.S. Challenger, during the years 1873–1876. By Professor A. RENARD, LL.D., Ph.D., F.G.S., Hon. F.R.S.E., etc., of the University of Ghent, Belgium.

PREFACE.

THE examination of the rocks which are described in this Report was commenced at the time when I became associated with Mr. Murray in the study of the deep-sea deposits collected during the cruise of the Challenger. Mr. Murray had discovered that loose volcanic materials played a very large part in the formation of the deposits of the deep sea, and it was considered desirable to institute a comparison between these and the products of the same origin in volcanic islands situated in, or on the borders of, the great ocean basins. These researches have been conducted with the object just indicated, and have led to a detailed description of the rocks placed in my hands. As this description has no direct relation to that of the deep-sea deposits, the Editor has judged it desirable to publish these researches in a separate Report, comprising especially questions relative to the lithology and mineralogy of the hand specimens collected on Oceanic Islands during the cruise of the Challenger.

All considerations of a more general order, as to the relations which these islands bear to the orography of the deep sea, will be treated of in the Report on the Deep-Sea Deposits.

I desire to thank here Mr. John Murray, Mr. J. Y. Buchanan, Professor H. N. Moseley, and Fleet Surgeon George Maclean, R.N., for all the information they have been so kind as to furnish concerning the rocks collected, and for placing their numerous specimens at my disposal.

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PETROGRAPHICAL DESCRIPTION OF THE ROCK SPECIMENS.

I.—ROCKS OF TENERIFE.

Few of the volcanic islands of the Atlantic have been the object of such important geological inquiries as Tenerife. It inspired L. von Buch's theory of elevation craters,[1] and since that time it has been very often visited by geologists. A large number of scientific papers have been devoted to its description, among which one of the most important is the remarkable monograph by von Fritsch and Reiss.[2] More recently G. A. Sauer has given a detailed lithological description of the phonolites collected at Tenerife by von Fritsch.[3]

The Challenger Naturalists, on a short visit to Pico de Teyde,[4] collected some specimens, the description of which must, in the absence of stratigraphical details, be limited to a few of those mineralogical and lithological features presented by some of these rocks, that from a petrological point of view deserve to be made known.

Near Puerto d'Orotava, basaltic scoriæ are found; they are greyish-black, rough to the touch, and vesicular; the vesicles, lined with a siliceous coating, measure from 2 to 3 mm. in diameter. None of the constituent minerals can be detected with the naked eye. With the microscope crystals of augite and rare crystals of olivine appear as elements of the first generation. The rather large crystals of augite show very fine examples of polysynthetic twinning, and were it not for the colour of the section, they might, at first sight, be taken for felspathic lamellæ twinned according to the albite law. The adjoining figure (fig. 1) shows some of those elongated sections of augite. The portion marked A is sensibly perpendicular to an optical axis; the portion B extinguishes in a direction parallel to the lengthened edges. In the upper part of the figure the prismatic cleavage is seen; at other points irregular fractures are observed, like those seen in sections of sanidine. Nearly all the sections of augite are twinned as in the figure; sometimes they are broken, and the fragments have been displaced. Olivine is rather rare, and the outlines of its sections are faint; the mineral is altered into serpentine, and the cracks are filled with calcite. A great deal of magnetite is found, but larger opaque patches ought to be

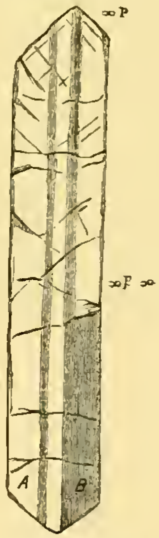

Fig. 1.—Basaltic scoriæ near Puerto d'Orotava. Section of augite with polysynthetic twinning.

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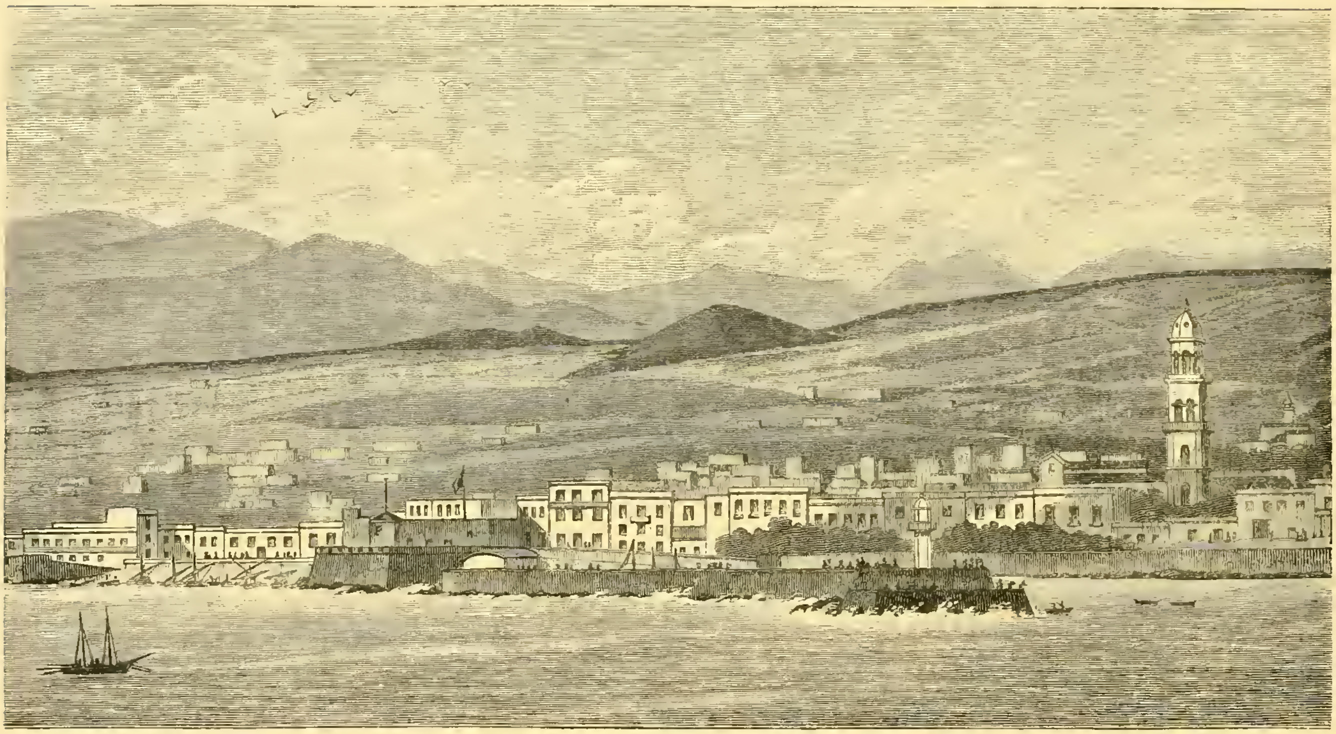
[1] L. von Buch, Physikalische Beschreibung der Canarischen Inseln, Gesammelte Schriften, Bd. iii. p. 229, Berlin 1877.

[2] Von Fritsch und Reiss, Geologische Beschreibung der Insel Teneriffe, 1868.

[3] Sauer, *Zeitschrift f. d. ges. Naturw.*, Bd. xlvii., Halle 1876.

[4] See Narrative of the Cruise of H.M.S. Challenger, vol. i. p. 53.

referred to titaniferous magnetite or to titanic iron. Crystalline outlines observed in these may be ascribed to a regular hexagon. These sections are surrounded by a zone of leucoxene, which appears brownish in transmitted, greyish in reflected, light. The ground-mass is formed by a network of small prismatic augites with rather sharp outlines; a brownish decomposed glassy susbstance is scattered between these, but this base plays a subordinate part. The almost complete absence of plagioclase, the characters of which have only been recognised doubtfully and then only in a few sections, and the predominance of augite, would tend to class this rock with the pyroxenites. The presence of olivine, on the other hand, connects it with the limburgites, but perhaps this mineral is too subordinate to enable the rock to be classed in the latter group.

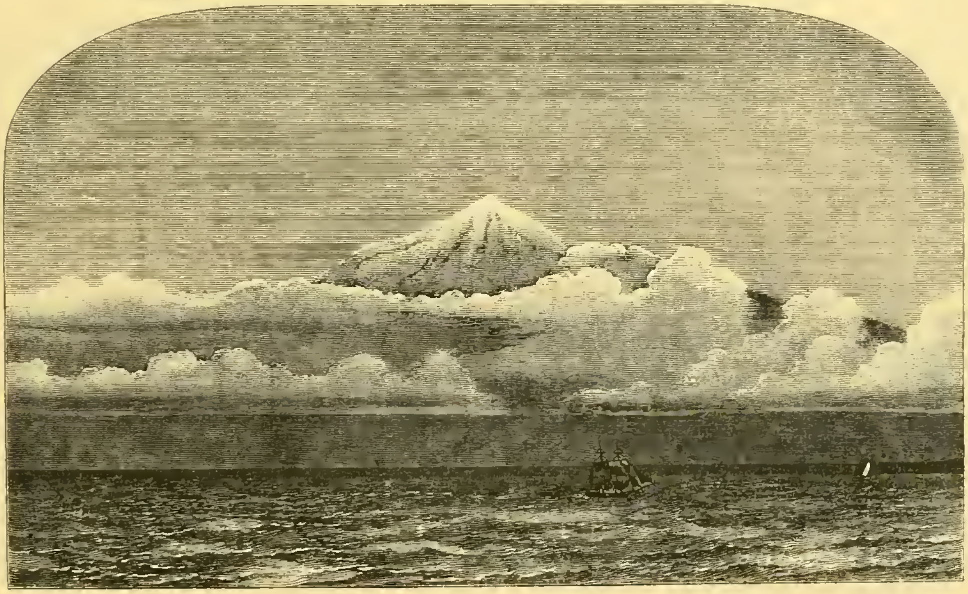


Santa Cruz, Tenerife.

Near the same locality, Puerto d'Orotava, a bluish black rock is found; it is filled with small circular vesicles, measuring 2 to 3 mm.; these contain a whitish mealy matter. Its fracture is irregular, and none of the constituent minerals can be distinguished with the naked eye. The specimen in question is a basalt of the felspathic type; its microscopical structure is that of a dolerite. The plagioclase crystals are lamellar, and grains of augite more or less well crystallised are embedded between them; larger sections of olivine are also seen. The plagioclases extinguish under rather large angles; they are very probably a mixture approximating to bytownite. This felspar shows

Carlsbad twins; the two principal individuals exhibit polysynthetic striation, and their extinctions are almost always unsymmetrical. The augite shows itself with the characters which it assumes in basalts. The olivine sections have rounded edges, with a yellowish zone of decomposition; the interior of the mineral is serpentinised, this alteration being made visible by the formation of green fibres penetrating all the fissures. These sections of olivine contain a rather large number of inclusions, with outlines suggesting the form of an octahedron; these are slightly transparent with a brownish tint, and are probably picotite.

The rocks we shall now describe were found in the Cañadas, a remarkable plain covered with scoriæ and shut in on nearly all sides by a perpendicular wall of basaltic rock. The present terminal cone of the mountain rises from this vast plain. The Cañadas represent an ancient and much larger crater, in the centre of the remnant of which the more modern smaller peak has been thrown up.[1]



Peak of Tenerife from the N.W., 40 miles.

A rock collected at the foot of the Cañadas is a basaltic scoriæ, the vesicles reaching a diameter of 5 to 6 mm.; it is covered with limonite, and a freshly fractured surface shows a compact violet mass. Under the microscope it is seen to be very much altered; its structure is sometimes that of dolerite or that of ordinary basalt. The plagioclase also shows all the transitions from rather large and twinned crystals to the microliths of the paste, which appear as small striæ, and in which the polysynthetic lamellæ can

[1] Narr. Chall. Exp., vol. i. p. 55.

with difficulty be detected. The augite is decomposed; it is yellowish on its edges, the centre still remaining rather violet. The olivine is also altered, being reduced to an external zone, where only the outline of the mineral can be seen. The interior of the section is filled with trichites having a pretty regular disposition and showing rectangular forms; they are associated with small reddish particles. Certain parts only of the olivine polarise, but the colours are not very brilliant. Perhaps we have here an hyalosiderite; this at least seems to be indicated by the great number of trichites, which are also developed in the vitreous decomposed mass forming the ground-mass.

Some other specimens collected in the Cañadas have a waxy appearance when broken, a black colour shading into yellowish brown, with an irregular fracture and containing rather large crystals of sanidine. With the microscope a ground-mass is seen formed by small plagioclases, perhaps also by microliths of sanidine, and by some subordinate vitreous matter. Large sections of plagioclase and of sanidine stand out in this mass. The former show nearly always both the Carlsbad twinning and that of the albite law. They are elongated, with very small extinctions, and ought to be classed in the plagioclastic series near oligoclase and andesine. As frequently occurs with andesine, the hemitropic striæ are exceedingly close and thin. The sections are crossed by two series of polysynthetic striæ; these two systems cut one another under sensibly straight angles, and in polarised light give the section the aspect of microcline, as can be seen in the adjoining figure (fig. 2), only the small veinules of albite are here missing. In some cases these striæ are so faintly visible, that the section might be mistaken for sanidine, but the plagioclastic striæ, be they ever so feebly marked, ought to set aside that interpretation. Sanidine is found in the rock in the form of irregular sections, of rather large size, and twinned according to the Carlsbad law, with the characteristic fissures of that felspar. It can be seen by the undulating extinction that these crystals, like those of plagioclase, have been subjected to mechanical deformation, which altered the optical properties, and renders any subsequent determination difficult. The presence of augite as crystals of the first generation is also ascertained; its pleochroic sections have often indistinct outlines; they are corroded and invaded by the ground-mass. Some small prisms of apatite are also observed, which show, in addition to the usual faces of the prism, a truncation on the edge $OP/\infty P$; they are terminated by the pinacoid OP. Magnetic iron is rather frequent; small hexagonal hardly transparent lamellæ are also seen, which may be referred to titanic iron. We have stated that the ground-mass is formed by the accumulation of small felspar crystals; these are of two types. Those of the first type are tabular, with less distinct outlines, and larger sections; those belonging to the second type are

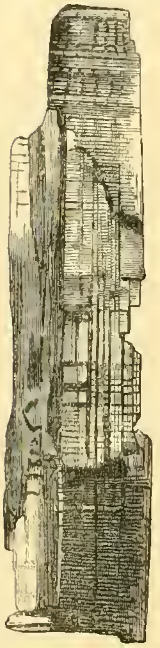


Fig. 2.—Augite-andesite, Cañadas. Section of plagioclase crossed by two series of polysynthetic striæ.

lamellar, their extinction taking place under very small angles, the crystals frequently showing twins without repetition; in short, all seems to indicate that their index of refraction is higher than that of the tabular felspar. The ground-mass reacts like annealed glass between crossed nicols, the tints being hazy. It is uncertain whether these phenomena are to be ascribed to contraction or to pressure which may have acted on the isotropic substance and caused its devitrification. This rock ought to be classed with the pyroxenic andesites containing sanidine, a type related to the trachytic series.

Another rock from the Cañadas is bluish grey, with an irregular fracture; it contains small vesicles with a homogeneous aspect, speckled with black granules. Examination of microscopic slides shows that the rock is a felspathic basalt. The plagioclases, of which numerous sections are seen, have very large lamellæ, and their extinctions are those of labradorite; the augite and the olivine have generally rounded outlines, the latter mineral being decomposed. With these minerals are associated grains and crystals of magnetite, which are rather numerous, and very elongated and truncated prisms of apatite. The ground-mass is formed of a vitreous matter, which is undergoing alteration, as shown by the phenomena of chromatic polarisation it exhibits.

Lastly, a porphyritic lava was collected in the Cañadas. This rock is black, massive, finely grained, scoriaceous, has an irregular fracture, and contains porphyritic felspar crystals. Microscopic examination shows that it has a vitreous base, with very distinct traces of fluidal structure. Crystals of augite, felspar, hornblende, and black mica stand out of the ground-mass, and give the rock a microporphyritic structure. The felspar crystals are twinned according to the albite law, these plagioclastic lamellæ being embedded in two principal individuals twinned according to the Carlsbad law. The separation between the two individuals is clearly marked only on a portion of the length of the section; in several places there is an irregular interpenetration of the two halves. Interposition of biotite scales in the plagioclases can occasionally be ascertained. The same mineral is found as inclusion in augite, as shown in the adjoining figure (fig. 3). The crystals of augite are distinctly prismatic and of light greenish tint, hardly pleochroic. Hornblende is not abundant; its sections are often irregular, sometimes they are aggregated, or form groups. They might be taken for twinned crystals, but there is only a simple juxtaposition; indeed, the lines of cleavage of adjoining sections never follow the direction they would do in the case of true twin crystals. The rays parallel to α are of a pale yellow colour, those parallel to β are reddish. The most characteristic mineral of the rock, and the most widely distributed, is without doubt biotite; sections cut parallel to the base are very frequently observed; these lamellæ are very pleochroic, the rays vibrating perpendicular to α being of a pale yellow

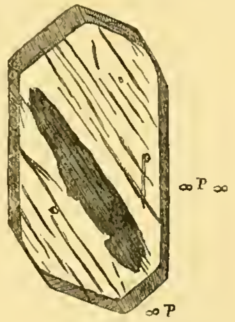


FIG. 3.—Augite-andesite, Cañadas.

Section of augite with biotite lamellæ parallel to a prismatic face.

while those parallel to β are almost black; the shape of these sections is nearly that of elongated parallelograms. This mineral is generally well crystallised; some sections perpendicular to the lamellæ are hexagonal, two of the sides being very elongated, the other much smaller, and the presence of the latter shows that the biotite has crystallised in this rock with pyramidal faces but little developed, truncated by the pinacoid *OP*. The lamellæ parallel to this last face remain dark through a complete rotation between crossed nicols, and in convergent light show a black cross. Sections of magnetite are wedged into the sides of the biotite, which sometimes appears to be altered, and in that case magnetic iron surrounds the decomposed sections. This association appears to show that the magnetite might very well have been derived from the alteration of biotite. In the ground-mass, small plagioclases predominate; these often assume a radial spherulitic arrangement which is repeated with a certain constancy. This rock might be classed among the micaceous augite-andesites.

A rock collected in the middle of the Cañadas is a basalt; it is massive, with more or less nodular blackish grey fracture; it does not show any macroscopic minerals. Under the microscope it is seen to be made up of plagioclase, rather large and irregular sections of olivine, and little crystals of augite; some black mica is also present.

A rock from the top edge of the Cañadas has a compact appearance and is blackish in colour; with the naked eye very elongated crystals of sanidine, embedded in a homogeneous mass, are to be seen. Microscopic examination shows a ground-mass composed of small microliths of felspar more or less radiated, large sections of prismatic and colourless felspar, whose sharp outlines stand out clearly in the surrounding mass. These microporphyritic sections are twinned according to the Carlsbad law, and ought to be referred to sanidine; plagioclastic striæ are never to be observed; the trace of the composition plane divides the section from end to end without ever deviating from a straight line. The usual fissures of sanidine traverse both the twinned individuals as if they formed but one. The extinction of these crystals may be noted here:—Sometimes a section with sharp outlines shows the trace of the twinning reduced to a simple line, in which case it may be assumed that the section is cut nearly perpendicular to the plane of symmetry *v. z. l.* in the zone $P:k$; the extinction of these sections shows that one of the individuals extinguishes nearly always in a direction parallel to the trace of the twinning, and the other at a greater or less angle. Sections, which do not show this sharpness of outline and the trace of the composition plane, ought to be considered as cut obliquely to the zone $P:k$. In this case, if the extinction angles are large and symmetrical, the section is in the zone of the prism; if, on the other hand, they are unsymmetrical and the angular difference very large, it is probable that the section is in the zone $P:M$ of one individual, and in the zone $P:x$ of the other, *i.e.* in a zone in which the extinction of one of the individuals increases but slightly (zone $P:M$), and that of the other rapidly (zone $P:x$). If the extinctions are very small it tends to prove that the section is in a zone intermediate between the preceding $P:M$ and $x:M$. The determination of the angles of extinction, measured from the trace of the twinning of these crystals, shows that nearly all these felspars have lain parallel to each other in a plane, and that the sections have been cut very nearly perpendicular to the plane of symmetry, inclining slightly to the zone $P:M$. The following extinctions have been measured for the two individuals (left and right):—

Left	Right
0°	5°
0°	7°
0°	13°

These crystals of sanidine are embedded in a finely granular ground-mass containing small lamellar felspars, which may also be considered as belonging to sanidine. These microliths are arranged in tufts, and are associated with very small greenish prisms belonging probably to hornblende. It is seen by the deposit of oxide of iron that the basis of the rock is altered; it was perhaps formerly of a glassy nature.

In the gulleys to the west of Fuente Pedro, a spring situated at the height of 3500 feet, a greyish rock speckled with prismatic crystals of sanidine was collected. This rock has a plane fracture, a waxy lustre, and is very like a phonolite. Microscopic examination shows that the ground-mass contains microporphyritic crystals of sanidine and of plagioclase, which are almost microliths, passing into those constituting the paste; augite and magnetite appear in rather large sections, probably owing their origin to the decomposition of the hornblende. The sanidine sections are large, but their outlines are not sharp; those of the plagioclases, on the other hand, are well defined, notwithstanding the mechanical deformations to which they were subjected. The sanidine shows the characteristic fissures of this mineral, and is twinned according to the Carlsbad law. The deformations produced in this felspar by mechanical action have rendered it fibrous at the extremities of the sections; many of the crystals are bent and broken. A fact that must also be ascribed to these deformations is that the sections show not only undulating polarisation but also deeper colours of chromatic polarisation. Where these phenomena of pressure are observed, instead of seeing the usual pale blue tints of sanidine, the colour is darker; it passes to an indigo tint of marked intensity. We are led to think that this accentuation of tint is caused by mechanical action, which has left its impress on all the constituent minerals of this rock. The crystals of plagioclase are far more numerous than those of sanidine; they are smaller, more elongated, and bent in all directions. These deformations, which are repeated in a marked way in all the sections of plagioclase, are accompanied by irregular fractures more or less perpendicular to the length of the crystal (see fig. 4). Augite can only be recognised in the larger crystals; these alone have withstood the pressure. This mineral is polysynthetically twinned; it is generally in a fragmentary condition, filled with fissures. Isolated hornblende cannot be found, but some rather large patches of magnetite surround the small sections of hornblende, forming a kind of zone, and accompanied by very small scales of biotite. This seems to show that the hornblende, once present in the rock, has been replaced by these two minerals. We ought also to mention a mineral playing a rather important part in this rock, sodalite. It is seen in hexagonal or quadratic colourless sections. They are of primary consolidation, as is shown by their forming a centre of aggregation for small crystals of plagioclase, disposed as spherulites round the sodalite. With the condenser a black cross is rather faintly indicated; they cannot be mistaken for nepheline or any other hexagonal mineral, because between crossed nicols all the sections remain obscured. The presence of sodalite in this rock is not an exceptional fact; it is known that this mineral is found in trachytic rocks associated with sanidine and augite, in nearly the same conditions as those we have mentioned. The ground-mass is formed by a network of plagioclase crystals and grains of augite. The rock has a doleritic structure, its mineralogical composition classing it among the augitic andesites, closely allied to trachytes.

FIG. 4.—Augite-andesite near Fuente Pedro. Crystal of sanidine and small crystals of plagioclase, bent and fibrous in the ground-mass.

In the same gulleys of Fuente Pedro a whitish altered rock similar to the preceding was collected. The ground-mass is nearly homogeneous, and contains irregularly disseminated grains of felspar; the fracture of the rock is irregular. Under the microscope the following microporphyritic minerals can be seen: plagioclase, sanidine, augite, and hornblende. Some sections of plagioclase have exceedingly thin polysynthetic striæ over the whole surface. Others show the Carlsbad twinning, and also that of albite; and lastly, some show in addition the periclinic striation crossing the albitic lamellæ. It is rather interesting to notice that, when the sections show the Carlsbad twinning, one of the two halves presents the polysynthetic lamellæ of the albite law, and the other half shows both the albitic and the periclinic striation. This phenomenon tends to prove that these plagioclases have crystallised also according to the Carlsbad law. Indeed, if we bear in mind that the periclinic lamellæ ought to be seen in sections parallel to x, and never in those parallel to P, and that in a Carlsbad twin the faces x

and *P*, for the two individuals, are placed side by side, we must admit, in order to explain the fact just mentioned, the existence of a Carlsbad twin : sections parallel to *P* are also parallel to *x*, and can only show periclinic lamellæ in the individual of which the face *x* has been cut. Symmetrical extinctions measured in the zone *P* : *k* have given, for several cases, values of about 5° ; the sections showing the periclinic striæ extinguish at angles of 12° to 14°. This seems to show that we are dealing here with an isomorphous mixture approaching that of oligoclase. There are also small sections of felspar, the physical characters of which contrast with those that we have just described. They are more corroded, have less regular outlines, and are crossed by fractures ; polarised light shows that they have crystallised according to the Carlsbad law, and do not show the polysynthetic striæ. The angles of extinction are usually rather large, but at the same time it is noticed that the outlines are feebly marked ; this shows that these sections belong to a zone intermediate between the zones *P* : *M* and *k* : *M*, closer to the latter. The frequency of these larger extinctions would prove that this felspar is more developed in the direction of the vertical axis than in the direction of the edge *P*/*M*. The crystals of hornblende have a very broken appearance, and are greatly elongated. One cleavage predominates, and irregular fractures are observed nearly perpendicular to that direction ; these fractures are caused most likely by mechanical action due to the contracting mass, giving rise to deformation in all the constituent minerals of the rock. The polarisation colours of the hornblende sections are orange, and show that decomposition is taking place. Extinctions of 4° or 5° have been measured ; pleochroism is very marked.

γ	>	β	>	α
dark brown		yellow brown		pale yellow

The sections perpendicular to the axis *c* are very rare and ill-defined, as may be expected from the very prismatic form of hornblende in this rock. Augite is more plentiful than hornblende ; it is elongated like the latter, and often shows twinning according to the usual law ; sometimes the sections are polysynthetically twinned, symmetrical extinctions on both sides of the twinned lamellæ measured 38°. This augite is not pleochroic ; yellowish spots are seen in the interior of the section, indicating incipient decomposition. Like the hornblende, this mineral often shows fractures and crevices caused by mechanical action. Numerous grains and crystals of magnetite are often accumulated in certain points. The ground-mass is composed of an aggregation of small elongated felspar crystals, interwoven in all directions, and very small augitic sections are wedged between them. The felspar microliths ought to be ascribed, like the microporphyritic individuals, to sanidine or to a plagioclase with small extinctions, twinned according to the Carlsbad law and that of albite. The small felspars of the ground-mass, which we also ascribe to sanidine, show the Carlsbad twinning without any trace of plagioclastic striæ. The features of the small sections of augite in the ground-mass ought to be mentioned. We have already stated that both this mineral and hornblende show traces of deformation by mechanical action. The augitic microliths have been crushed, they have become somewhat fibrous, and taken the appearance of uralite; this fibrous structure may be nearly always connected with the bends and fractures which are observed in the mass. The little augite prisms are often bent and broken at the top of the curve. The broken portions have become displaced, and the space between the two fragments is filled with fibres which connect the disjointed portions. The greenish substance scattered in filaments between the felspathic microliths of the ground-mass is probably nothing but crushed and stretched out augite. Under the high powers of the microscope, very small scales with extremely sharp hexagonal outlines are observed; these lamellæ have a certain thickness so as to enable the edges of the prismatic zone and of the pinacoid to be seen. In other cases they are more irregular and scattered all through the mass of the rock. At first sight they might be taken for red hematite, but their colour is rather greyish violet than red. This colour recalls that of lamellæ of titaniferous iron as observed in some phyllites of the Ardennes. We consider these small hexagonal sections to be the same mineral; it can be ascertained that they are monaxial. The rock which we have just been describing ought to be referred to augite-andesite, but the presence of hornblende and sanidine make it a transition form to the trachytes.

On the path to the Peak, another rock was collected with a massive ground-mass, black in colour, of basaltic appearance, containing large vesicles, some of which have a thin coating of a zeolitic or siliceous substance. This rock ought to be classed as a dolerite. Under the microscope the ground-mass is seen to be formed of small plagioclase lamellæ, between which are scattered microscopical crystals of augite. In the ground-mass are crystals of augite and olivine of the first generation. Generally the felspar is less developed in large crystals; the olivine often shows sections very well defined on a part of the outlines, which at other parts are broken up and corroded. It does not seem probable, if we are to judge by the fluidal structure of the ground-mass around the crystals, that this corrosion has been produced by the action of the magma; possibly the olivine was already in a fragmentary state before the last movements of the magma, which preceded the solidification of the rock. The olivine is rather altered, and is bordered by a yellowish zone which penetrates the interior of the sections. The smallest crystals of this mineral are quite decomposed; they appear as yellowish grains, and their nature can only be made out by following all the phases of alteration between the larger sections, with corroded outlines, and these microscopical individuals. The olivine, as also the altered augite, contains trichitic skeletons and crystals of magnetite. Another somewhat common mode of decomposition has been observed in this mineral; it is shown by a fibrous structure, the fibres lying parallel to the axis *c*. The felspars belong to two types; one of these is lamellar, the other occurs in short prisms. The latter, generally, have less numerous plagioclastic lamellæ than the former, and the angles of extinction are large. These plagioclase sections generally show a large individual, in which are one or two hemitropic lamellæ, the thickness of which is very small compared to the size of the section. Some crystals of albite and of anorthite have the same peculiarity, and in this case the extinctions seem to indicate that the felspar may be anorthite. The lamellar felspar, on the other hand, judging by the extinctions, seems rather to be labradorite. These plagioclases do not kaolinise; when altered they appear of a milky colour and slightly granular. With polarised light they remain dark or assume a very faint bluish tint. Perhaps this modification is a transition to a zeolitic substance, the nature of which it is difficult, if not impossible, to ascertain. The augite has the ordinary characters of that mineral in doleritic basalts. The grains are generally wedged into the triangular space formed by the inter-crossing of the lamellæ of plagioclase. When decomposed, its violet colour is weakened. The vitreous base, rather distinct patches of which are found around the augitic microliths, sometimes forms a narrow and colourless zone, surrounded in turn by an isotropic rim of a light brownish colour, filled with a blackish globulitic granulation. The existence of these zones may be explained if we bear in mind that when the augite crystallised the surrounding parts of the magma gave up their metallic pigment to the crystal that was being formed, and so the first zone was necessarily discoloured. The darker external vitreous zone may be considered as a residuum of crystallisation richer in metallic oxides; these have often become isolated, assuming the globulitic form. As we have already stated, this rock belongs to the felspathic dolerites with a vitreous base.

Below Casa Blanca a brownish rock was collected; it is earthy, with an altered appearance, has an irregular fracture, is fine grained, and contains tabular crystals of sanidine measuring 3 to 5 mm. Microscopic sections show a ground-mass composed of lamellæ of tridymite with a faint yellow colour. Rather large sections of felspar and augite can be distinguished in it; this latter mineral is frequent in small sections embedded in a tridymite mass. Two kinds of felspar are to be seen; some lamellæ have small extinctions like those of oligoclase, which is known to occur in the older rocks containing orthoclase and quartz. The other felspathic sections are those of a monoclinic felspar; they have irregular and indistinct outlines, and never show polysynthetic striation, but they are twinned and composed of two individuals. The outlines of these sections and their extinction show that this felspar is twinned according to the law of Manebach; these sections show, like sanidine twinned according to the Carlsbad law, two halves joined together, but, whereas in a Carlsbad twin, the direction of cleavage remains the same for both individuals in the section, with the twin of Manebach each individual has its cleavages, ending at the line of the composition plane, forming an angle of about 66° with one another. One of the two better marked lines of cleavage belongs to the trace of *P* (composition plane). The other, less marked, is the prismatic cleavage. The two halves of the sections extinguish symmetrically at an angle of about 7° (*A A'*), the extinction being positive (see fig. 5). These details show that this mineral is sanidine. In some cases it has crystallised according to the Carlsbad law. The augitic sections are greenish, and they are not very common. The ground-mass contains augite microliths embedded in lamellæ of tridymite. Under low magnifying powers it might be fancied that the rock possesses perlitic structure or contains trichites, but under higher powers it is ascertained that these indistinct forms and lines are extremely thin lamellæ, superposed one upon the other or imbricated as in the case of tridymite. The hexagonal outlines of these lamellæ are shown by rather distinct traces, rendered slightly more apparent by a brownish coloration due to limonite. This fact is analogous to what is often observed for tridymite in other eruptive rocks, and in some meteorites. Generally the scales in question are well outlined; in other cases they are, as it were, slightly notched. Their optical properties cannot be studied on account of their extreme thinness and their superposition. All that can be said is that the colours of polarisation are faint, and similar to those of quartz in sections of the same thickness as that of the tridymite.

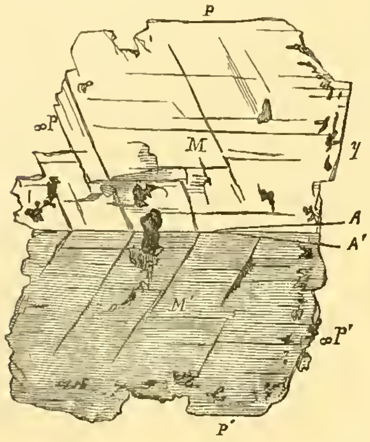


Fig. 5.—Altered rock below Casa Blanca. Section of sanidine twinned according to the Manebach law.

Other specimens collected on the same excursion to the Peak are augite-andesites, more or less scoriaceous, and felspathic basalts with or without vitreous base, often globulitically devitrified. These rocks do not present any character which was not mentioned in the basalts described above. Several specimens of obsidian were also collected, with alternate black and greyish bands, often more or less fibrous, on account of the elongation of the pores. A striped and fibrous obsidian exactly resembles pumice, except that in the former there are massive portions. These obsidians are rich in trichites of various forms, which are more numerous the fewer minerals the rock contains. Among the latter may be noticed plagioclase, hornblende, augite, and magnetite. Small felspar lamellæ are seen in the vitreous mass, straight or slightly crescent shaped, indented at the two ends. The pumice collected does not show any difference from the obsidian except in structure. It has a light greenish tint, and a silky appearance. No minerals can be distinguished by the naked eye, but with the microscope felspar, hornblende, augite, and magnetite can be seen.

II.—ROCKS OF THE CAPE VERDE ISLANDS.

A. *Rocks of St. Vincent.*

The archipelago of Cape Verde consists of eight large islands, two of which, St. Iago and St. Vincent, were visited by the explorers of the Challenger; they also landed at Bird Island, one of the islets of the group situated near St. Vincent. We shall examine first the rocks collected on the last-mentioned island, which is essentially of a volcanic character, presenting an arid and desert aspect. The hills around Porto Grande are formed of igneous rocks, of which each of the superposed beds do not attain a metre in thickness. These sheets are slightly inclined, their dip increasing as they recede from the port. They are frequently traversed by vertical dykes of basalt, of which the general directions are N.-S. and E.-W. These injected basalts show a columnar structure perpendicular to the sides of the rocks traversed. This prismatic structure is also found in the beds of the rock constituting the principal mass of the hill. At the contact of the intrusive rocks with the beds which they traverse, both are much decomposed and disintegrated,—the latter being partially converted into a substance resembling kaolin. As these veins traverse the hill from base to summit, and offer more resistance to denuding agencies, they remain as walls of rock crowning the heights with a jagged outline which is very characteristic.[1]

According to Professor Doelter,[2] the history of this volcano may be sketched as follows. St. Vincent is the ruin of a strata-volcano of which the height was considerably greater than the crest of that part of the crater now remaining. It is difficult to determine the exact dimensions and the position of this ancient crater; it appears, however, probable that it must have been situated within an area at present comprising the port, the undulating ground, and the plains which extend behind Porto Grande. Erosion and the action of the waves have produced such profound modifications of the surface, that it is scarcely possible to indicate exactly the original form of the volcano. It appears to have been formed on a land surface of considerably greater extent than the present island, as indicated by the hills formed of eruptive rocks of ancient type (diabases, syenites), the age of which it is difficult to determine with precision. On the south-west side of this great volcano, which is characterised by sheets of lava, and occasionally by tufas traversed by numerous dykes, a considerable number of secondary craters have been formed, that do not appear to be of ancient date. The presence of somewhat recent calcareous beds, which are spread out on the slopes of Monte Viana and at other points, especially on the north shore,

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[1] Buchanan, On geological work done on board H.M.S. Challenger, *Proc. Roy. Soc.*, vol. xxiv. p. 612, 1876.

[2] Doelter, Die Vulkane der Capverden und ihre Produkte, p. 44, Gratz, 1882.

indicate that the volcano has been affected by a movement of elevation since its formation.

In the specimens which we have examined we have not found any of the rocks of ancient type mentioned by Professor Doelter in the passage above alluded to. All those collected by the Challenger belong to recent volcanic rocks, which we shall now describe; they come from localities not far from Porto Grande.

We shall first describe the specimens from the dykes, which traverse sheets of lava. They are basalts presenting the microscopic characters of that lithological type. One of the specimens is a dolerite; under the microscope sections of olivine of small size and lamellæ of felspar are seen enclosing grains and crystals of augite. The sections of plagioclase show the characters of the felspar of the basaltic rocks. The same may be said of the augite. Generally the latter mineral is in sections with irregular outlines, in other cases it is seen in the form of intercrossed groups. The augitic sections showing these groupings in our preparations were not cut so as to allow of estimating exactly the angle at which the twinned crystals were joined, or of determining the law of twinning; but their aspect resembled sufficiently that of the twin of augite according to an acute pyramid, which has been observed macroscopically by Vrba, and of which Professor Becke has indicated the presence in microscopical specimens. These augitic sections are also twinned, following the ordinary law parallel to $\infty \bar{P} \infty$. The olivine is not microporphyritic; it is seen in small sections often lozenge-shaped, with a centre of the same form of which the sides are parallel to the outlines of the section. It is often yellow by decomposition; and disposed in the mass of the rock so as to contribute to its doleritic structure. Small scales of biotite are occasionally seen; sections of magnetite, on the other hand, are numerous. Finally, a small quantity of a yellowish fibrous matter is found amongst these minerals, which, it appears very probable, was originally a vitreous substance.

Another basaltic rock, forming a dyke and covered with zeolitic incrustations in which may be observed isolated crystals of chabasite, must, like the last mentioned, be referred to the felspathic basalts; it contains crystals of augite visible to the naked eye. In the ground-mass, formed of a colourless base with microliths of augite and felspar, crystals of the same minerals but of a larger size are seen associated with olivine and magnetite. The augite is generally perfectly crystallised; the pleochroism and absorption are—

$$\gamma \text{ and } \beta \text{ purplish} > \alpha \text{ pale yellow.}$$

With respect to the plagioclase, the extinctions on the face M are negative and about 27°; for two adjacent hemitropic lamellæ symmetrical extinctions are seen with the maximum value 34°, which brings this felspar very near to anorthite. These plagioclases have often crystallised according to the albite law, and at the same time show the Carlsbad twinning. The presence of the latter twin may even be recognised on the sections more or less parallel to *M*. These sections are then divided in two parts, and show two series of cleavages, which join each other at an angle of about 52°; a third cleavage parallel to the junction may also be observed. It is probable that the crossed cleavages correspond to the traces of *P*, and those of the less perfect cleavage to the traces of the prism. These facts would seem to prove that the two twinned crystals are joined parallel to a face of the zone *P*:*k*. The olivine shows sections which are entirely transformed into red hematite, but in which the form of the outlines and the cleavages are clear. The latter are observed in the greater number of sections to run parallel to the base; they are traversed at right angles by less distinct lines, which would correspond to the prismatic cleavage. In symmetrical hexagonal sections the acute angles are about 80°, which would correspond to the faces of the dome *k*. It is observed that sometimes these sections are surrounded by a very distinct zone of a quite colourless glass.

A rock coming from a dyke at the south-west of the island is an augitic andesite, rather rough to the touch, vesicular, in which may be seen with the naked eye plagioclases and altered crystals of augite; zeolites have formed in the cavities. The rock is altered like most of those collected in this island. The mineral which plays the part of microporphyritic element is the plagioclase; it is always rather rare, occurring as large isolated crystals, in which case its outlines are deficient in sharpness; they might be said to have been blunted by the action of the magma. This mineral has crystallised according to the Carlsbad and albite laws; it contains numerous vitreous inclusions. The ground-mass is composed of small lamellæ of plagioclase and very numerous microliths of augite having a peculiar colour; these have a slightly bluish tint, and are very decidedly pleochroic; this property is observed principally in the sections parallel to ∞Ꝑ∞: in these the rays vibrating perpendicularly to the length are the darkest. Considering the minuteness of these microliths, often very thin, and their pleochroism as well as their peculiar tint, they might be considered at first sight as allied to hornblende; but we have observed extinctions which exceed 40°. In transverse sections, more or less perpendicular to the axis *c*, it is seen that they are tabular in the direction of one of the vertical pinacoids. This rock is silicified; the silica penetrates into all the interstices, and covers the crystals of augite and felspar with a layer of chalcedony. This substance is distinguished from the zeolites, rather common in these rocks, by a more intense chromatic polarisation, by more decided concentric zones, somewhat similar to the zonary structure of the agates, and by the radiating fibres, which are very sharp, fine, and acicular.

Some specimens were collected on the road which leads to the summit of Green Mountain, an eminence of volcanic origin 2482 feet in height. One of these rocks is a tufa in which rather numerous small scales of black mica are seen by the naked eye.

Under the microscope these scales show two optical axes of a very small angle; the sections where the lamellæ are seen superposed are pleochroic, showing a yellow tint for the rays parallel to the scales, and a brownish one for those perpendicular to them. Irregular cracks appear on the scales parallel to *OP*. In general this mineral is much altered. It is associated in the same rock with pretty large fragments of augite and olivine; the former are cracked and of a greenish colour. These different minerals are grouped in an irregular manner and mingled with microscopic lapilli. The mica often forms small groups. This heterogeneous assemblage of minerals leaves the impression that the rock is of clastic origin.

A reddish brown spongy lava of basaltic nature containing zeolites is nearly allied to the tufa of which a short description has just been given. This lava, like the tufa, contains black mica and augite; the latter mineral is granular; more rarely its sections possess regular outlines with traces of twinning. This is almost the only microporphyritic mineral. The alteration of the rock is seen by the little lamellæ of biotite which take a reddish colour from the deposit of ferric oxide. These micaceous sections are pleochroic, and present, with regard to their physical properties, some analogy with those of the preceding rock. The ground-mass is formed of a vitreous base, in which there are to be observed numerous plagioclastic lamellæ of rather small size, entirely transformed into zeolitic matter. With these plagioclases are associated small crystals of augite. In certain cavities between the crystals just mentioned a layer of greenish substance has been deposited; it is more or less mammillated on the surface, resembling delessite, and is probably derived from the decomposition of a bisilicate. Amongst the minerals of secondary origin may be mentioned zeolitic masses which fill the small cavities of the rock with fine fibro-radiated needles. These zeolites are often covered with or accompanied by a deposit of ferric oxide. The tufts of zeolites are formed of small very elongated prisms with straight extinctions, often thinning at their point of insertion, and thickening towards the summit which advances to the opening of the little drusy cavity. This summit is often terminated by an obtuse pyramid, or else it has the pinacoid *OP*. The sharpness of these little prisms, their aspect, their localisation, and their clearly marked character of rhombic minerals, can leave no doubt as to their identification with the minerals of the zeolite group, and they might, from their crystallographic characters, be placed with natrolite or brevicite.

Finally, we have to mention a blackish rock, studded with more or less circular zeolitic points and with large crystals of augite. Under the microscope its aspect resembles kersantite in a striking manner; lamellæ of plagioclase, associated with a mineral which might be taken for biotite, are seen. But in observing the extinctions of these brown lamellar sections it is perceived that they do not extinguish parallel to the length, but at an angle which attains on an average 10°. This mineral must therefore be hornblende; hexagonal transverse sections are seen. In the very elongated sections, which are common, the pleochroism is strongly marked; the brown tint is darker for the rays parallel to *c*, it is yellowish brown for those perpendicular to that direction. The larger felspar crystals are generally much altered; the hemitropic lamellæ are scarcely visible. In certain cases these crystals are filled with secondary products, amongst which calcite may be distinguished; perhaps this mineral is associated with scales of mica, or of quartz, or secondary felspar. The felspathic crystals of secondary formation, which are scattered throughout the mass, are much more decomposed than those of the first generation. They extinguish at rather small angles, which would seem to refer them to oligoclase. These small plagioclase crystals occur rather often in the form of a cross; probably we have here to do with a twin analogous to that of Baveno. The sections of augite are large and rather rare; this mineral is here seen with the ordinary characters which it presents in basalt. It is difficult to determine the ground-mass, as it has been invaded by products of decomposition; calcite has been developed in certain cavities. If we take into consideration its mineralogical composition, and if we set aside its structure, which is exceptional, this altered rock might be classed with the amphibolic andesites.

The harbour of St. Vincent is surrounded by a circle of heights formed of eruptive rocks; at its entrance there are isolated rocks, which may be considered as having been formerly attached to the chain of hillocks terminating at the coast. These rocks are called Bird Island; they are covered up to high-tide mark by a wide border of calcareous incrustations consisting of corallines. We have examined a specimen coming from this islet; it is a somewhat fibrous lava, which may be classed with the pyroxenites,[1] and is very closely allied to the basalts. It has the appearance of a basaltic rock; the very elongated crystals of augite visible to the naked eye are ranged parallel to each other. This disposition determines an almost fibrous structure in the rock, all the vesicles being stretched in the direction of the elongation of the pyroxenic crystals. With the microscope it is ascertained that the felspathic element is not present, and that this lava is essentially formed of augite. Some crystals of that species are porphyritic, as has just been said, others are microlithic. The large crystals of pyroxene present remarkable peculiarities, as is shown by their microscopical examination. They assume a lengthening quite unusual for this species; they may attain a length of 7 to 8 millimetres, with a breadth of 0·1 mm. On following one of these sections of augite in all its length under polarised light, it is seen that it extinguishes simultaneously between crossed nicols; it is therefore a single crystal which extends from one end of the section to the other.

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[1] Doelter, *loc. cit.*, p. 187.

B. *Rocks of St. Iago.*

St. Iago is one of the most remarkable islands of the Cape Verde archipelago. It was explored by Darwin[1] during the voyage of the "Beagle," and more recently by Professor Doelter.[2] Our observations having been confined to a few specimens collected near Porto Praya, we shall restrict ourselves to the description of these rocks, referring for further information to the works of Darwin and Doelter. We shall merely state that the part of the island where the rocks were collected of which we are about to give the analysis, constitutes a natural division of St. Iago,[3]—a plateau which stretches from Pico d'Antonio to the sea. This plain is formed of lavas slightly inclined, and pierced by more recent eruptions. The thickness of the lava varies from 300 to 900 feet, each sheet having a thickness of 30 to 45 feet; the layers are separated by rather thin intercalations of tufa. In this part of the island a bed of limestone may be observed; it is of recent formation, for it contains shells now living in the surrounding sea. The ancient lavas of Pico d'Antonio are anterior to this limestone, which contains fragments of them.

Amongst the rocks collected near Porto Praya are to be mentioned, in the first place, specimens which may be referred to limburgite. They are of a reddish grey colour, with numerous vesicles in which natrolite has crystallised. Under the microscope it is seen that this rock contains an abundant, brownish, vitreous base, and is transformed, along the veins and fissures, into a reddish substance which may be observed in rocks of the basaltic series undergoing modification into palagonite. In this base are observed pretty large and remarkably well outlined sections of olivine. This mineral is little if at all altered, and the only inclusions observed in it are crystals of magnetite. Several crystals are frequently joined with parallel axes; the sections in this case show outlines with re-entering angles; but in many cases it may be ascertained with polarised light that these crystals are not twinned, but simply juxtaposed. There are others, however, in which the phenomena of polarisation show that the axes of elasticity are oriented so as to render the existence of a twin highly probable. The two crystals are joined at an angle of about 45° or 50°, but the irregularity of the contours does not allow it to be measured with precision. If these crystals are examined with convergent light, there may be observed on one of them a bissectrix, indicating the plane of an optical axis perpendicular to the long edge. On the other may be already observed the lemniscates, and an arm of the hyperbola oriented in the same way. The observations make it sufficiently probable that the two crystals may be twinned, with a dome as composition plane.

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[1] Darwin, Geological Observations on Volcanic Islands, pp. 1–22, ed. i., London, 1844.

[2] Doelter, Die Vulkane der Capverden.

[3] Doelter, *loc. cit.*, p. 44.

In the brownish vitreous mass there are numerous small microliths of augite, almost colourless, or of slightly purplish tint; these crystals are often grouped in the form of a cross or star, but it was not possible to ascertain the law of this intercrossing. The zeolites, as is generally the case with the rocks of this type, have been formed in drusy cavities, lining them with a rather thin layer, which is almost colourless or only slightly bluish between crossed nicols.

A rock with an enamelled calcareous coating, found on the coast, must also be classed with limburgite. It is black, more massive than the preceding, slightly vesicular, and has the macroscopic characters of basalt. Examined with the microscope it is seen that all the constituent elements are the same as in the rock just described; its base is, however, less developed, and all the microporphyritic crystals, especially those of augite, are of a larger size. The olivine shows its cleavages in a more distinct manner, and it is penetrated and corroded by the magma. The vitreous mass is less homogeneous, and less transparent than in the rock last described; in some places it is filled with trichites, and irregular granules of magnetite.

A rock specimen broken from a steep cliff near the slaughter-house of Porto Praya is of a greyish dark-blue colour, compact, and with an even fracture. No mineral is discernible by the naked eye. With the microscope it seems to be allied to felspathic basalt. Grains and crystals of olivine, already changed into a yellow substance on the edges, are, with magnetite, the most conspicuous elements; they are enclosed in a network of minute crystals of plagioclase and augite. Small veins, lined or filled with zeolites, traverse the rock.

In this locality other basaltic rocks were collected which must be classed with the dolerites. They are remarkable for the large dimensions attained by the crystals of augite, which often measure more than a centimetre. Under the microscope the outlines of the sections of augite are very distinct, and show that this mineral is perfectly developed on all its faces. It is often twinned according to the ordinary law ∞Ᵽ∞; at other times the crystals cross each other in such a way that the traces of the faces r : r′ form an angle of about 80°; in this case all would seem to indicate that the crystal is twinned following the dome −Ᵽ∞. Some crystals of pyroxene are zonary, and possess the hour-glass structure; some of these have an internal structure which only shows itself with polarised light. A section with irregular outlines shows striæ in connection with the zones of growth; this section is traversed by a series of parallel lines corresponding to the prismatic cleavage. It may be seen between crossed nicols that it is traversed by three series of lamellæ, of which one is almost perpendicular to the direction of the cleavage, the two others being perpendicular to one another, and making an angle of about 45° with the first. The pleochroism is—

β	$>$	γ	$>$	α
reddish.		violet.		yellowish.

Between these large crystals of augite may be seen grains of olivine often partially serpentinised, and pretty common lamellæ of biotite and magnetite; the plagioclase is partially transformed into saussurite, and almost always presents itself in the form of elongated lamellæ with large extinctions similar to those of labradorite. These felspars, which are generally small, form almost alone the ground-mass enclosing the other crystals.

A lava from the same locality is slightly scoriaceous, of a reddish grey colour, with an irregular fracture. Olivine reddened by oxide of iron may be seen with the lens. Amongst the microporphyritic minerals, which are perceived under the microscope, may be specially mentioned olivine and magnetite with subordinate felspar. These larger minerals are enclosed in a ground-mass formed of a base, devitrified by globulites, microliths of augite, and of felspar and secondary minerals, such as hematite, etc.

The large sections of olivine, perfectly crystallised, are magnificent examples of pseudomorphs of hematite. This last mineral appears opaque with transmitted light; with reflected light its dark-red colour is clearly seen. In this nearly perfect transformation of the hyalosiderite into hematite, certain parts of the primitive crystal have preserved their transparency and all their optical properties. This apparent anomaly is explained if it be remembered that this alteration of the mass of olivine does not take place in a uniform manner; the trichites or the small veins of hematite advance in directions determined by microscopical cracks; they afterwards enlarge, sometimes leaving small patches where the alteration has not yet commenced, and these preserve all their properties. By the form of these pseudomorphosed sections, it seems that it is really olivine which formerly occupied all the space invaded by the hematoid substance. When the little colourless patches of these sections are examined in polarised light, they all darken at the same time; this in its turn proves that they form the last remains of a single crystal.

The felspars show themselves in an abnormal manner. Usually, in the basalts, plagioclase presents itself with a considerable clearness of outline. Here, on the contrary, they have the appearance of an intercalated mass of which the crystallisation has been impeded by the surrounding minerals. They are grains without regular outlines, and the striæ of the plagioclase are scarcely marked; they present in places an undulating extinction, produced perhaps by alteration. If an analogy to these felspathic grains were to be sought for in other rocks, they might be compared with the plagioclases as they exist in meteorites of the type of chrondrites.

Small augites, yellow by alteration, form almost the whole of the ground-mass; they are found together with grains of magnetite, and transparent reddish brown sections extinguishing parallel to the edges. This mineral cannot be precisely determined. If the form, almost always quadratic, which it presents be taken into account, it might perhaps be classed with perowskite, but the colour is too red, it is not sufficiently purplish. On the other hand, this mineral is found with the form of parallelogrammic sections which have in their aspect a great analogy to bronzite; the optical properties of the mineral under parallel light might agree with this opinion, although the great number of quadratic sections seems unfavourable to it. The minute size of this mineral prevents its examination in convergent light, and we therefore leave it undetermined. As stated before, the base has undergone globulitic devitrification.

One of the specimens collected near Porto Praya belongs to the phonolites. This rock is greenish grey, with waxy lustre, compact, with shining macroscopical felspathic lamellæ, which can be seen with the naked eye in the ground-mass. Under the microscope this rock shows the structure and composition of phonolite. Rather large hexagonal and quadratic sections must be ascribed to nepheline; they are colourless, crossed in the quadratic section with rectangular lines of cleavage; the hexagonal sections remain dark when rotated between crossed nicols; the quadratic, on the other hand, extinguish parallel to the sides. The polarisation colours are of a bluish shade, and rather pale. The hexagonal sections show, with convergent light, a very indistinct black cross; the double refraction is negative. The lines of cleavage are very marked, and are parallel to the base of the prism; twinning is never observed in them; but the optical phenomena show certain anomalies which must be due to mechanical action. This rock also contains large crystals of sanidine, twinned according to the Carlsbad law; they show the characteristic fractures and extinction of this mineral. These peculiarities, but specially the optical phenomena in convergent light, prevent these sanidine sections being mistaken for nepheline. These sections show the arms of the hyperbola of biaxial crystals; and, moreover, a section twinned according to the Carlsbad law sometimes shows on the left individual, for example, a bissectrix indicating that the plane of the optical axis is parallel to the composition plane, whilst the other individual presents phenomena very analogous in aspect to those of the monaxial crystals. Here, no arm of hyperbola is to be seen, but as it were a very eccentric cross, whose arms are perpendicular and parallel to the length. To observe these phenomena it is not necessary that the section should be twinned: we see, indeed, single crystals, prismatic like those in question, some of them showing the bissectrix, the others the pseudo-black cross. Rather numerous crystals of titanite and lamellæ of biotite are found in the microscopic preparations. It is difficult to ascertain the true nature of small dichroic needles, with vague outlines and slightly fibrous at both ends, which are embedded in the rather altered ground-mass. Some of these needles give straight extinctions, others extinguish at about 20°; it seems probable that they belong to augite.

We have examined some specimens of calcareous rocks found near the coast at the south of St. Iago, to which Darwin devoted a very detailed description.

Among our specimens there were fragments of the limestone taken from the raised beach he describes.[1] We refer to his book on Volcanic Islands for the details relating to the changes which have affected this calcareous rock in contact with the overlying volcanic products. Doelter[2] remarks that he was able to trace this alteration only on a layer of 10 inches, at the contact of the limestone and lava. The limestone has become granular, and some of its grains are rather large. These are the only phenomena of contact observed by Professor Doelter at San Jago. Other observations on the same subject made by Darwin must, according to Doelter, be explained in another way.

A specimen of limestone from this raised beach has been collected at the contact of the lava. This calcareous rock is massive; the layer near the lava is opal blue, and the grains are somewhat larger; the other part of the specimen is brownish. Calcareous grains and small fragments of volcanic material are cemented by infiltrated calcite. Near the zone of contact the grains are of a deeper blue, but the saccharoid structure is not clearly shown. The calcite of this thin zone of contact effervesces with hydrochloric acid, leaving a residue composed of organic matter; it yields only a trace of magnesia. The white and bluish grains are fragments of organisms, as can be ascertained by microscopic examination. Under the microscope it is seen that the organic structure is not entirely destroyed; the sections showing this are less transparent than those of infiltrated calcite, and they are speckled with brown and bordered by a yellowish zone. The secondary calcite is clear and crystalline, showing the rhombohedral cleavage characteristic of this species. The small volcanic fragments embedded in this limestone are splinters of basalt, palagonite, augite, olivine, hornblende, and biotite. They are isolated and entirely surrounded by infiltrated limestone. Microscopic concretions of iron and manganese oxide are also to be seen.

Another specimen from this raised beach is very like that we have just described, but it contains more volcanic fragments; among these are found all the rocks and minerals above mentioned. Augite is specially abundant. As in the former case, saccharoid structure cannot be observed. The details of the organic structure are not washed out, and the hemitropic striæ following $-\frac{1}{2}R$ are never seen.

We shall mention, in conclusion, a specimen of limestone which covers the lava on the coast near Porto Praya, and which ought to be considered as a stalactitic deposit. This specimen is brownish yellow, and is formed by the superposition of more or less folded and slightly adherent lamellæ. Calcite has crystallised in the cavities, and some small elongated scalenohedric crystals can be recognised. This coating contains compact black volcanic splinters two or three centimetres in length; these are glassy fragments passing to palagonite. Darwin observed these inclusions, and compared them rightly to the palagonite found by him in the Galapogos Islands. Under the microscope no

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[1] Darwin, *loc. cit.*, p. 3.

[2] Doelter, *loc. cit.*, pp. 45, 191.

organic remains can be detected in the specimen, all the calcite sections showing that this mineral has a stalactitic origin. The rock is almost entirely composed of sharply defined crystalline grains often giving triangular sections; by their juxtaposition they present a serrated appearance. The centre of these sections is generally of a brownish yellow colour, surrounded by a clearer zone; in form they can be derived from an acute rhombohedron or from a scalenohedron. This incrustation is thus essentially formed of very small acicular crystals of calcite closely packed against each other, the interspaces having been filled later by a calcareous deposit to which the rock owes its compact and shining appearance.

III.—ROCKS OF ST. THOMAS (WEST INDIES).

The specimens we have examined are fragments, concerning the original situation of which there is no information, some of them being rolled pebbles. It is consequently necessary, in the absence of stratigraphical details, to confine ourselves to a description of lithological and mineralogical features.

One of the rock specimens has a porphyritic structure with large crystals of hornblende (three to four millimetres in diameter), imbedded in an essentially felspathic ground-mass. Examination under the microscope shows it to be a much altered quartziferous diorite. The fine-grained ground-mass presents rather distinct crystals of hornblende and quartz, patches of little prisms and grains of epidote and titaniferous iron, and aggregations of decomposition products. Hornblende is the best developed and least altered of the minerals of the first generation. The maximum angle of extinction was found to be about 19°, and the characteristic cleavages are sharply marked. The pleochroism is shown in the following manner: for α pale yellow; for β yellowish brown; and for γ pale green; the absorption being $\beta > \gamma > \alpha$. These sections often show a zonary structure, the special colours of each layer being sometimes sharply defined. They are frequently twinned polysynthetically according to the law: plane of twinning $\infty \bar{P} \infty$ in sections parallel to $\infty \grave{R} \infty$, in which symmetrical extinctions of 19° are obtained on both sides of the lamellæ. Although the hornblende is relatively little altered, it is seen to be traversed by fissures which have become filled by secondary quartz, probably derived from the associated minerals. Quartz takes otherwise a very important place in the composition of this rock. The sections show, instead of the common irregular fractures of this mineral, a series of fissures which follow the cleavages of the rhombohedron. These quartz grains touch along straight lines, which gives them a strong resemblance to Carlsbad twins such as are shown by sanidine. On the other hand, the abundance of liquid inclusions with moving bubbles, and, in certain cases, the outlines and their relation to the direction of cleavage, the smooth surface of the sections, and the optical characters, leave no doubt as to the true determination. Some sections, in fact, show the black cross and that the mineral is positive. Epidote is also well developed in the rock, this secondary product appearing in the form of grains, often grouped or scattered uniformly between the crystals of hornblende. The epidote is distinguished in this case by the brilliancy of its polarisation colours, and a very feeble pleochroism, citron-yellow or an almost colourless shade of green. This mineral is sometimes crystallised in fibro-radial bundles. Titaniferous iron is also somewhat common, and is decomposed into leucoxene. Crystals of grey titanite, probably derived from the decomposition of ilmenite, may also be detected. The last-mentioned mineral has sometimes left hexagonal hollows where leucoxene and epidote have subsequently developed. The ground-mass is chiefly formed of quartzose grains, epidote, and the remains of a few indistinct crystals of plagioclase. The microscopical structure shows that this rock is a diorite, and this conclusion is confirmed by the examination of the sections of hornblende. The completeness of these crystals as to their external form, and their freshness, clearly show, it seems to us, that this mineral is primordial, and does not take its origin from the paramorphosis of augite into hornblende, as frequently happens in altered diabases. The presence of quartz also indicates that the rock may be related to the quartziferous diorites, but in order to establish this determination one element—plagioclase felspar—seems to be wanting. Still, on taking into consideration certain other specimens of similar rocks from the same place, which show sections of plagioclase associated with quartz and epidote, it is easy to believe that, in the rock under consideration, the plagioclase has undergone alteration into epidote. It is necessary to mention the fact that for the classification of the rock as diorite there is no other ground than the mineralogical composition and structure, all stratigraphical data being wanting.

Another rock presenting considerable analogy with the preceding is finer grained, massive, greyish in colour, and breaks with a slightly conchoidal fracture. It also may be classed as a diorite. The naked eye detects in the mass very small crystals of felspar, and more rarely of hornblende. The microscope shows a ground-mass containing rather large sections of hornblende, the crystallographic and optical characters of which are like those of the same mineral in the rock just described, only it is more decomposed, and the zonary structure does not appear. On the other hand, plagioclase, of which only traces were perceptible in the former rock, is here much less altered, and it is possible to determine the species. The lamellar sections of this plagioclase gave an average extinction of about 6° on the trace of *M*. The symmetrical angles of extinction on the two sides of the polysynthetic lamellæ gave as an average 5°. Sections of plagioclase are sometimes observed which are quadratic and show the striation of albite and pericline. In these sections, which are in the zone $P:k$, the extinction takes place almost parallel to the trace of M; hexagonal sections extinguish at an angle, the mean value of which does not exceed 6°. These measurements and the nature of the rock appear to show that the plagioclase in question is oligoclase. All the steps in the transition may be observed from rather large crystals of plagioclase to the small entangled felspathic lamellæ which form almost the entire ground-mass of the rock. These microliths are polysynthetic and extinguish at very small angles, showing that, from the point of view of the plagioclastic mixture, they are akin to the larger individuals which belong to an earlier stage of consolidation. It is perhaps not without interest to point out this analogy of the microliths of the base and the microporphyritic crystals. The microscopic preparations are sprinkled with black grains of magnetite or titaniferous iron. In addition epidote, and in particular calcite, may be mentioned as rather common secondary products. Calcite occurs in somewhat large sections traversed by polysynthetic lamellæ following—$\frac{1}{2}R$. Finally, quartzose veinules were observed penetrated by small colourless lamellæ, which appear iridescent in polarised light, and are very probably scales of white mica. On taking account of the facts that no trace of calcite appears in the quartz veins, and no quartz in the sections of calcite, one is led to conclude that the infiltration of quartz and of calcite occurred at different stages in the series of secondary modifications to which this diorite has been subjected.

In the two rocks just described the specimens were referred to diorite, and we remarked the profound alteration which had attacked the hornblende in one case and the plagioclase in the other. The difficulties in the way of exact determinations may readily be understood when decomposition has to so great an extent veiled the true nature of the rock, and when so many of the specimens are rolled pebbles picked up on the shore. We incline to believe, however, that they belong to the ancient type, and these general remarks apply equally well to the specimens from the same locality which remain to be described.

The next to consider is a fine-grained greenish rock, dotted with felspar, and breaking with an irregular fracture. Microscopical examination shows the rock to be greatly altered. The felspar is associated with secondary minerals, epidote, calcite, and chlorite; sections which might belong to bisilicates are not detected with certainty, but everything goes to show that these were present in the rock before it was decomposed. It is remarkable that the felspar should not have been more altered, the polysynthetic lamellæ being still perfectly apparent. These crystals are somewhat large, and appear enclosed in a mass which is composed principally of minute lamellar sections of plagioclase. These microporphyritic crystals sometimes present sections in the form of an octagon with two long sides. This would indicate that the crystals have pyramidal faces in the zone $P:M$ (n) or in the zone $x:M$ (o). The sections extinguish at a rather small angle, which leads one to believe that the plagioclase is akin to oligoclase or andesine. Some individuals are found extinguishing parallel to the lengthened sides, and showing no plagioclastic lamellæ, which would seem to indicate that they are orthoclase. It is difficult to decide this question, but the hypothesis is not without some basis, since the rock presents the association of quartz and felspar, which is known as micropegmatite. Now it is well known that no plagioclase intergrows in this manner with quartz. We lay no stress on the secondary minerals; the epidote appears as in the diorites already described, quartz of secondary formation is abundant, and also lamellæ of chlorite united and entangled with epidote. These minerals either penetrate the entire ground-mass, or have crystallised in microscopic geodes and fissures. The specimen examined is not homogeneous, and everything points to the conclusion that it is a volcanic tufa of ancient type, but decomposition has proceeded so far that no definite opinion can be arrived at on this point. The rock just noticed may be described as related to the diorite type, to which it shows special affinities in the small angle of extinction of the felspar. Another one now to be described departs altogether from this type. It is fine-grained and crystalline, with numerous small crystals of plagioclase and augite, and greenish black brilliant scales of a chloritic mineral. It contains a black mass which seems to have been enclosed; the fracture is almost plane. The augite crystals and the very high angle of extinction of the plagioclase distinguish this rock from the preceding. Plagioclase plays an important part in it, appearing in the form of large crystals or aggregations, and being twinned according to the albite and pericline laws. In the sections in which hemitropic striæ appear (those following the albite law crossing those of pericline at right angles), the symmetrical angle of extinction for the polysynthetic lamellæ may rise above 30°, which seems to indicate that this felspar is not far removed from bytownite or anorthite. Pyroxene appears in the form of rather large rounded crystals often twinned polysynthetically according to the ordinary law. Its colour is not dark, sometimes indeed a very pale yellow tint. This mineral has undergone mechanical changes which have given its sections a fragmentary appearance; they are decomposed on the surface, and calcite has crystallised along the edges. The augite contains cavities that may have been originally vitreous, but they have been modified by decomposition, which has also altered the base, probably vitreous at its origin, and transformed it in great part into secondary quartz and matter resembling chlorite. Although it is extremely difficult to give a decided opinion on the nomenclature to apply to rocks collected in isolated fragments and which have undergone great alteration, still, by taking account of the texture, the mineral association, and the special characters of the augite and plagioclase, one may venture to class the specimen under consideration with the diabases.

A greenish pebble with irregular fracture, sprinkled with large, more or less circular, patches of calcite, contains only one macroscopical mineral, greenish in colour, probably augite or epidote. Microscopical examination shows that this rock may be considered as forming a transition between the series of diorites and of diabases. Although much altered, we can class it amongst the *Diabas Mandelstein* of the German lithologists. The ground-mass is formed almost entirely of felspar associated with numerous grains of epidote and other decomposition products, while a glimpse is sometimes caught of small vague prisms of augite. Crystals of felspar of the first generation are rather well developed; they occur as thick shortened prisms, several being sometimes grouped together. They are twinned according to the albite law. The angles of symmetrical extinction on the two sides of the hemitropic lamellæ, and of that following the trace of *M*, are generally somewhat small, seldom exceeding the average value of 7° or 8°. Augite is the best represented mineral of first generation; it appears as grains, and shows the characteristics we recognise in amphibolic rocks such as diorite. There would be no hesitation in classing this rock as a diorite, if the hornblende were better characterised, but only doubtful traces of this mineral are to be found in the form of hexagonal sections which might have been amphibolic originally, but are now only pseudomorphs. These sections are almost as large as those of felspar, the contours being sometimes clearly defined; in other cases they merge into the surrounding ground-mass. With polarised light the mineral in question behaves like an aggregate; some indistinct patches take a bluish tint or remain unaffected, and these might possibly be nepheline or apatite. Secondary quartz is developed, but not to such an extent as epidote, which appears to penetrate the whole mass; its grains, although often very small, are recognisable by a slight citron-yellow pleochroism, brilliant colours of polarisation, and an irregular surface. It is abundant in the cavities, where it has crystallised in the form of a fan, and is associated with calcite. Sometimes the nearly circular vesicles, which give the rock the appearance of a *Diabas Mandelstein,* are filled with these two minerals often associated with chlorite.

A rolled pebble, reddish brown in colour with dark green grains of augite and white grains of altered felspar, is a clastic rock. This tufa contains all the minerals mentioned in the rocks already described. The ground-mass is made up of small, more or less abundant, crystals of plagioclase, and of lapilli, which are distinctly separated from each other and cemented by a coating of ferric hydrate. The large fragments of felspar, which are seen scattered sporadically through the preparations, have the same optical and crystallographic properties as those described above. These sections are usually rounded, and are partly altered, not however by kaolinisation, but rather by zeolitisation; instead of small micaceous lamellæ with iridescent tints in polarised light, these sections are seen showing a blue colour which extends over pretty large surfaces separated by colourless intervals. Numerous crystals of zeolites are also to be seen in the vesicles of the rock. Epidote has crystallised in the interior of the felspar; with calcite and chlorite they occasionally entirely fill the place of the primary plagioclase. The sections of augite show the fragmentary nature of the mineral even better than those of felspar by their notched and cracked outlines. This pyroxene is almost colourless, as was the case also in the other rocks from this locality which have been described. It is recognised by its vivid colours of polarisation and by its characteristic cleavage. Although epidote appears for the most part to have been formed where it is found, there are sections of it which bear unmistakeable traces of having belonged to an original crystalline rock. We have said that epidote has crystallised in the vesicles of the diabases from St. Thomas, where it assumes the form of almost colourless fibro-radial groups, more or less spherical or ellipsoidal in shape; now, in the specimen just described fragments of this amygdaloidal epidote are found. This mineral is characterised by its brilliant polarisation colours, its pale tint in ordinary light, absorption, and the citron yellow pleochroism it exhibits, as well as by a slightly rough appearance of the surface of the sections. Like the felspar, this epidote appears to show vague polarisation phenomena, resulting from the stress to which the rock was subjected. Aggregations of epidote, chlorite, and quartz, which are sometimes seen as yellowish green or almost colourless patches, may very well be derived from the decomposition of a bisilicate, all further traces of which have vanished through alteration. Besides zeolites resulting from the transformation of part of the felspathic substance, these secondary minerals are found in all the vesicles of the rock, where they appear as a coating or as small colourless crystals sometimes prismatic. Occasionally they all appear to be chabasite, twinned crystals of which are recognisable.

To summarise briefly the leading features characterising the descriptions given above, we may say that, taking account of all the transitions which have been shown, the specimens from St. Thomas represent an uninterrupted series, from amphibolic rocks with acid plagioclase (oligoclase) to augitic rocks containing a plagioclase approaching anorthite.

IV.—ROCKS OF FERNANDO NORONHA.

The group of small islands called, from the principal islet, by the name of Fernando Noronha, is situated in the Atlantic, about 3° 50′ S. lat. and 350 miles off the coast of South America. The soundings made by the Challenger in the neighbourhood of these islands show that they rise somewhat abruptly from the bottom of the sea.

Peak of Fernando Noronha, sketched from the deck of H.M.S. Challenger.

Darwin, in his work on Volcanic Islands,[1] reports that he visited Fernando Noronha during the voyage of the "Beagle," but his stay there was of short duration. He states that these islands are of volcanic origin, but that he did not observe any crater. According to Darwin, one of the most salient features of the topography is a hill about 1000 feet high, forming an escarpment, and crowned by a summit, 400 feet high, of a phonolithic rock; this rock contains, he says, numerous crystals of felspar and some prisms of hornblende. From the highest point of this hill he was able to observe that the other islands of the group had conical summits of the same nature. He recalls the fact that at St. Helena, also, great phonolithic masses occur, rising vertically to 1000 feet; these have evidently been injected into crevices while fluid. If this hill of Fernando Noronha, he adds, owes its origin to the same cause, as seems probable on other accounts, we are forced to admit that denudation has occurred here on a great scale. Near the base of this eminence Darwin observed some beds of whitish tufa, traversed by numerous dykes, some of amygdaloidal basalt, others of trachyte. He noticed, also, some beds of fissile phonolite, in which the planes of schistosity ran N.W. and S.E. Certain parts of this rock, where the crystals are less numerous, resemble slate altered by contact with a trap dyke. The lamination of the rock, which at first had incontestably been in a state of igneous fusion, seemed to him an important subject for investigation. Darwin concludes his brief description by adding that he found on the shore numerous fragments of compact basalt; they appear to come from a columnar rock which is seen in the neighbourhood.

The craggy phonolithic mass, to which Darwin alludes, is St. Michael's Mount. Mr. Buchanan[2] remarks that at the foot of the eminence the rock is columnar, while towards the summit it assumes a massive structure. On the west side of Fernando Noronha the columns are inclined at an angle of about 30° to the horizon. Their section is almost square, but the angles are greatly rounded off, and the columns are not very thick. He adds that the rock is greenish, and that crystals of sanidine occur in it, lying with their broad faces in a plane perpendicular to the length of the columns. The slopes of St. Michael's Mount are covered with blocks of massive phonolite, often decomposed, and thus exhibiting the sanidine crystals in relief. This rock possesses the characteristic properties of the phonolites: it rings under the hammer. The specimens which we have examined are less schistose or fissile than many of the rocks of the same type, but both the naked-eye and the microscopical characters confirm the determination of Darwin and of Buchanan.

One specimen, taken from a columnar block, appears compact to the eye, is greenish grey in colour, dotted with white, has an irregular scaly fracture, and a

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[1] Darwin, Geological Observations on Volcanic Islands, p. 23. See also Wyville Thomson, The Voyage of the Challenger, The Atlantic, vol. ii. p. 109, London, 1877; Moseley, Notes of a Naturalist on the Challenger, London, 1879.

[2] J. Y. Buchanan, *Proc. Roy. Soc.*, vol. xxiv. p. 613, 1876.

slightly waxy lustre. With the naked eye only some crystals of sanidine, from 2 to 3 millimetres in length on the average, can be made out among the constituent minerals; cleavage lamellæ parallel to *M* are seen gleaming. The rock yields some water on heating in the closed tube; when attacked by acids it gelatinises readily. Its specific gravity is 2·635. The specimens of massive phonolite from the summit of the mountain do not differ in any essential manner from that of which the macroscopical characters have just been given.

When examined with the microscope, this phonolite shows a microporphyritic texture; embedded in a very close-grained ground-mass, in which one notices only small, somewhat irregular microliths of augite showing fluidal structure, there are seen, as minerals of the first generation, sections of nepheline, sanidine, augite, hornblende, magnetite, titanite, and nosean. We shall now consider the characters of these minerals of first generation.

Sections of nepheline are very common; they are distinguished at a glance from the other constituent minerals by the sharpness of their contours, and by their completeness. Comparison of the form of sections, cut in various directions, show that the nepheline in this rock takes the form of crystals slightly tabular, parallel to *OP*, with the faces of the prism somewhat shortened. The commonest sections are equilateral hexagons with an angle of 120°; they are remarkably limpid, and very slightly blue or almost colourless in tint. This mineral has no inclusions except titanite; it is perfectly homogeneous. The lines of cleavage which traverse it are distinct; they have the appearance of regular blackish strokes, parallel to three alternate sides of the hexagonal sections. In parallel polarised light these sections remain constantly obscured throughout a complete rotation; in convergent light it is rather rare to be able to observe the usual black cross of monaxial crystals. This mineral also presents rectangular sections with a similar physical aspect. They show two cleavages: the more distinct of the two is indicated by streaks parallel to the traces of the prism; the other, perpendicular to the first, is less marked, and is parallel to the pinacoid *OP*. These sections always extinguish parallel to the sides. Nepheline often occurs in this phonolite in aggregates of several crystals grouped parallel to the vertical axis; these aggregates are recognised by the outlines forming reëntrant angles, and, between crossed nicols, these adherent crystals are distinguished one from another by different shades of the same tint. The tints of chromatic polarisation are feeble, and generally clear blue. An alteration is sometimes seen between crossed nicols, which has already been pointed out as occurring in nepheline; we refer to a more or less complete zeolitisation. In polarised light several sections assume a darker tint than usual, at the same time they look as if stumped; but sometimes certain patches are almost colourless, and a kind of marbling is produced by this want of homogeneity. On examining these sections more closely, one sees that this appearance is due to the presence of tufts, filaments, and lamellæ intertwined in all directions. Their aspect and their polarisation tint recall precisely the appearance of certain zeolites. The nepheline has been but slightly subjected either to the corrosive action of the magma or to mechanical deformations. It is this that distinguishes it at a glance from the sanidine, with which, but for the twins, and the peculiarities that are to be described in the latter, it might perhaps be confounded. The relief of the contours and the phenomena of polarisation, so far as colour is concerned, give us little help in differentiating these two minerals at first sight. But they can be distinguished by the irregular breaks of the sanidine, the elongation of its sections, and by its Carlsbad twins.

The sanidine occurs, as we have just indicated, in lamellæ elongated parallel to the edge *P*/*M*; indeed it can be observed that certain sections, in which the Carlsbad twinning does not appear, and which are therefore almost parallel to *M*, have elongated rhomboidal forms, in which are seen the outlines of the faces of the prism and of *P* or *x*. This mineral is almost always cracked by more or less irregular fissures, which seem in sections parallel to *P* to be perpendicular to the greatest length, while in those taken parallel to *M* they are sensibly parallel to the vertical axis. The action of the magma has often been exerted along these fissures, which are filled by the ground-mass; this action is also shown by the corrosion of the outlines of the mineral, so much so that no rectilinear outlines are now to be found; they are scooped out more or less deeply, serrated and sometimes rounded off. Besides these corrosions there are other phenomena in the sanidine that are to be attributed to the fluidity of the magma: the sections appear dislocated and twisted; the various fragments of a crystal are scattered and overlap one another, and it is rare to see a section of sanidine in which one cannot make out displacements and ruptures. In parallel light sections showing the composition plane of the Carlsbad twin distinctly exhibit straight extinction, which occurs parallel to their greatest length. In convergent light sections cut perpendicularly to the prismatic zone show in each of the two individuals one of the two axes situated along the length of the section at opposite sides of the plane of vision. This seems to indicate that in this sanidine the optical axes are in the plane of symmetry.

Augite is one of the most widely distributed minerals in this rock. It occurs firstly in large individuals, then microporphyritically, and lastly as immense numbers of microliths in the ground-mass. We have here to describe the large augites of first generation. The character which at once distinguishes them is their green tint; these sections are very dichroic. The forms usual in this augite are octahedral sections, with the sides that represent the traces of the prisms more developed than those corresponding to the traces of the pinacoids. The prismatic cleavage is not well marked,—on the contrary, lines of cleavage more distinct than these are to be seen running parallel to the pinacoid $\infty P\infty$. Sections of the vertical zone are furrowed by rather indistinct cleavages parallel to the axis *c*, and by fractures more or less nearly parallel to the pinacoid *OP*. It is somewhat rare to find the outlines well shown in these various sections: they are usually bordered by a rim of small augite prisms, which belong to the second phase of consolidation. In the sections more or less parallel to the clinopinacoid, extinctions are observed that exceed 20° and sometimes amount to 30°. The pleochroism and absorption are—

α >	β >	γ
yellowish brown.	greenish yellow.	green.

In exceptional cases it is found that the green tint of this augite changes to the reddish coloration so common in the pyroxene of basalt. The inclusions seen in these augite sections are microscopic prisms of apatite, and a few granules of magnetite.

The hornblende of this phonolite ought to be regarded as an accessory mineral; it occurs only in some few individual crystals, these being for the greater part transformed into magnetite. It has the shape of very deformed hexagonal sections, at the centre of which are brown patches markedly dichroic in brownish shades, the differences, however, arising generally from differences of absorption. These sections are bordered by a broad zone of magnetite, which tends to encroach upon the centre of the crystal, where nothing but a round nucleus usually remains. The black opaque girdle which surrounds it is homogeneous, and is not formed of an aggregation of isolated grains as is often the case,—in the amphibolic andesites, for example. This zone of magnetite is frequently larger than the amphibolic centre; in some instances the hornblende is entirely displaced, the contours of the section being the only indications of the pseudomorphosis. We always find around these sections of hornblende bordered by magnetite a second zone made up of small augite microliths crowded one over another, indeed, such a girdle of small green augite crystals is almost always found round all the microporphyritic crystals of this rock.

Of the accessory minerals titanite is that which next to hornblende is best represented in this phonolite. Its sections are in general smaller than those of the latter mineral, descending even to the dimensions of the microliths in the ground-mass. This mineral has crystallised most perfectly, and has best preserved the entirety of its forms. Sections with rhombic outlines are the commonest,—they can be set down as sections of the zone *Px*, for the extinctions are parallel to the diagonals, and the angular values correspond to those of the prism (129°-133°). One might conclude from the abundance of these sections that titanite has crystallised in this rock in the tabular form, and that the dominant face is more or less nearly perpendicular to the zone of the prisms. Besides these sections we find some of the same mineral that are more elongated, and, finally, others that have reëntrant angles and appear twinned in polarised light. The surface of the sections is fretted; they show a very pronounced relief; their dicroscopism is slightly marked,—the rhombic sections just mentioned exhibiting variations of tint from slightly greyish to brownish yellow. The colours of polarisation, without being conspicuously vivid, present a peculiar appearance which may be termed irisation.

Nosean is also one of the microporphyritic elements; its sections are square-shaped, hexagonal, or octagonal; the reëntrant angles indicate multiple groupings. The individuals of this mineral are not homogeneous, the interior of the sections being riddled with inclusions often disposed in a network. The peripheral zone is not so dark in tint as the nucleus, being often greyish, or inclining to clear blue, or coloured by hydrated ferric oxide. Polarised light fails to reveal the striæ characteristic of certain noseans,—the sections are perfectly isotropic.

Besides magnetite found round the crystals of hornblende, as mentioned above, that mineral occurs also in grains, as an element of the first generation, as inclusions in certain constituent minerals,—in augite, for instance.

The ground-mass is characterised by fluidal structure. The constituent minerals are, hornblende excepted, precisely those that have already been recognised in the form of microporphyritic individuals. This ground-mass consists almost entirely of small lamellar felspars, which extinguish very often in directions parallel to the long edges, and exhibit, in most cases, the Carlsbad twinning. These small crystals of sanidine are associated and often combined with some sections of the same tint and appearance, which sections, however, are broader, better defined, and are never twinned; the outlines of these sections and their optical properties enable us to recognise them as nepheline.

The most conspicuous mineral in the ground-mass is a microlithic pyroxene; it has a green tint analogous to that of the large crystals of the same species that occur in this rock. In general the outlines of these small augites are indistinct; they are rather of the shape of elongated grains than prismatic, and where they are found to have a prismatic appearance, the outlines are indented. They are twinned according to the usual law of augitic pyroxene; they are pleochroic like the microporphyritic augites, and in some instances one can make out in vertical sections extinctions that exceed 30°. It seems very probable that titanite is represented in the ground-mass by some very small crystals. It remains to refer to one more mineral, namely, apatite. It always occurs in very small individuals, the sections being frequently parallel to the vertical axis; they show traces of the pyramid, and not merely the pinacoid as is usually the case. They extinguish parallel to the line of their length; sometimes a slight dichroism is noticed, the rays vibrating parallel to the vertical axis being bluish, those which vibrate in a plane perpendicular to the greatest length almost colourless.

Mr. Buchanan collected in the fissures which in two places scored St. Michael's Mount from summit to base, a substance having the appearance and hardness of quartz.

This mineral is concretionary, and is sometimes foliated into thin plates; it is whitish, yellowish, or yellowish brown. It scratches glass readily, and does not effervesce when treated with acids. Slices, 2 to 3 millimetres thick, are translucent. When heated in the lamp, it becomes white without melting, and the residue after this operation crumbles between the fingers. In the closed tube it yields water with an alkaline reaction, and gives off an empyreumatic smell. Qualitative analysis shows in it phosphate of aluminium and of iron, silica, and sulphate of lime.[1] Analysis gives the following composition :—

Silica, SiO_2,	0·27
Sulphuric acid, SO_3,	1·40
Phosphoric acid, P_2O_5,	50·72
Alumina, Al_2O_3,	37·03
Ferric Oxide, Fe_2O_3,	5·42
Lime, CaO,	0·98
Loss on ignition,	4·54
	100·36

The explorers of the Challenger landed afterwards at Rat Island, the most important islet of the group after Fernando Noronha. Mr. Buchanan observed on the west of Rat Island a massive basaltic rock, which we shall describe, and on the east a granular calcareous rock. "It is probable," he adds, "that this calcareous grit overlies the basalt; its structure seems to indicate that it has been laid down as drift. This consolidated sand is calcareous, and contains a large number of shells. On our way to Rat Island, in passing alongside of Booby Island, we saw that it also is almost entirely formed of this calcareous grit. No old igneous rock is to be seen in it; and seeing, from the ripple marks, that the stratification may continue under the sea-level, there is some reason to think that Booby Island is subsiding, or that it has subsided at some previous time." We shall shortly return to the calcareous grit just mentioned, but will first describe the basalt of Rat Island.

Examined macroscopically this rock is black, massive, perfectly homogeneous, and has a sub-conchoidal fracture. In the very fine-grained ground-mass some yellow granules of olivine are visible, and some very small prisms, which ought to be identified as nepheline. When reduced to powder, this rock gelatinises markedly with acids. Its specific gravity is 2·957. Microscopical examination places it among the nepheline basalts. At first sight, what strikes one is the absence of polysynthetic felspathic lamellæ. The very fine-grained ground-mass is seen under high powers to be composed essentially of nepheline and augite, without interposition of vitreous matter. These two minerals have in general vague outlines, still there can be distinguished some colourless hexagonal sections that remain dark during a complete rotation between

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[1] J. Y. Buchanan, *loc. cit.*, pp. 613, 614.

crossed nicols, and some rectangular sections, slightly elongated parallelograms, that extinguish in directions parallel to the sides. It is not difficult in this case to recognise nepheline, though in other cases it is disguised in the mass under the form of rounded grains, but these are connected by a complete series of transitions with the distinct sections just described. The granular shape prevents this mineral from being confounded with felspar, which never has this appearance except where, as in granitoidal rocks, it is associated with quartz. With these microliths and grains of nepheline are associated small prisms of augite, slightly yellowish or brownish and with vague outlines, some of which have large extinctions. Owing to the difference of refractive index between nepheline and augite, the latter is sharply separated from its neighbouring mineral. An interesting feature of this rock is the presence of large olivine crystals, almost always fragmentary; it is the only microporphyritic mineral present, and is much larger than the two species just mentioned. The sections of olivine are rugose, almost colourless; they are bounded by the traces of the dome and of the prismatic faces; they extinguish parallel to the line of their length. Often they suggest by their shape a well-developed crystal of olivine; at other times we see that they are only fragments of a single individual, which can be readily restored with the help of the corresponding pieces to be found in neighbouring sections. It is apparent that these olivine crystals, belonging to the very first phase of consolidation, have been subjected to dislocation and to the corrosive action of the magma. They are broken at the edges, and sometimes the ground-mass has penetrated the interior of the crystal. All the olivine sections are altered to yellow on the sides; when the sections are small this zone of hydrated ferric oxide is so much developed that nothing may remain but a small colourless area at the centre of the section. A tendency to assume a fibrous structure is noticeable in the sections of this mineral. Several sections of olivine are often seen grouped and joined together; in polarised light these clusters sometimes exhibit phenomena that vividly recall those observed in twins, but here the planes of junction are too vaguely indicated to allow a positive statement; nevertheless there are such sections showing two individuals laid together and having a shape perfectly reconcilable with that of well-known twins of the rhombic system. Amongst the accessory minerals we must note black mica, occurring in irregular scales strongly pleochroic, and giving straight extinction; this mica is often intimately associated with the decomposed olivine; it sometimes even occurs as an inclusion in that mineral, which contains also some particles of secondary calcite. This carbonate is present also in very fine filaments in the ground-mass; it is recognised by its irisation, by the twins parallel to $-\frac{1}{2}R$, and by its cleavage. Worthy of interest is the presence of very numerous minute grains of perowskite distributed throughout the ground-mass, where they play a part almost as important as that of magnetite. Perowskite is hardly ever found in well crystallised individuals, though sometimes traces of octohedra can be made out.

Usually it takes the form of grains with rugose surface, sometimes broken, transparent, with a blue tint inclining a little to violet, and with very decided relief; in general these sections are isotropic. Magnetic iron in the shape of grains or of microscopic crystals is tolerably abundant, and is distributed throughout the mass. Lastly, there are still to be noted some small prisms of apatite.

The limestone mentioned above, which was collected by Mr. Buchanan in the south-east of Rat Island, shows on a freshly-fractured surface a compact rosy or yellowish mass, with small white crystalline specks and yellow or blackish grains less than a millimetre in diameter. The white specks are shells, the yellow and black grains are fragments of rocks and of volcanic minerals. This rock is moderately hard; it often presents on its surface a scoriaceous aspect, and sometimes also cavities are seen in the interior. When treated with hydrochloric acid it leaves a residue of about 30 per cent. of its mass. Under the microscope this rock resolves itself into crystallised colourless limestone, devoid of any trace of organic structure, and forming, one may say, the paste or cement of the clastic grains of organic or mineral origin. These grains of calcite are of two sizes: some are very large, while others, smaller and probably of secondary formation, occupy the intervals left between their larger neighbours. Carbonate of lime also occurs, in microscopic acicular crystals. The mineral and organic particles are all clastic and worn, each being surrounded by a narrow zone of calcite. Among the minerals olivine is frequently visible, coloured red by decomposition; other grains consist of small splinters of basaltic rock,—among them being some particles of basaltic glass changed into palagonitic matter. A rock almost identical with this limestone of Rat Island was found by Mr. Buchanan overlying the basalt of Platform Island, of which we are about to speak.

The islet of this group that goes by the name of Platform Island is composed of columnar basalt, on which lies an extensive and uniform bed of calcareous rock, the specimens of which are, as we have said, analogous to the limestone of Rat Island. The basalt of Platform Island is slightly more granular than the nepheline basalt described above. It is black, and slightly vesicular, while to the naked eye only some crystals of augite are visible, embedded in the ground-mass. Under the microscope this rock proves to be felspathic basalt. In a ground-mass, in which from their number certain small felspathic lamellæ predominate, we find large microporphyritic crystals of augite, and sections of olivine of smaller size; the plagioclase as well as the magnetite are always microlithic. The augite sections are not very prismatic; the crystals are more shortened than those usually observed in basaltic rocks. Sections parallel to ∞Ꝑ∞ are often unsymmetrical hexagons, whose outlines represent the traces of faces of the zone *n* and *t*, and of those of the prisms. Octagonal sections also occur, unsymmetrical like the former; these are perpendicular to the plane of symmetry, and extinguish parallel to the line of their length. The extinctions measured on the face $\infty \not{P} \infty$ exceed 40°. Sections more or less perpendicular to the axis c are fairly regular octagons, in which the traces of the pinacoids are more developed than those of the prisms. The augite is filled with vitreous inclusions, which are accumulated at the centre of the crystals; round this non-homogeneous nucleus is a zone of slightly reddish tint, the nucleus being usually not so dark. The optical phenomena are disturbed by an incipient alteration, which shows itself in the formation of chloritic material. The prismatic cleavages are not distinct; they are, rather, irregular cracks; the cause of this anomaly lies in the presence of so great a quantity of vitreous inclusions. Besides the twin following the ordinary law, some sections of augite seem to be twinned with a composition plane parallel to a face of a pyramid, as has already been observed in augite. The vitreous inclusions are irregularly shaped; their colour is generally faint, but sometimes they assume the colour of the augite which contains them. One is led to suppose that there might have been a partial refusion of the pyroxenic element, but what renders this interpretation hypothetical is that the external zone which surrounds these nuclei, and which is entirely homogeneous, has not been altered at all. This fact appears to dispel all idea of a later caustic action exerting itself on the crystal. Besides the vitreous inclusions, some are to be seen consisting of grains of magnetite or of greenish patches of secondary origin, and probably of a chloritic matter.

The olivine shows under the microscope some interesting peculiarities in regard to its decomposition. This mineral occurs in grains or in sections of the ordinary form, and with the trace of the pinacoid *OP*, hence some sections have octagonal forms. When the olivine is not altered it is colourless, its surface rugose, its chromatic polarisation vivid; still, it is somewhat rare to see this mineral undecomposed. Sections are often observed having the outlines of olivine, but showing that this mineral is invaded by alteration products. At first the olivine is changed into a yellow pleochroic substance possessing the characters of biotite. It shows a lamellar cleavage, along the traces of which absorption is more marked. The colour is brownish yellow along this direction, yellowish in the line perpendicular to these lamellæ. They extinguish following the direction of the joined lamellæ. The sections parallel to the lamellæ remain dark during a complete rotation between crossed nicols; with convergent light these latter sections exhibit a black cross. The double refraction is negative. All these characters completely justify the determination as biotite. In certain cases the olivine presents a less advanced decomposition. The yellowish matter which tends to encroach upon it bears less distinctly the characters of black mica; it is not lamellar, and it is difficult, even when it is possible, to detect any absorption; perhaps this is mica in the course of formation. In some cases one sees around the biotite certain more or less capillary accumulations, presenting sometimes a vaguely radial arrangement, and probably arising in their turn from the decomposition of the biotite. Without insisting too strongly on this point, these accumulations, to judge from their form, bear a resemblance to those of hornblende called *pilite* by Dr. Becke, a product which he has pointed out as the result of the decomposition of olivine in certain kersantites of the Waldviertel. In some cases the product of decomposition of the olivine is a greenish substance, the absorption of which is less marked than that of the biotite; it is more finely fibrous than the latter mineral, and the fibres are more interlaced and less continuous than are the lamellæ of black mica; we regard this green substance as serpentine. Amongst the inclusions of the olivine, we must mention magnetite and some chestnut-brown grains belonging probably, judging from their transparency, to a spinel.

The ground-mass contains a large number of augite sections which are generally more prismatic than the microporphyritic crystals of this species. The plagioclases, which occur only in the ground-mass and as microliths, yield very elongated sections with polysynthetic striæ. The extinctions observed in the sections of the zone $P : M$ are moderately large, and they are included between the angles 5° and 26°; it is therefore likely enough that this mineral is allied to labradorite. Among the microlithic crystals of the ground-mass one notices very small patches of a vitreous colourless substance. Sometimes this base is coloured slightly yellow, but this tint is secondary, arising from the decomposition of the ferruginous minerals that constitute the rock. To this same decomposition is to be attributed small nests of greenish chlorite which line certain cavities wherein this mineral has crystallised in interwoven lamellæ. We may remark, in conclusion, that this basalt approaches the doleritic type in its texture.

V.—ROCKS OF ASCENSION.

Darwin in his book on Volcanic Islands has given a very detailed description of the rocks of Ascension;[1] but during the time (almost half a century) which has elapsed since the appearance of that work, no one has, to our knowledge, published any special paper on the petrography of this island.[2] We are now able, in some measure, to fill this gap, thanks to the materials collected during the stay of the Challenger, and by Dr. Maclean, R.N., one of the Challenger officers, who lived for some time on the island. Dr. Maclean has placed at our disposal specimens of the principal rocks that he collected, and also some local information, of which we have availed ourselves in the following notice. We have arranged our material very much in the order adopted in Darwin's Geological Observations, and have recapitulated a good many of his local details. It

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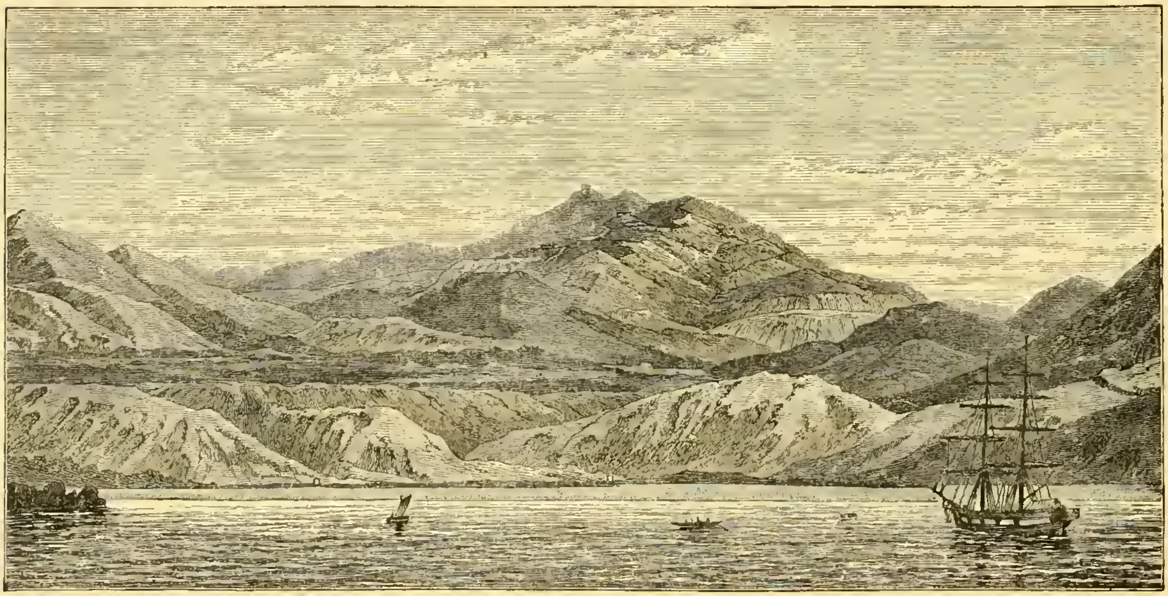
[1] Darwin, *loc. cit.*, pp. 34–72.

[2] Murdoch has analysed the well-known obsidian of Ascension (*Phil. Mag.*, 1844, p. 495). Vom Rath described the crystals of hematite of this island, associated with magnoferrite (*Zeitschr. d. deutsch. geol. Gesellsch.*, Bd. xxv. p. 108, 1873). Ehrenberg has shown the nature of certain siliceous deposits of the "crater of an old volcano" (see p. 68 of this Report).

is worth while noting that, although he wrote at a time when our knowledge of crystalline rocks was in its infancy, the main features of his system remain unaltered. It is right to add that Darwin had been preceded at Ascension by Lesson, who had already given pretty precise indications of the nature of the rocks of this island.

The Island of Ascension is situated in the South Atlantic Ocean, in latitude 8° S., and longitude 14° W.; according to observations made by the officers of the Challenger, the central summit is in latitude 7° 56′ 58″ S., and longitude 14° 20′ W. The form of the island is an irregular triangle, each side measuring about 6 miles; it is $7\frac{1}{2}$ miles long and 6 miles wide. The surface is very irregular, and on a general view appears sterile and miserable in the extreme, presenting an expanse of black, burnt rocks, unrelieved by the least vestige of soil. The highest point of Green Mountain, situated in the east of the island, rises to 2870 feet above the sea, and from the summit one sees forty or more little peaks scattered about in all directions. The accompanying woodcut will give some idea of the appearance of the island, which is entirely volcanic,[1] and in


The Green Mountain and Extinct Craters, Ascension Island.

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[1] Lesson, in his description of Ascension, states his belief that the island is formed of a single volcano, the dejecta from which built up Green Mountain. "All the other eminences which rise to the north and on the plateau of the island without regular order, either as isolated cones or in groups, are more recent volcanic openings, the craters of which, symmetrically formed as a rule, are directed towards the principal volcano, Green Hill, on the side of the prevailing wind, producing a steep declivity in this direction. These fire-breathing mouths are very regularly characterised in the secondary mountains of Ascension, but less so in those of Cross Hill, Red Hill, Zebra Hill, etc.; the greater number present craters in a state of perfect completeness. Green Hill derives its name from the verdure of a vigorous growth of plants upon its summit. The vegetation ceases at the lower third of the mountain, which is composed of naked rock piled up confusedly according to the fractures it has undergone. All the other mountains are quite bare, covered with ferruginous scoriæ of a prevailing red colour. The surface of the island is composed of a detritus of trap and trachyte pulverised and deposited here and there in beds of small extent, bordered everywhere

the absence of proofs to the contrary Darwin considered it as of subærial origin. Like most volcanic islands in the course of prevailing winds, Ascension has steep precipices on the exposed side, where landing is very dangerous; the west coast is less abrupt, and there the British Residence is established. The influence of the prevailing winds appears not only on the exposed coasts, but cinders and lapilli have been carried from the centre of action in a westerly direction, and these have even been blown into the sea, where the accumulation of incoherent volcanic products forms a bottom which affords good anchorage. No traces are anywhere to be found of the island being at present in a state of volcanic activity, but the cones of tufa are so little altered, their contours are so sharp, and their brown and red colours so fresh, that they produce an irresistible impression that the island has been quite recently formed by an accumulation of cinders and scoriæ, and that the fire still smoulders under the crust. The fundamental rock is everywhere of a pale grey colour, and belongs to the trachytic series. These masses of trachyte are best seen in the south-east part of the island. Almost the entire surface is covered by streams of black scoriaceous lava of a basaltic nature. These beds are dominated in certain places by hills, or isolated trachytic rocks. From the Challenger's anchorage no trace of vegetation was visible except the light greenish tint near the summit of Green Mountain, 6 miles from the coast; all else was lava, black and grey cinders, and volcanic peaks and cones. We might refer for geographical details to Campbell's map,[1] in Darwin's Geological Observations, but it does not present an exact and complete view of the island. It is now advantageously superseded by that of C. A. Bedford, of H.M.S. "Raven," published by the Hydrographic Office in 1838, a copy of which accompanies this Report (Map II.). Bedford's map shows the limits of the scoriaceous rocks sufficiently clearly; they stretch along almost the whole coast-line on the north and south, dipping towards the sea, and are cut through by the channels of the streams. The layers of scoriaceous lava are less apparent on the east and west; they only appear here and there, or form a belt along the shore. To the north of the island these beds crop out again to a great extent, and send out branches which surround the isolated hills of East Crater, Sister's Peak (1459 feet), and Bear's Back. In the central and most disturbed part of the island lava is less common; it is, properly speaking, the region of trachytic rocks. In this central region, a little to the east, the

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with heaps of the fragments of black lava called 'clappers' by the English. . . . The shore is also composed of black, trachytic, and porous lava, the surface being vesicular. . . . High sharp rocks shoot up from the sand. Elsewhere, at the west point of Sandy Bay, the rocks are of black basalt, or covered with a thin greyish-white layer of obsidian like a varnish." Lesson also notes calcareous deposits on the coast. We have cited this passage from the naturalist of the "Coquille," because it is, we believe, the first work in which the geology of the island is sketched. These few lines give the gist of his description. We shall return farther on to some of the details he pointed out. We may refer for the history of Ascension, and an account of its fauna and flora, to Sir Wyville Thomson's work, The Atlantic, vol. ii. p. 262, etc.; to Moseley's Notes of a Naturalist on the Challenger, p. 561; and to the Narrative of the Cruise of H.M.S. Challenger, vol. i. p. 927.

[1] A Plan of the Island of Ascension, by Lieut. Robert Campbell, 1819; frontispiece of Darwin's Geological Observations.

most important mass in the island occurs, Green Mountain, of which we have already spoken. It includes, besides the peak to which allusion has just been made, several pretty high summits. Weather Post Hill (1965 feet) is situated towards the east, and a little farther south there is a large depression in the form of an elongated ellipse which bears the name of Cricket Valley. Booby Hill[1] (1790 feet), to the south of the valley which borders the central heights of Green Mountain, is also associated with that mass. In the same central region, but more to the west, is Riding School Crater, and still farther west Red Hill. Cross Hill is situated near the village of Georgetown. We have now enumerated and stated the position of the principal hills which will be referred to in this Report.

AUGITIC TRACHYTES.

We have said that trachytic rock forms the fundamental mass of the island, and we shall commence the description of the rocks by that of the trachytic type, giving first, according to Darwin,[2] the macroscopic characters. They occupy the highest and most central part of the island, and also occur in the south-east region. This trachyte is usually of a pale brown colour, speckled with black spots; it contains folded and broken crystals of glassy felspar, grains of hematite, and black microscopic particles which Darwin referred, doubtfully, to hornblende. The greater number of the eminences are formed of a white friable rock.[3] Obsidian, hornstone, and several other zonary felspathic rocks are associated with the trachyte. The last-named is never stratified, nor are crater-formed orifices ever found on the eminences. The trachytic region must have been violently dislocated; the fissures are still open, or partially filled with loose fragments. The space occupied by these trachyte masses is bounded by a line which surrounds Green Mountain and joins the hills of "Weather Post Signal" and "Crater of an old volcano." Trachyte predominates in the region thus circumscribed; it is traversed by some veins of basalt, and near the summit of Green Mountain there is a stratum of vesicular basalt enclosing crystals of glassy felspar with rounded outlines.

The soft white rock mentioned above bears a close resemblance to a sedimentary tufa when seen in the mass. Darwin hesitated for some time, as many other geologists have done in analogous cases, before he rejected this theory of its origin. He observed, on two separate occasions, that the white earthy rock formed isolated hills; in another

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[1] Dr. Maclean points out in a manuscript correction of Bedford's chart, of which we avail ourselves, that the name "Booby Hill" should be substituted for "Red Hill." The latter name should be given, as I say in the text, to the hill west of Riding School Crater. The rocks described in this Report as coming from Red Hill were collected by Dr. Maclean, and were obtained from the hill situated in the position which he has marked on the map.

[2] Darwin, Geological Observations, pp. 42–44. In summarising passages we have preserved as much as possible the mineralogical and petrographical nomenclature, and the interpretation of facts given by the author. One might, in some cases, be able to modify them, but this would involve the risk of making more or less arbitrary changes, since we have not the specimens Darwin employed to refer to.

[3] It may be that in certain cases the rock spoken of by Darwin as whitish trachytic tufa is siliceous earth, as in the case of the whitish deposits of Riding School Crater.

place it was associated with a columnar and zonary trachyte, but he could not make out the contact. The white rock which he studied contained numerous crystals of vitreous felspar, and black microscopic points. It is speckled, like the surrounding trachyte, with dark grains. On examining the ground-mass with a lens, Darwin found it to be earthy; sometimes, however, it possesses a crystalline structure. On the eminence called "the crater of an old volcano," it passes into a greyish green variety, which only differs in colour and by being more compact. Here an insensible transition between the two rocks is observable. Another variety is made up of numerous round and angular fragments of the greenish rock embedded in the white matrix. Both these varieties of trachyte are traversed by irregular veins which do not at all resemble intruded dykes, and Darwin states that he never saw the like elsewhere. Both kinds of trachyte contain isolated fragments, varying in size, of a dark scoriaceous rock, the vesicles of which are filled by the white mass. This trachyte also includes large blocks of dark cellular porphyry, containing many crystals of opaque white felspar and altered crystals of oxide of iron. The cavities are encrusted with capillary crystals. These fragments project from the decomposed rock in which they are embedded, and exactly resemble the nodules of sedimentary rocks. But, adds Darwin, we know many cases of pieces of cellular rock being shut up in trachytes and phonolites, and therefore cannot draw as a conclusion from the facts described that these rocks were of sedimentary origin. The insensible passage of the greenish into the whitish variety in some cases, and the isolated nodules in others, may result from a greater or less difference in composition. The rounded form of the blocks may be due to corrosion by the fused mass in which they were stuck. He considers the veins to be due to the infiltration of silica. The principal reason Darwin brings forward for believing that these earthy and friable rocks are not sedimentary is, that it is extremely unlikely that crystals of felspar and grains of mineral should occur to precisely the same extent in a sedimentary mass as in a trachyte with which the former was associated. Besides, he observed that the rock matrix showed a crystalline structure when magnified.

After giving these details from Darwin of the appearance and occurrence of the trachytes of Ascension, we shall describe the specimens of this type which we have studied.

As Darwin's account shows, trachytic rocks play a considerable part in the island. It would not be easy to devote a special description to the specimens of each locality, especially since very often—not to say always—we have no information as to the definite part of the bed from which the rocks were taken, the label only bearing the name of the hill. We may add that all the rocks of this kind, from whatever part of the island they come, are very like each other.

We shall accordingly describe them together, grouping the rocks according to their lithological affinities, but, in the case of those meriting special attention, mentioning the locality from which the specimen came.

The rocks under consideration may be described under the general name of *Augitic trachytes*, and are characterised by the association of three constituents in greater or less amount: monoclinic felspar, augite, and a vitreous ground-mass. Their mineralogical composition is very constant, and the characters well defined,—the slight variations being due to differences of texture, and to the more or less important part played by the vitreous matrix. All stages of transition are to be found between holocrystalline varieties showing an aggregate of augitic and felspathic microliths, with some microporphyritic crystals of sanidine, and vitreous varieties, in which there occur a few extremely minute crystals of sanidine and augite. Finally, the vitreous element becomes supreme, and the rock passes into obsidian.

The trachytes properly so called are whitish grey in colour, sometimes bluish grey, with a rough granular structure. The ground-mass is homogeneous, rarely slightly schistoid. Sometimes they are slightly vesicular, and pass into pumice; or are more compact, and, according to the predominance of the vitreous element, darker in colour and with a somewhat glossy sheen. The fracture is usually irregular. In some cases the trachytes are friable, in others they are rough to the touch and coherent. Some specimens which have commenced to alter, and are marked with round brownish stains, are impregnated with oxide of iron, which gives them a red or brown colour. These trachytes, when examined with the lens, are found generally to be composed of crystalline grains, but the species could not be made out, except in the case of sanidine, crystals of which are sometimes visible to the naked eye.

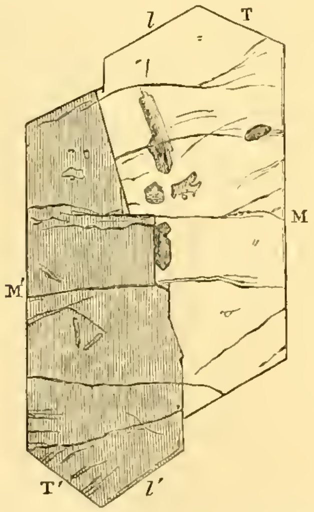

Fig. 6.—Trachyte of Weather Post Hill. Section of sanidine cut almost parallel to *P*/*M*, Carlsbad twin. The composition plane is *M*, and another face probably $\infty \breve{P} 3$. $\frac{1}{20}$ crossed nicols.

Microscopic examination shows that all the trachytes of Ascension have an almost identical microtexture. They possess a ground-mass chiefly composed of confused microliths of sanidine and augite, to which large sections of felspar give a microporphyritic structure; the sections of augite are less numerous. Sometimes a base is interposed between the microliths of the ground-mass; the latter is seldom devitrified in spherulites or trichites. A peculiarity of the minerals in the ground-mass is that they are always comparatively small; this minuteness, and the confused setting of the microliths, makes their determination difficult. The sanidine appears in large crystals with the distinguishing peculiarities of this species. These large individuals are always corroded, their outlines are blunted, they are furrowed by lines of fracture which sometimes correspond to traces of cleavages ∞P, and almost always twinned according to the

Carlsbad law. We may point out, in speaking of these twins, that the plane of union may vary in one and the same crystal. Fig. 6 shows a section of the mineral twinned according to this law. It is cut almost parallel to the edge *P*/*M*; and it may be observed that the plane of composition is now *M*, traces of which appear on the two long sides of the section; and again another plane, which may correspond to a prism, perhaps to ∞ Ᵽ 3, a face known to occur in sanidine. These large sections have frequently an undulated extinction. The felspathic microliths of the ground-mass are referable to the same species. The striæ of plagioclase are never observed. One form predominates—it is that of extremely thin lamellæ, which, when seen on the face *M*, appear almost always twinned. Two of the individuals are regularly superimposed, but one does not entirely cover the other. Fig. 7 gives an example of one of these twinned crystals: it shows two tabular individuals of sanidine superimposed on the face *M*, and twinned according to the Carlsbad law; traces of *P* and *y* are discernible, and the internal zones give an indication of *x*. Extinction takes place with an angle of + 5°, the angle *P P′* is 127°; it is thus equal to that which the same faces of sanidine twinned according to the Carlsbad law form. The aspect of this twin may vary to infinity, but the fundamental form is so constant that it is certain to occur in each preparation; it is produced even when the crystals become infinitesimal, as in the case of the very vitreous varieties of this rock (see fig. 8).

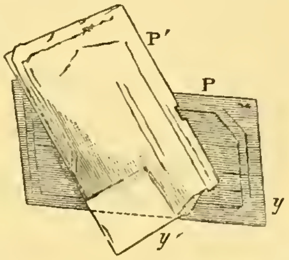

FIG. 7.—Tracbyte of Red Hill. Small twinned crystals of sanidine, two tabular individuals superimposed on the face *M*, the traces of *P y*, and, in the internal zones, the trace of *x* can be seen; the angle *P P′* is about 127°. $\frac{1}{60}$ crossed nicols.

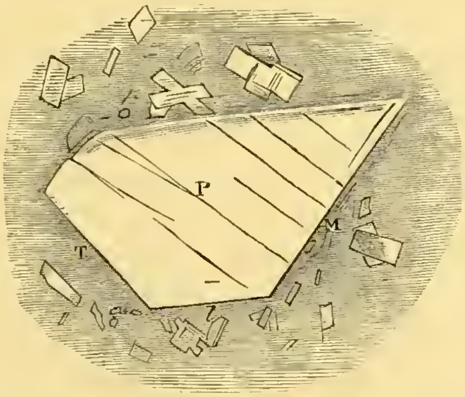

FIG. 8.—Trachyte of Red Hill. Large section of sanidine in a vitreous ground-mass is surrounded by small lamellar crystals superimposed and twinned, embedded in the base. The cracks traversing the large section are almost perpendicular to *M*. $\frac{1}{20}$ crossed nicols.

Plagioclases, sharply distinguished by hemitropic striation, occur very rarely. Felspathic sections may sometimes be observed showing some appearance of polysynthetic lamellæ, which are, however, indistinct compared with those of plagioclastic felspars. The sections showing these striæ have almost always undulated extinction, and are grooved by fissures; they are sometimes broken in several pieces and cemented together by the matrix. These facts clearly show that the felspars exhibiting those striæ have been subjected to mechanical strain, which has induced a more or less pronounced lamellated structure, and this, under the microscope, has an appearance resembling that of a plagioclase. These sections, then, are nothing else than sanidine modified by mechanical action. But there is another kind of alteration in this felspar to which attention must be drawn. We have said above that the large sections of sanidine almost always appear corroded at the edges. This action of the magma is not confined to the border of the crystal, but in some cases has affected the whole mass, softening it and transforming it almost beyond recognition. The facts, as they were observed in a great number of specimens of trachyte from Ascension, were as follows:—Certain sections, which were naturally supposed to be ground-mass, so crammed were they with microliths of irregular outline, extinguished polarised light as if they formed one crystalline individual. What seems to go against this interpretation is, that these sections are filled with the same felspathic microliths composing the ground-mass. On examining them more closely, however, one can find all stages of transition represented, from the perfect crystal of sanidine downwards, and the conclusion must be that they are nothing else than large crystals of sanidine attacked by the action of the magma. In fact, some of these patches, with half-effaced contours, are surrounded by little crystals of sanidine forming an external zone, and encroaching on the primitive crystal, sometimes to the centre. The magma, in which these crystals of sanidine floated, may be admitted to have penetrated them in some way, and to have given rise to the microliths. The influence of the fused mass had not been sufficient to make the crystals lose their individuality completely; their outlines were effaced, and they were invaded by microliths, but they did not mix entirely with the magma, and hence did not lose their molecular structure.

Augite is the second essential element of these trachytes. We have said that it never attains the dimensions of the sanidine; it always occurs in the prismatic, almost acicular, form, and is confined in the ground-mass with the little lamellæ of sanidine. In most cases augite is associated with a vitreous base. The small crystals are greenish, slightly dichroic; the octagonal form of sections perpendicular to the vertical axis is rarely seen; the angle of extinction is often greater than 45°. The microliths of augite are sometimes reduced to mere lines, especially in those specimens where the vitreous matter predominates. These fine needles are nearly always altered, as can be seen from the yellow tint they assume, the colour changing from green to yellow or brownish red. In some rather rare cases they become fibrous, as if they had been subjected to uralitisation. Sometimes microliths belonging to a second generation are observed; the comparatively large crystals are surrounded by an outer zone of minute green needles of the same nature. In very vitreous varieties it is not uncommon to see the microliths grouping themselves in a manner resembling the arborescent forms which certain pitchstones exhibit.

Accidental constituents play a very small part in the rocks we have just described. Magnetite occurs pretty frequently, titanite and apatite more rarely, and sometimes sections of quartz; but these are probably of secondary origin, as are also the grains and veins of hematite and limonite.

We give below an analysis by Dr. Klement of one of the trachytic rocks; the specimen came from Weather Post Hill, and its characters correspond with those described above.

I. 1·0401 grammes of the substance, dried at 110°C and fused with carbonates of soda and potash, gave 0·7384 gramme of silica, 0·1543 gramme of alumina, 0·0430 gramme of ferric oxide, 0·0062 gramme of lime, 0·041 gramme of magnesium pyrophosphate, and traces of manganese.

II. 0·8480 gramme of substance treated with hydrofluoric acid gave 0·1871 gramme of sodium and potassium chlorides, and 0·1048 gramme of potassium chloroplatinate.

III. 1·0950 grammes of substance treated in a sealed tube with hydrofluoric and sulphuric acids was titrated by potassium permanganate. 0·7 cubic centimetre of solution (1 c.c. = 0·005405 gramme of ferrous oxide) was required to oxidise the ferrous oxide.

IV. 1·0370 grammes of substance fused with sodium-potassium carbonate, according to the method of Sipöcz, gave 0·0041 gramme of water.

PERCENTAGE COMPOSITION OF THE SPECIMEN.

Silica, SiO_2,	70·99
Alumina, Al_2O_3,	14·84
Ferric Oxide, Fe_2O_3,	3·76
Ferrous Oxide, FeO,	0·35
Manganese,	traces
Lime, CaO,	0·60
Magnesia, MgO,	0·14
Soda, Na_2O,	5·94
Potash, K_2O,	2·40
Water, H_2O,	0·40
	99·42

The percentage of silica given by this analysis is too high for normal trachyte; in fact in unaltered specimens it only amounts to 65 per cent., which corresponds to the amount of silica in sanidine. In exceptional cases certain trachytes may contain as much as 71 per cent. of silica (the tridymite trachyte of New Zealand, for example), but this large proportion is due in great part to the infiltration of siliceous matter subsequent to the consolidation of the rock. To infiltration of this kind we have recourse in order to explain the anomaly in the present case. We have already said that the trachytes of Ascension contain little veins of quartz of secondary origin, and the ground-mass is sometimes penetrated by silica. Darwin remarked the frequency with which siliceous veins occur in the whole region, and infiltration of silica of secondary origin accounts for the divergence in the analysis before us. The small proportion of ferrous oxide, magnesia, and lime clearly shows that pyroxene is a very subordinate constituent of the rock. We see besides, as analyses of trachytes often show, that soda predominates over potash in a marked degree. Perhaps we have here a monoclinic felspar which would approach those described by Förstner (2·1 mol. $Na^2 Al^2 Si^6 O^{16}$, with 1 mol. $K^2 Al^6 Si^6 O^{16}$). Vom Rath showed that in the sanidines of Laacher-See soda may be present in larger amount than potash; perhaps small plagioclases are hidden in the ground-mass, which may itself contain a glass more or less rich in soda.

We have considered the pyroxenic trachytes, and now turn to the specimens which show a transition to obsidian.

The ever-increasing predominance of base over crystalline elements is shown very well in a specimen from Red Hill (?). The external appearance is still quite that of ordinary trachyte; to the naked eye it shows a rather pronounced schistoid appearance. The colour is grey, darker than the ordinary trachytes of the island; it is still slightly rugose, and has not assumed a vitreous texture. Crystals of sanidine from 3 to 4 millimetres long determine a porphyritic structure in the rock. When a thin section is examined, the large share which the vitreous mass has in its constitution becomes apparent. The schistose appearance is also found in the preparation,—it is produced by lines of vesicles, which, like those of pumice, are due to the liberation of gases during cooling. Well-developed felspar and augite microliths are ranged in the same direction as the vesicles. It is without doubt to its fluidal structure that the lamination of this rock must be attributed. Large sections of sanidine and augite, but mostly the former, detach themselves from the vitreous ground-mass, which is light brown in colour with slightly darker bands. The sanidine is sometimes found crystallised as a Carlsbad twin. Plagioclase is occasionally detected. Besides the minerals already mentioned, the ground-mass is filled with little bundles of crystals extremely minute and only appearing under the highest powers. Relying on microscopic analyses only, these obsidians could not be separated from the augitic trachytes. In fact, one sees that the latter rock is related through all its transitions with the former, and that the constituent minerals are the same in both; only the vitreous element tends gradually to take the place of the minerals, which grow smaller as the trachyte approaches the vitreous variety. Obsidian is simply the last term of this series, and its external characters are then sharply defined. We shall describe here some of the more or less vitreous varieties of trachyte, but as the texture and the mineralogical composition are always fundamentally the same, it is unnecessary to follow all the stages of transition. We shall accordingly say a few words about the highly vitreous trachytic rocks, and afterwards enlarge upon the well-characterised obsidian of Ascension.

Vitreous augitic trachyte sometimes appears as a greyish mass, soft and very friable, somewhat scoriaceous and passing into pumice, but more homogeneous in the fracture. Its macroscopic characters are like those of a tufa, but microscopically the ground-mass is seen to contain no heterogeneous fragments, being composed of microliths and a vitreous mass. In this matrix microporphyritic crystals of sanidine appear; the crystals of augite are always smaller than those of the felspar with which they are associated.

OBSIDIAN.

All the obsidians of Ascension are closely related to the trachytic rocks which have just been described. Before discussing the mineralogical characters of these volcanic glasses, it will be well to give a *resumé* of Darwin's very detailed observations[1] upon them. He first describes the transition of the rocks into zonary[2] beds between which the obsidian is intercalated. These outcrops of the beds of obsidian in the middle of the trachytic region west of Green Mountain are highly inclined, and partially covered by more recent eruptions; for this reason Darwin could not observe their contact with the trachyte, nor satisfy himself as to whether they had been poured out like lava, or injected like the veins in the adjacent rocks. At the point explored by the author three beds of obsidian appeared, the largest at the base of the section. These alternating rocks attracted the particular attention of Darwin, and he described five varieties which passed into each other by all gradations. We refer the reader for particulars regarding these varieties to the complete description given in the chapter of Darwin's book dealing with the subject.

The transition of these zonary rocks to beds of true obsidian takes place in several ways. At first angulo-nodular masses of obsidian of varying size appear isolated in a schistoid or massive felspathic rock of a light colour and conchoidal fracture. Then irregular nodules of obsidian are seen, isolated, or grouped in layers not more than the tenth of an inch thick, which alternate repeatedly with thin strata of a zonary felspathic

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[1] Darwin, Geol. Observ., pp. 54-62.

[2] We employ "zonary" instead of Darwin's term "laminated" in this description. He explains his meaning of the latter word in a note at the foot of p. 54 *loc. cit.*: "This term might be misunderstood; it is applied to rocks which divide into thin leaves of the same composition, or are formed of closely united layers of different mineral species without a tendency to split up, but distinguished by special colours. The term laminated is employed here in the latter sense. When a homogeneous rock has a cleavage plane along which it may be readily split, like slate, I apply the term *fissile*."

rock resembling agate, and sometimes passing into pitchstone. A white substance resembling pumiceous cinders fills the interstices between the nodules of obsidian. Finally, the substance, which previously was spread through the rock, becomes an angulo-concretionary mass of obsidian of a pale grey colour, and often traversed by coloured bands parallel to those of the enclosing rock. Darwin then describes the rocks which usually occur as stages in the transition to obsidian, and treats in a specially detailed manner of the linear arrangement of spherulites. He explains the nodular form of some specimens of obsidian by viewing them as concretionary masses like spherulites. After discussing the chemical composition of these obsidian spherules, as known at that time, he attributes the nodular and spherulitic forms to a process of segregation in the fused mass which led to the separation of the parts richest in silica. He pointed out the similarity between the phenomena exhibited by volcanic glasses and the devitrification of artificial glass. Finally, Darwin compares his observations on the obsidian of Ascension with those of Beudant in Hungary, of Von Humboldt in Mexico and Peru, and with the descriptions by other geologists who had brought analogous facts to light in various volcanic regions.

Having recalled Darwin's work on the obsidians of Ascension, we shall proceed to give a lithological description of the specimens of this rock which we have examined; these came from Green Mountain. When the specimens are not weathered, they present all the ordinary characters of obsidian, being black, vitreous, with a brilliant lustre, conchoidal fracture, and transparent at the edges. They are often cracked, the margins of the fissures appearing as white lines, and sometimes they are slightly scoriaceous with a more irregular fracture. When weathered the surface becomes greyish and earthy in appearance, and when the rocks decompose they sometimes assume a waxy lustre like retinite. They are often veined with greenish or greyish lines, and at other times finely zonary; in this case they are seen by the naked eye to be furrowed with little undulating parallel veins that stand out grey against the black background of the rock. When zonary obsidian weathers, its conchoidal fracture is obscured, and the fragments break along the zones. The only macroscopic constituent is sanidine, which stands out from the ground-mass in vitreous grains, sometimes of considerable size. Microscopic examination shows that all the obsidians of Ascension are made up of a light brown vitreous matter, the colour of which becomes darker in bands where microliths accumulate. Microporphyritic structure is somewhat rare, and when seen it is always brought about by sections of sanidine. The glass is, however, never homogeneous; besides the elongated vesicles, often arranged in bands, there are little lamellæ of sanidine and minute prisms of augite[1] scattered through the base.

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[1] Darwin points out (p. 55 *loc. cit.*) that Miller determined as augite some fine green needles in the rocks of Ascension associated with obsidian. The rocks yielding these microliths also contain, according to Miller, crystals of quartz, which he measured and found possessed of the faces *P*, *z*, *m*, without a trace of *r*.

These crystals are often infinitesimal, appearing as mere lines, which it would be impossible to identify were it not that they merge by insensible gradations into well-characterised crystals of these species. It is only by following the gradually diminishing size of these minerals, step by step, from the augitic trachytes, in which they are easily recognised, to the obsidians, that they can be determined in the latter rocks.

Sanidine is, as we have said, the only constituent attaining any size. Sections of this felspar cut parallel to the face *M*, and showing the traces of *P*, *y*, *T*, give positive extinction. Carlsbad twins are sometimes seen, but never hemitropic striæ; the latter observation holds good of the large crystals as well as of the numerous microscopic sections of felspar in the ground-mass. These very minute colourless microliths are probably also sanidine; the mode of their development, their form, and their twinning relate them to the larger crystals of these species. Only the faces *P*, *y* are usually to be seen; but in certain cases *x* is also represented. Like the larger specimens of sanidine, these are tabular, extremely thin, and elongated following *P*/*M*. They are often twinned according to the Carlsbad law, as we have already described in the case of trachytic rocks. Two of these thin lamellæ are often superimposed with oblique axes, and this mode of composition recurs so persistently that there is no doubt of its being a twin, although the extreme minuteness of the crystals makes it impossible to ascertain the law. The felspathic crystals grow smaller as the vitreous ground-mass becomes more developed, but they are always distinguishable from augite, being colourless, and generally rather larger than those of pyroxene. The augite crystals never attain the proportions of those of sanidine; they are always prismatic, but with ill-defined margins; the colour is greenish, and the angle of extinction rises from 35° to 40°. This is also the angle of extinction of the little microliths, but when these assume the form of capillary lines, their optical properties cannot be observed, and their identity is only arrived at by considering the transitional forms.

The obsidians are sometimes devitrified, and exhibit a finely granular texture; some of the vitreous rocks of the obsidian series show perlitic structure, and have the shining appearance of pitchstone.

The following is an analysis of a specimen from Green Mountain, which presented all the appearances of an unaltered volcanic glass. An early analysis by Murdoch[1] is given for comparison.

I. 1·0752 grammes of substance dried at 110°, and fused with sodium-potassium carbonate, gave 0·7818 gramme of silica, 0·1376 of alumina, 0·0461 of ferric oxide, 0·0062 of lime, 0·0029 of magnesium pyrophosphate and traces of manganese.

II. 0·7699 gramme of substance treated with hydrofluoric acid gave 0·1415 gramme of sodium and potassium chlorides, and 0·1538 of potassium chloroplatinate.

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[1] Murdoch, *Phil. Mag.*, 1844, p. 495.

III. 1·5307 grammes of substance, treated in a sealed tube with hydrofluoric and sulphuric acids, was titrated by a solution of potassium permanganate (1 c.c. = 0·005405 gramme ferrous oxide), of which 4·2 c.c. were required for oxidation.

IV. 1·2723 grammes of substance fused, by Sipöcz' method, with sodium-potassium carbonate, gave 0·0061 gramme of water.

PERCENTAGE COMPOSITION OF THE SPECIMEN.

	Klement.	Murdoch.
Silica, SiO_2,	72·71	70·97
Alumina, Al_2O_3,	12·80	6·77
Ferric Oxide, Fe_2O_3,	2·64	6·24
Ferrous Oxide, FeO,	1·48	...
Manganese,	traces	...
Lime, CaO,	0·58	2·84
Magnesia, MgO,	0·10	1·77
Soda, Na_2O,	6·50	11·41
Potash, K_2O,	3·87	
Water, H_2O,	0·48	...
	101·16	100·00

TRANSITIONS OF AUGITIC TRACHYTE INTO AMPHIBOLIC TRACHYTE, ANDESITE, AND RHYOLITE.

The Green Mountain contains a great many rocks transitional between augitic trachyte and neighbouring lithological types.

We shall first consider amphibolic trachyte. This is a compact greenish grey rock, in which crystals of sanidine may be discerned by the naked eye; the surface is partly covered with brilliant crystals of hornblende, to which reference will be made later. The microscope reveals hornblende also amongst the essential constituents, which are otherwise similar to those of augitic trachyte. The sections of hornblende show decided pleochroism, the absorption being almost as intense as for biotite; they are characterised by the cleavage, but the planes of separation are not sharp; on account of a slight deviation in their direction, they appear as curved lines. Titanite may be noticed in the form of inclusions in the amphibole. It seems very probable that free silica in the form of quartz is a constituent of the ground-mass; but, perhaps, this mineral is a secondary product, as is very frequently the case in the rocks of Ascension, a great number of which are silicified.

This rock shows a very interesting peculiarity which has been already observed, particularly by Vom Rath, on some blocks ejected from Vesuvius. The whitened and softened appearance of the specimen indicates that it has been subjected to the action of fumaroles. The altered surfaces are sown with extremely brilliant little black crystals, standing out in relief, and never forming a part of the ground-mass on which they are set. They are found in every hollow, but never on a freshly broken surface. These crystals are never more than 1 or 2 millimetres long; several individuals are often united with the axes parallel; often also they are hollow or present a skeleton-like appearance. Microscopic examination shows that the dominant faces are ∞P, which are usually relatively well developed; indications of $\infty \bar{P} \infty$, $\infty \breve{P} \infty$, P, OP are also seen. The angle of the prism *mm* measures 124° 30′. With the microscope a well-marked cleavage following the faces of the prism may be made out, and when the crystals are broken the very elongated prismatic solids of cleavage present the same angle of 124°; these little prisms have a maximum angle of extinction of about 15°. Although only slightly transparent, the crystals show a perceptible pleochroism; the light ray vibrating parallel to c is of a more or less deep green, that perpendicular to this direction being reddish green. These details prove beyond doubt that the crystals are hornblende, and that they must have been formed by sublimation like their congeners of Vesuvius, which, as described by Vom Rath,[1] are in every way similar. No true amphibolic trachyte has been found amongst the specimens from Ascension. The rock just described is only a transitional type, and the same may be said for the next specimen to be considered. This rock, from a quarry near Georgetown, is an augitic trachyte passing into amphibolic andesite. To the naked eye it hardly differs from the common trachyte of the island; it has the same greyish colour, but is perhaps a little more scoriaceous, as indicated by a certain roughness to the touch. The microscope shows a ground-mass composed of microliths of felspar and minute corroded crystals of hornblende, showing the characteristic cleavage, brownish green in colour and dichroic. Small augites, extinguishing under a high angle, and with the usual appearance of this mineral in the trachytes of the island, also occur, and magnetite is a somewhat frequent constituent. Sanidine in large sections is the principal mineral constituent; the crystals, which have an undulating extinction and are corroded, occur in groups and twins as described in the case of augitic trachytes. Finally, there are some finely striated fragments of plagioclase, occasionally twinned according to the Carlsbad or Baveno law. The presence of plagioclase indicates a transition from the series of trachytes to that of andesites.

Pyroxenic trachyte passes in some cases into rocks in which the siliceous element is isolated, and this forms a transition to rhyolite.

A specimen from Red Hill (?) is an example of this transition. It is bluish grey, spotted with black, and contains lamellæ of sanidine 3 or 4 millimetres long amongst a compact crystalline ground-mass. This mineral appears arranged in parallel lines; indeed, only the large shining face of a cleavage plane, parallel to *M*, is to be seen there.

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[1] Mineralogische Mittheilungen (*Pogg. Ann.*, Ergänzungsband vi., p. 198, 1874.)

Thin slices show a magma impregnated with quartz (perhaps of secondary origin), and containing sections of felspar, augite, quartz, and biotite. The felspars are both sanidine and plagioclase; these two felspars are to be seen in the same section, as is often the case in transitional rocks such as that under consideration. The centre is, in these cases, finely striated like an oligoclase or andesine, and surrounded by a zone in which plagioclastic lamellæ no longer appear. These lamellæ in the nucleus extinguish at a very low angle, which confirms the determination as a triclinic felspar approaching the oligoclase series. The felspathic microliths of the ground-mass are often Carlsbad twins, and frequently appear almost rectangular in section. This leads to the conclusion that their prevailing form is determined by the lengthening of the edge *P/M*. The crystals of augite present only indistinct or irregular outlines; this mineral is little, if at all, pleochroic. The biotite is in the form of corroded lamellæ, which sometimes take a greenish tint, indicating an incipient alteration into chlorite. Some colourless sections show the properties of quartz, giving the cross of monaxial crystals in convergent light. This mineral is, very probably, also represented in the ground-mass of the rock. It is noteworthy that all the older constituents, especially the felspars, have been very much corroded, as if they had been subjected to the energetic solvent action of an acid magma.

More distinctly rhyolitic rocks occur in Ascension, especially in the interior of the crater-like orifice of Riding School. A specimen of this type is compact—in some places a little scoriaceous—with a nearly plane fracture, and of a brick-red colour. The naked eye can only detect some crystals of felspar. The microscope shows that the red colour is due to an amorphous powder of hematite, which has penetrated all the fissures and vesicles of the rock. The colourless ground-mass is spherulitic and impregnated with quartz; large sections of sanidine appear in it. This mineral is crystallised in a tabular form, sometimes in shortened prisms, and the Carlsbad twin is common. A section in the zone *P* : *M*, in which cleavages corresponding to *P* and to the prism with traces of *T* or *l* are clearly shown, has made it possible to measure the angle of extinction on *M*. It was found to be positive and 10°, which confirms the determination of the felspar as sanidine. Some colourless homogeneous sections with irregular outlines must be referred to quartz, as in convergent light they show the cross of monaxial crystals and the usual properties of thin slices of that mineral. The presence of quartz as a microporphyritic constituent leads us to refer to the same species certain much smaller sections, which present the same appearance and the usual optical properties of this mineral in parallel polarised light. These little sections are, as it were, drowned in the ground-mass; they are associated with numerous sharply defined felspathic microliths. The ground-mass is thus essentially quartzose, and is characterised besides by the presence of spherulites, which resemble pseudo-spherulites, the cross being vaguely indicated, and its arms not at right angles. Probably this is a fibro-radial mixture of small microliths of felspar and quartz, such as is often observed in certain porphyries and rhyolites. The pseudo-spherulites have a black opaque centre, composed of a reddish or greenish non-transparent material, which assumes a more or less starlike form, and underlines the fibres of colourless minerals forming the radiated aggregate. The dark substance of the spherulites may be related to certain rather rare small pleochroic sections which possess some of the properties of hornblende or of biotite. Perhaps hornblende, now decomposed, formed at one time an integral part of the rock.

Rhyolitic tufas also occur in the island, but amongst the specimens of rocks from Ascension which we have examined, only one belongs to this type. To the naked eye it exhibits a number of bluish grey, zonary, slightly schistoid splinters, embedded in a pretty homogeneous mass. Under the microscope the rock appears like a breccia of volcanic fragments cemented by chalcedony, or, in some cases, by hyaline quartz. The fragments are angular and irregular in form, as if crushed; they are essentially vitreous, and contain felspathic microliths, which are so minute that the species cannot be established except in rare cases when microlithic plagioclases are observable. The spherulitic structure, to be seen in certain cases, also confirms the reference of these fragments to rhyolite. In the centre of the spherulites, or following the radii, there is a black opaque substance like magnetite, trichitic rods of which may be seen scattered through the whole ground-mass, and giving it a blackish tint. Like a great many of the rocks of Ascension, this tufa contains scales of hematite. The cement uniting the fragments is siliceous; in polarised light one sees that the quartz forms a brilliant mass of grains bordering and planted on the sides of the lapilli. These grains fill up the gaps, and when the space is not quite filled up by them, it forms a geode, in which crystals of quartz, with faces of the prism and pyramid, may be distinguished.

Finally, we shall consider a tufaceous rock from Dry Water-Course. This tufa is shown by the microscope to be composed of fragments of different kinds of rock, all belonging, however, to types which are represented at Ascension. These splinters, or lapilli, have been embedded in a more acid vitreous mass, showing fluidal structure and of a yellowish colour, which, penetrating the interstices between the fragments, corroded them. The large crystals of sanidine are rounded at the edges; the augite seems to have been entirely fused. Spherulites are visible in the vitreous substance; the silica has been subsequently infiltrated. There is enough quartz in the ground-mass to justify the name of rhyolitic tufa which we apply to this rock, but there is also silica of secondary origin, which has penetrated the crystals of felspar; they appear in polarised light as a mosaic of quartzose grains.

Basaltic Rocks.

We have said that almost the entire surface of Ascension is covered by streams of black, scoriaceous, basaltic lava, through which the trachytic escarpments crop out. According to Darwin,[1] this lava is sometimes vesicular and at other times massive. It is black in colour, and sometimes contains many crystals of felspar, olivine predominating in rare cases. The streams appear to have been not very fluid; the lateral walls are extremely steep, and attain a height of 20 or 30 feet. The surface is very scoriaceous, and from a little distance it appears covered with small craters. These mounds are heaps of scoriaceous lava of the same kind as that forming the mass of the stream; their form is more or less regularly conical, and they are traversed by fissures, which give them a columnar appearance. These hillocks rise to 10 or 20 feet above the stream, and Darwin attributes their formation to the accumulation of viscous lava at points where some obstacle presented itself to the flow. At the base of these conical heaps, and at other points on the stream, blocks of lava are to be seen, resembling arches in appearance. Fantastic masses of scoriæ rise up over the whole surface, occasionally, according to Darwin, presenting such an extraordinary appearance as hardly to be distinguished from trunks of trees. Some of these lava-flows may be traced to their point of origin at the base of the great trachytic mass, or to the isolated conical hills of reddish rock situated in the north and west of the island. Darwin counted twenty or thirty of these cones of eruption from the central eminence. Most of them have their summits truncated obliquely, the steepest slope being on the south-east side facing the prevailing wind, as Lesson[2] points out. Hennah remarks, in addition,[3] that in Ascension the most extensive beds of ashes are always found in the lee of the wind.

This arrangement of the volcanic hillocks may be explained by taking account of the fact, that during eruptions the incoherent products would be carried in the direction to which the prevailing winds blew.

The basalts collected by the Challenger Expedition at Ascension are almost always of the felspathic variety; dolerites rarely occur.

Amongst the rocks of the type of ordinary basalt we may describe the specimens from Red Hill. They are completely penetrated with oxide of iron, and present a porphyritic structure by reason of crystals and grains of plagioclase—attaining a maximum diameter of a centimetre—embedded in a slightly vesicular ground-mass. Olivine is very rarely seen, and augite more rarely still. Microscopically the rock is formed of a ground-mass in which plagioclase microliths predominate, almost always twinned according to the Carlsbad law, and associated with little crystals of augite. Larger sections of magnetite, augite,

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[1] Darwin, Geol. Obs., p. 34.

[2] Lesson, Voyage de la "Coquille," p. 490.

[3] Hennah, *Proc. Geol. Soc. Lond.*, vol. ii., p. 189, 1835; cited by Darwin, *loc. cit.*, p. 35.

olivine, and triclinic felspar appear in this mass. The triclinic felspars are prismatic, relatively very thick, and zonary. The zones are not numerous, as in the case of andesine, for example, but usually consist only of a nucleus and an outer coating. Extinctions of about 37° have been measured on sections parallel to *k*, which indicate a plagioclastic mixture approaching bytownite. The cut (fig. 9) shows a section of one of these felspars perpendicular to the edge *P*/*M*. The traces of two cleavages parallel to *P* and *M* are visible, and on the right there are the remains of a twinned individual following the albite law, and almost entirely removed by the process of polishing. The two individuals extinguish symmetrically at 40°, which again establishes the very basic nature of this plagioclase. This section is instructive in exhibiting clearly the form of the large felspars in the rock under consideration. The felspar is often corroded or broken, and the fragments scattered at a little distance from one another, separated by the ground-mass. It is also apparent that certain sections have been subjected to pressure; they present traces of undulating extinction, which is particularly the case in the plagioclase represented in the figure, where this extinction is indicated by the shade in the middle towards the right margin. In other specimens of basalt the plagioclases have quite a simple structure—as in the case just spoken of: they show the Carlsbad twin and one or two hemitropic lamellæ interposed, the somewhat small angles of extinction making them approach labradorite.

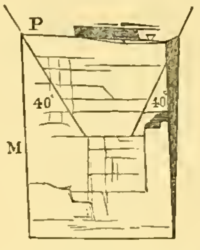

FIG. 9.—Basalt of Red Hill. Section of plagioclase perpendicular to the edge *P*/*M*, with the traces of two cleavages parallel *P* and *M*; on the right, remains a part of an individual twinned following the albite law. $\frac{1}{20}$ crossed nicols.

Olivine appears in sharply defined sections. The decomposition of this mineral is somewhat remarkable, as it changes into hematite with the simultaneous development of trichites. Such an altered crystal with the curved and parallel lines of the trichites invading the mineral is shown in fig. 10. Sometimes the little olivines of the ground-mass have a quite pronounced prismatic form, which makes it difficult to distinguish them from microlithic augite. The augitic microliths are colourless like olivine, but the sections of the latter are edged with a zone of limonite which serves to distinguish the species. There is little to say about the large crystals of augite, which appear less often in these specimens than is usual in basalts, the commonest form in this case being microlithic.

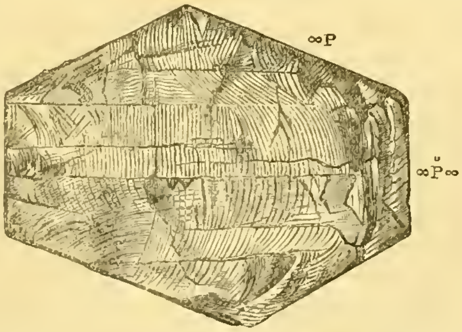

FIG. 10.—Basalt of Red Hill. Section of olivine decomposed into hematite and filled with trichites. $\frac{1}{40}$ crossed nicols.

These rocks have often a vesicular appearance when in thin slices, although they seem perfectly massive when looked at with a lens. The vacuoles are generally due to the disappearance of sections of peridotite, which crumble and are swept away during the polishing. The basalts of the island are often scoriaceous; a basaltic lava from Riding School which we have examined is particularly so: it is a reddish scoriæ, very alveolar and rough, and containing heterogeneous half-fused fragments.

The microscope shows a ground-mass of a very fine grain and pitted with pores. Olivine and plagioclase appear in microporphyritic sections; the former predominates and is often fragmentary, although when the crystals are very small they are sharply defined. Augite is found in the form of microliths in the ground-mass, which contains very little vitreous matter. Little granules of hematite occur throughout the mass, penetrating all the felspathic sections where they appear in zones.

Finally, there are basaltic rocks of the dolerite type. These are greyish, almost saccharoid in texture, with pretty large grains; plagioclase crystals are visible to the naked eye, and the lens shows grains of augite between them. With the microscope it is seen that these basalts do not possess what can, properly speaking, be termed a ground-mass. The lamellæ of plagioclase felspar are twinned according to the Carlsbad and albite laws; they are comparatively little striated, and thus resemble the felspars of those basalts we have just described. The extinctions show that the plagioclase approaches labradorite. The augite intercalated in the felspar lamellæ occurs as greenish violet grains associated with magnetite, the sections of which, generally irregular, are surrounded with hematite. The olivine has corroded outlines, and is coloured red or green by alteration. The greenish secondary matter is sometimes more or less fibrous; it is dichroic, and to a certain point resembles hornblende. This transformation into amphibole would explain the oblique extinction which has been observed in olivine sections that have undergone the same alteration.

Andesites.

Certain rocks, much resembling basalts, which may be classed as andesites, are met with in various parts of the island, particularly on Red Mountain.

Some specimens of andesite from Red Mountain are bluish black or iron-grey in colour, pretty compact, breaking with a plane fracture, and resembling basalt externally. No constituent minerals can be detected by the naked eye. Other specimens of andesite are more earthy; they have a reddish colour, are impregnated with oxide of iron, and surrounded by a rather thick crust of sublimed specular iron, which is often covered with beautiful little crystals of the same mineral.[1]

Microscopic examination shows that this rock must be classed with the pyroxenic

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[1] The Island of Ascension is a well-known locality for fine crystals of hematite, which probably come from Red Hill. Vom Rath found octahedral crystals of magnoferrite on a specimen of Ascension hematite. This association indicates a formation by fumaroles (see Vom Rath, *Zeitschr. d. deutsch. geol. Gesellsch.*, Bd. xxv. p. 108, 1873).

andesites; but the pyroxenic mineral is bronzite. Plagioclastic microliths and little reddish crystals of bronzite make up the ground-mass, and a good number of rather large crystals of felspar also appear in it. At first sight these seem to be sanidine, as they have the glassy appearance and the lines of fracture which one is accustomed to consider as characteristic of this felspar; but the homogeneity disappears with polarised light, and the crystals are seen to be striated like plagioclase by the intercalation of a very large number of polysynthetic lamellæ. Sometimes this felspar is crystallised simultaneously according to the albite and Carlsbad laws. In certain cases some individuals show a zonary structure. These extremely close striæ recall similar observations in sections of oligoclase and andesine, and this resemblance is confirmed by the fact that the extinction in the felspar of this rock takes place at a very low angle.

The mineral identified as bronzite is always altered, and the decomposition shows itself by the deep red tint which clothes the sections. Sometimes crystals cut perpendicular to the prism, show an octagonal form like that of augite sections. This form is, however, equally characteristic of bronzite, to which the optical properties in parallel light plainly refer the crystals, but their small size and the alteration of the mineral makes an examination by convergent light impracticable. These prismatic sections always extinguish following the length, and never show pleochroism. The alteration of this mineral not only changed the colour, but in some sections part of the substance has been eliminated, and greenish matter deposited in the hollows. The red colour produced by alteration makes these little prisms resemble certain olivines, but the outlines of the sections and the elongated form of the prism do not confirm this supposition. This bronzite is rarely found in sufficiently large crystals to induce microporphyritic structure, but occasionally some are of such a size, and in this case they are often deeply indented. A very pronounced fluidal structure appears round the larger crystals of bronzite. The mineral may be traced from the large sections, on which its determination is based, to extremely small microliths in the ground-mass. It is by analogy also that the minute crystals of plagioclase in the ground-mass are related to the larger individuals of the same species, the microliths being sometimes so minute that the polysynthetic lamellæ can hardly be discerned. Finally, we may mention amongst the constituent minerals of this andesite large and irregular sections of magnetic iron, which usually appear as skeleton crystals.

To andesite must be referred also the rock forming veins in the trachyte of the hill known as "Crater of an old volcano." Darwin[1] thus describes the very numerous veins in the earthy trachyte exposed on the sides of this mountain. The rock forming them contains crystals of glassy felspar, some black microscopic grains, and small stains of a dark tint. The ground-mass is very hard and compact, and the rock is more

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[1] Darwin, Geol. Obs., pp. 44–45.

brittle and less fusible than the trachyte which encloses it. The veins vary much in thickness, measuring sometimes only a tenth of an inch, at others exceeding an inch. The surface is rough, and the veins are either horizontal or inclined at any angle; they are generally curvilinear, and cut each other. Being hard and compact, the veins do not weather so quickly as the surrounding rock, and they frequently project for one or two feet above the surface of the ground for several yards at a time. The rock composing them is very sonorous, and vibrates when struck; the fragments lying on the ground clink like iron when thrown against each other. The shapes assumed are sometimes singular; Darwin observed a pedestal of earthy trachyte covered with the veiny rock so as to resemble a parasol large enough to shade two persons. He points out, in order to explain these facts, that the hill in question shows numerous jasperoid and siliceous veins, indicating that in this region there is an abundant deposit of silica. He admits that the rock differs from trachyte only in its greater hardness and brittleness and its less fusibility, and that probably the veins originated from the infiltration or segregation of silica much as oxide of iron accumulates in certain parts of sedimentary rocks.

Amongst the specimens collected by Dr. Maclean there is a fragment labelled "Piece of Clinkers,"[1] of which the name and all the characters correspond to Darwin's description of the veins of sonorous rock of the "Crater of an old volcano." This rock is entirely penetrated with limonite; it breaks in little plates 2 centimetres in diameter, with an unequal surface, which scales off, is fusible with difficulty, and resounds when struck. None of the constituents can be detected by the naked eye on account of the complete impregnation with iron oxide.

Under the microscope the rock presents certain analogies to the basalts from its structure, but the mineralogical composition shows it to belong to the pyroxenic andesites. The ground-mass is made up of little entangled crystals of augite of a nearly violet colour, with microliths of felspar and grains of magnetic iron. Embedded in this there are pretty large crystals of felspar and augite. The vitreous base, so common in andesites, is wanting; but, on the other hand, there is no trace of olivine, so that in spite of the basaltic appearance when under the microscope the rock is rather a transition to andesite. An examination of the felspar contained in it leads to the same conclusion. This mineral is twinned according to the albite and pericline laws, and sometimes after the Baveno type. Sections cut parallel to M show a more basic central nucleus, which extinguishes at $-7°$. They are bounded by a colourless zone, hence the plagioclase is probably an andesine, not a labradorite or bytownite. We know that andesine is almost never the felspar of basalt, and recent optical researches go to confirm the opinion of the older lithologists, who considered it characteristic of andesites. Some sections twinned according to the albite law have extinctions of which the

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[1] According to the label this specimen comes from Southwest Bay.

double angle hardly exceeds 10° as a mean. We have just said that several of the plagioclase crystals showed a zonary arrangement: the interior zones have more faces than those on the periphery. This fact seems to indicate that the plagioclastic mixture was modified during the growth of the crystal. The largest crystals of augite are greenish, as is generally the case in pyroxenic andesites; they are sometimes twinned according to the ordinary law, and the mineral here presents a very pronounced prismatic form. The augite is generally altered and coloured brownish yellow by iron. The little microliths of plagioclase in the ground-mass are, like their larger congeners, usually twinned according to the albite law, and related by their extinction—which takes place at very small angles—to the microporphyritic plagioclases.

The examination of another specimen of pyroxenic andesite has enabled us to make observations which confirm what has just been said. As in the preceding specimen, the microscope showed the ground-mass to be composed of an accumulation of plagioclastic and augitic microliths and small sections of magnetite. In this mass there were large plagioclases, some of which gave good opportunities for studying their characters; others, on the other hand, formed irregular grains composed of colourless granules, as if the crystals had been crushed; and others were much corroded by the action of the magma, presenting curves and sinuosities in outline in place of the right lines of crystalline faces. This corrosion has been followed by a deposit of inclusions, surrounding the nucleus which has resisted solution. After the corrosion and deposit of inclusions a fresh deposit of plagioclastic substance, of a more basic character than that forming the nucleus, took place. Indeed this very thin external zone, which closely follows all the contours of the primitive crystal, extinguishes at an angle of about 16°

FIG. 11.—Andesite of Ascension. Sections of plagioclase corroded by the magma, with a zone of small scales of hematite; the external felspathic zone is labradorite, the internal part of the plagioclase is more acid, the extinctions of which are those of andesine. $\frac{1}{20}$ crossed nicols.

(the angle of some labradorites) in sections parallel to *M*, and the internal part at an angle of 10°. Sections perpendicular to the edge *P*/*M* extinguish at 20° for the central part, and at 30° for the outer zone. These observations confirm our previous statements, that the central crystal is andesine, the enveloping pellicle labradorite (see fig. 11). We may add that many of the crystals, even the microliths of the ground-mass, show the Carlsbad twin. The smallest plagioclastic microliths have the extinction of labradorite, the second generation of felspar is then more basic than the first.

EJECTED FRAGMENTS OF AMPHIBOLIC GRANITE, GRANITITE, DIABASE, AND GABBRO.

Darwin[1] observed heterogeneous fragments of rocks included in the scoriaceous volcanic masses of Green Mountain, and his description of these may be recalled here. Nearly all the specimens had a granitic structure; they crumbled readily, were rough to the touch, and their original colour was altered. Darwin classed these fragments, and grouped them as follows :—

1. A whitish syenitic rock, striped and spotted with red markings. Felspar is well crystallised, and numerous small brilliant grains and crystals of quartz are visible. The felspar and hornblende were determined by means of the reflecting goniometer, and the former mineral appeared from its cleavages to belong to a potash felspar. The quartz was determined by the blowpipe.
2. A fragment of a brick-red colour, composed of felspar, quartz, and dark particles of an altered mineral, which appears from its cleavages to be hornblende.
3. A mass of whitish felspar crystallised in a confused manner and containing small cavities filled with a decayed mineral, dark in colour, with rounded edges, shining fracture, but no definite cleavage plane. Comparison with the preceding specimen justifies the conclusion that it is fused hornblende.
4. A rock which appears like an aggregation of large crystals of dark-coloured labradorite, amongst which granules of whitish felspar, numerous micaceous lamellæ, and altered hornblende are found, but quartz is absent.

Darwin states also that he picked up at another point a conglomerate containing small fragments of granite, of cellular or jasper-like rocks, and of porphyry, enclosed in a wacke traversed by many fine threads of concretionary pitchstone passing into obsidian. These beds are parallel, gently undulating; they continue for only a short distance, thinning out at the extremities like the lenticular enclosures of quartz in gneiss. He adds that it is possible that these fragments were not thrown out separately by the volcano, but that they were brought to light enclosed in a fluid mass resembling liquid obsidian.

Amongst the specimens we have examined there are several which may be referred

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[1] Darwin, Geol. Obs., pp. 40–42.

to crystalline rocks of the ancient type, and which have, as Darwin states, been torn up from the depths by eruptions of basalt or trachyte. We shall describe them in detail, commencing with those from Green Mountain, the locality of Darwin's specimens just described.

Amphibolic granites occur amongst the fragments brought to light by recent volcanic masses. They resemble the granitic rocks we shall describe as enclosed in the augitic andesites of Camiguin. The specimens are rather brittle, and are composed of vitreous-looking grains. The felspathic mass is milk-white, dotted with the projecting black points of little crystals of hornblende, which also line the walls of small geodes. To the naked eye the rock presents the fritted appearance we will describe in speaking of the granitic inclusions in the volcanic rocks of Camiguin. Under the microscope the texture is distinctly granitoid; numerous felspathic sections may be observed, and a few of hornblende and quartz. The sections of felspar are often twinned according to the Carlsbad law. The intercalation of plagioclastic lamellæ, which do not fail to appear in triclinic felspars, is not observable. The sections, however, do not show the homogeneity of ordinary sections of orthoclase; those parallel to the face *M* are furrowed with little veins slightly expanded in the middle. These short veinules are ranged in lines in the direction of the prismatic cleavage. On measuring the angles of extinction on a section parallel to *M*, it is found that the principal individual (that in which the veinules are imbedded) extinguishes at + 5°, the value of extinction for orthoclase on this face. The spindle-shaped veinules, on the contrary, have an extinction of the same sign, but much greater, the angle attaining 18°, the extinction of albite. We may conclude that this felspar is orthoclase, including fine lamellæ of albite (see fig. 12). This determination as microperthite is again confirmed by the fact that we have never been able to detect in any of the felspathic sections the intercrossed lamellæ of microcline. The innumerable gas enclosures with which the sections are riddled, giving a scorified appearance to the mineral, seem to characterise this felspar, and perhaps to indicate the high temperature to which it was exposed during its transport by the molten lava. With the exception of this the sections of felspar show only very slight traces of modification. Hornblende presents itself in irregular sections. They are very pleochroic:

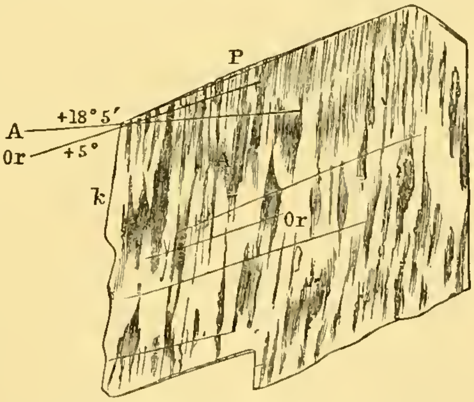

FIG. 12.—Amphibolic granite. Section of orthoclase with veinules of albite ranged in lines following the prismatic cleavage (microperthite). $\frac{1}{40}$ crossed nicols.

$\beta >$	$\gamma >$	α
almost black.	dark green.	brownish yellow.

Were it not that there are certain sections showing the characteristic cleavages of hornblende to guide us, we might hesitate in some cases to classify these green sections with this species. Sometimes they may almost be mistaken for indented plates of mica; in other cases, when they are not lamellated, they are more like a mineral of the clintonite group; but the cleavages are certainly those of hornblende. Quartz has crystallised last. The sections of this mineral are cracked in a remarkable way, each forming a true breccia, the fragments of which are surrounded by a black border. The cracking conveys the idea that the mineral has been splintered by the action of heat. Another peculiarity of the quartz in this granite is the number and size of its inclusions. They are relatively very large, often presenting the form of a negative crystal, containing gas-bubbles and a liquid; sometimes they contain some small well-known cubic crystals. In this respect we may compare the inclusions with those of quartz in the rocks of Laurwig. Enclosed minerals are rarely found in these quartz sections; we may, however, mention fine needles of schorl occurring as inclusions. Finally, amongst the constituent minerals there are small sections of somewhat irregular form which, from the index of refraction, the colours with polarised light, and extinction, seem to be zircon.

Another fragment from the same locality is referable to granitite; it appears to the naked eye with the texture of a porphyritic granite, and the shining crystals of orthoclase may attain 2 or 3 centimetres in diameter. Black mica appears scattered through the ground-mass, giving it a slightly gneissose structure. As in the case previously given, the large felspathic sections are microperthite; sections of micropegmatite are occasionally found, and more rarely the felspathic element is plagioclase, which presents at the same time the twin of albite and that of pericline. The black mica is very dark biotite, which often forms little nests, or the lamellæ are intercalated between the various constituents. Zircon sometimes occurs included in quartz, the crystals being comparatively large.

We shall now describe another rock resembling that last treated of in some respects, although the black mica is not so abundant. The texture is granitic, but the specimen is much altered, being entirely penetrated by iron oxide, which gives it a reddish colour. The naked eye can only distinguish felspar with rather bright cleavage faces. The rock, so far as one can examine it with the microscope, is impregnated with hematite, which has infiltrated into all the interstices and cleavages, and appears in isolated scales of indistinctly hexagonal outline. Felspar is represented by orthoclase and plagioclase. The orthoclase has often crystallised as a Carlsbad twin, but the plane of composition seems to be *k* in place of *M*. The plagioclases present no feature which is not common to the monoclinic felspar with which they are associated; the sections are riddled with gaseous and vitreous inclusions. The constancy with which these inclusions occur in the felspar of all those rocks that have been carried along by lava, seems to show that igneous action has had something to do with the development of the inclusions. The form of the grains into which the quartz sections are divided shows clearly that the parts belong to one large individual. The cause just invoked to account for what may perhaps be termed the scorification of the felspar probably produced this cracking of the quartz. Sections of micropegmatite are less common than in the granitite previously described, but they sometimes appear. Besides the rare scales of biotite, there are some small crystals of hornblende ; these are almost colourless, but some sections with the characteristic cleavage show incontestably that they are amphibolic.

Other specimens of older rocks from Green Mountain must be classed with diabase, although, as we shall see, the micro-structure is not altogether identical with that of rocks of this type. These fragments are very much altered, and easily crumble down. The naked eye distinguishes felspar, biotite, and a granitoid structure. The microscope shows that the rock is formed of an aggregate of plagioclastic lamellæ, augite, and biotite, with hornblende as an accidental constituent. The triclinic felspar shows extinctions which lead one to believe it to be labradorite. The augite shows itself in excessively broken-up sections, formed of an accumulation of irregular granules. The grains of augite do not appear to result from fractures along the lines of cleavage ; the mass rather resembles a crushed crystal. Fibrous hornblende appears between the grains, and shows itself most clearly at the extremities of the pyroxenic sections, where it may be seen to pass into black mica. The augite is greenish in colour, and more like that of diorite than of diabase. The lamellæ of biotite are often twinned, the limit of the twin being parallel to the lamellæ ; the composition plane is probably the pinacoid *OP*. Grains of augite sometimes appear associated with biotite ; in this case it is not uncommon for the former to be oriented with the vertical axis parallel to the lamellæ of this mica. Hornblende, which is rather rare in the preparations, is only distinguishable from biotite in ordinary light by its structure, and by a decided prismatic cleavage. Sometimes, when this mineral borders augite, it is fibrous. Finally, we note the transparent prismatic crystals of a mineral which appears grey from the number of inclusions it contains. It would be classed as cordierite if its colours with polarised light were a little more vivid ; perhaps it is an altered felspar.

At Red Hill, as at Green Mountain, fragments of old rocks are found which have been brought up by recent eruptions. The specimens from Red Hill may be classed with the gabbros, and microscopic examination shows them to be olivine gabbros. The rock has to the naked eye a granitoid texture ; in colour it is reddish, being impregnated with limonite. Triclinic felspar is distributed through the mass in the form of grains, and is intimately associated with a pyroxenic mineral. The elements of this rock measure about 5 millimetres in diameter.

Under the microscope the structure of olivine gabbro is brought out. Elongated lamellæ of plagioclase, containing between them sections of augite moulded on the associated elements, do not appear here; the felspar is in large sections of irregular outline, in very rare cases assuming a form more or less resembling a parallelogram. The symmetrical extinctions, measured on sections more or less nearly parallel to the face *k*, give values of from 36° to 40° on each side of the albitic lamellæ. These extinctions have been measured on sections showing at the same time lamellæ of albite and of pericline crossing at an angle of about 80°, the sections being thus sensibly parallel to *k*. For sections of the zone *P* : *k*, which give symmetrical extinction, the angle only varies from 12° to 20° on the average. These values indicate in each case a very basic felspar, almost a mixture of bytownite and anorthite. This determination agrees both with the form this felspar assumes here and with the nature of the rock in which it occurs. It is known that the plagioclase of the Neurode gabbro, for instance, is anorthite.

Plagioclase isolated from the rock has been analysed by Dr. Klement, with the following result:—

I. 1·2166 grammes of the substance dried at 110°C, and fused with the carbonates of soda and potash, gave 0·6203 gramme of silica, 0·3708 of alumina, 0·0134 of ferric oxide, 0·1751 of lime, and 0·0030 of magnesium pyrophosphate.

II. 0·5398 gramme of the substance treated with hydrofluoric acid gave 0·0405 gramme of potassium and sodium chlorides, and 0·0058 of potassium chloroplatinate.

PERCENTAGE COMPOSITION.

Silica, SiO_2,	50·99
Alumina, Al_2O_3,	30·48
Ferric oxide, Fe_2O_3,	1·10
Lime, CaO,	14·39
Magnesia, MgO,	0·09
Soda, Na_2O,	3·80
Potash, K_2O,	0·21
	101·06

The results of analysis given above confirm the optical determination. The mixture, in fact, corresponds in composition to 30 per cent. of albite and 70 per cent. of anorthite, which is—

Silica, SiO_2,	50·68
Alumina, Al_2O_3,	31·73
Lime, CaO,	14·05
Soda, Na_2O,	3·54
	100·00

The sections of olivine are much altered on the edges; they are sometimes transformed into red hematite, and trichites penetrate them in every direction. That the trichites are of secondary formation is made evident by the fact that they are developed in the interstices between fissures, and sometimes follow the curves marked out by the latter.

Augite is often lamellated as it appears in some diabases. The lamellæ are produced by the repetition of twinned individuals interposed parallel to the pinacoid ∞ Ꝑ ∞. The nature of this mineral confirms our determination of the rock. The absence of cleavage in these pyroxene sections is striking—they are rarely furrowed by the regular fractures so common in this species, but this peculiarity may be due to the unusual thickness of the microscopic preparation submitted to examination.

Another specimen of a similar rock contains a very basic plagioclase, as in the preceding case, and also greenish augite, but there is no olivine, its place being taken by some rare sections of a rhombic mineral. These might be mistaken for olivine by ordinary and by parallel polarised light. The sections are colourless, but brilliantly coloured in polarised light; they stand out in high relief, the outlines being blunted and the surface shagreened. They are, however, distinguishable from olivine by the presence of extremely fine black linear inclusions, running parallel to each other and to the length of the sections, and sometimes assuming the form of negative crystals. Extinction takes place parallel and perpendicular to these inclusions and to the traces of faces of the zone of the prisms. In convergent light it becomes apparent that this mineral should be classed with the rhombic pyroxenes, such as enstatite. The determination as enstatite is confirmed by the use of the condenser, which enables one to distinguish an eccentric optical axis so situated as to show that the plane of the axes is parallel to ∞ P̆ ∞.

VEINS AND SILICEOUS INFILTRATIONS.

In his geological description of Ascension, Darwin[1] calls attention to the numerous veins of siliceous material which cut through the rocks of the "Crater of an old volcano." These veins he described as white, composed of a material with low specific gravity and conchoidal fracture. The colour sometimes becomes reddish; in other cases it is yellowish white and the fracture angular, while a whitish powder fills the cavities. Both varieties occur as amorphous masses in the altered trachyte, or as wide irregular veins coloured red and running vertically or in a tortuous manner. This rock, which resembles sandstone in appearance, is nothing but an altered trachyte. Jasper of an ochreous colour is found in large masses, and occasionally in the form of veins enclosed in altered trachyte, or in scoriaceous basalt. The cavities of the latter rock are lined

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[1] Darwin, Geol. Obs., p. 45.

or entirely filled by concentric layers of chalcedony coloured red by ferric oxide. Irregular angular grains of red jasper, with an outline gradually becoming less definite and passing into the surrounding mass, are found in the most compact parts of the same rock; there are also other grains which hold a position intermediate between jasper and decomposed iron-coloured basalt. The jasperoid portions contain circular cavities of exactly the same form as those occurring in scoriaceous basalt. Darwin explains these facts by supposing a siliceous solution to have penetrated the rock after the elimination of certain altered constituents. This interpretation appears very natural, but with the specimens at our disposal, it would be rather difficult to judge of its applicability; we would require to see many more specimens than those we have studied. With reference to these siliceous deposits, Darwin recalled the frequency with which a similar action occurred amongst the altered trachytic tufas.

Amongst the specimens collected by the Challenger, we have only found a few fragments showing the siliceous infiltration to which reference has been made. Some rocks from Riding School, and from the plain at the foot of Red Hill, show silicification well. In proportion as silica develops in the rocks, the characters of the constituent minerals become obscured, and various modifications of silicic acid invade the ground-mass.

One of the rocks from Red Hill is a true siliceous tufa, in which the original constituents can hardly be distinguished. The rock is yellowish white to the naked eye, decayed, so hard that steel will not scratch it, and milky fragments of quartz break off from the mass. Under the microscope the ground-mass is seen to be nothing but an aggregate of minute quartzy grains firmly compacted together. They are angular and colourless, and behave between crossed nicols like the basis of certain quartziferous porphyries.

A volcanic glass almost entirely converted into silica is found at Riding School. This rock is like a eurite, whitish in colour, very hard, homogeneous in texture, and has a slightly scaly fracture. Microscopic preparations show a slightly vesicular vitreous ground-mass. Chalcedony has formed in the pores and interstices of this glass, and in some places the rock seems impregnated with imbricated crystals of tridymite.

Siliceous Deposits of Organic Origin.

The wide circular hollow, about half a mile in diameter, which surmounts the "Crater of an old volcano," is not a crater according to Darwin.[1] The hollow is almost filled with many-coloured layers of scoriæ, cinders, and incoherent volcanic products. The general appearance of the beds is saucer-shaped. They are all visible at the edge of the hollow, where they show as a succession of variously-tinted rings, giving a

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[1] Geol. Obs., pp. 47–49.

singular character to this eminence. The outer ring is large, distinguished by its white colour and its resemblance to a racecourse,—hence the name of Devil's Riding School. According to Darwin these beds of ashes must have covered the whole region formerly, but they have been dispersed by wind—those which had fallen into the hollow on the summit were sheltered, and became to a certain extent cemented and consolidated by rain. One of the beds has a rosy colour, and is formed essentially of small fragments of pumice. It contains numerous concretions, which are spherical and vary from half an inch to three inches in diameter; sometimes they are cylindrical, like the concretions of pyrites in the chalk. These concretions are formed of six or eight clearly-defined concentric layers, separated by colourless zones, and surrounding a nucleus which appears to be homogeneous. The central part is often traversed by fissures like those of septaria; these are bordered by black veinules, which sometimes assume a metallic aspect, or by white patches. Amongst the largest concretions, some were found which simply formed a spherical shell full of incoherent volcanic ashes. These concretions contain only a small proportion of calcium carbonate. Before the blow-pipe a fragment crepitates, whitens, fuses into a frothy enamel, but does not become caustic. The mass enclosing the nodules contains no trace of calcium carbonate. Darwin adds that he never met with a description of similar nodules, and what rendered them the more remarkable, in his estimation, was their hardness and compactness, which must have been acquired under the influence of atmospheric water alone.

So far, with regard to these concretions, we have only cited Darwin, whose description corresponds very exactly with the facts he observed. At the time of publishing his book on Volcanic Islands, he considered these spheroidal concretions, and the material with which they were associated, as exclusively made up of incoherent volcanic products. After his voyage he submitted a specimen of the concretions to Ehrenberg. Microscopic examination showed that it did not present the characters of ordinary volcanic ashes, but that the rock was only an accumulation of particles of organic origin. According to Ehrenberg, these particles are not very much modified, although they no longer contain any compounds of carbon. He attributed the elimination of these bodies to the action of heat. He did not admit that these organisms periodically accumulated in the hollow, as it would be necessary to suppose if they lived where their remains were discovered. The whole mass was apparently formed of organic débris, and Ehrenberg observed 30 species of siliceous organisms in the deposit. He even considered the more or less amorphous matter which is associated with the particles as being exclusively composed of this siliceous débris in a state of dust. These organisms all belong to fresh-water forms, the greater number of small siliceous particles being derived from grasses. It is very remarkable that no marine forms have been discovered on this island. In concluding his paper, Ehrenberg rejects the idea that this deposit is the residue of the vegetation of the island.[1]

Darwin in his Voyage of a Naturalist modified his first explanation of this deposit, and stated the results of Ehrenberg's examination. After mentioning that Ehrenberg considers this siliceous matter to have been ejected in its present state from the volcano, he states that the appearance of the layers has led him to believe that they were deposited under water, and considering the extreme dryness of the climate, he has been compelled to suppose that torrents of rain had probably accompanied some great eruption, and that a temporary lake was thus formed in which the ashes were laid down. Perhaps one might now be justified in supposing that the lake was not temporary. Although it were so, we may be quite sure that at some earlier period the climate and productions of Ascension were quite different from what they are now.

The specimens of white earth and the concretions from the Devil's Riding School, which we have examined, correspond with Darwin's macroscopic description, and, in general, with what Ehrenberg said of their microscopic constitution. Amongst the specimens we have studied three varieties occur ; two of these are concretionary, and both pass into the third by insensible gradations. The common variety is a pulverulent earthy rock, soiling the fingers, and to the touch resembling mealy diatomaceous earth ; the colour is yellowish white, inclining to pink. This variety is associated with the spherical concretions of which Darwin speaks ; these are embedded in the mealy mass. The nodules we have examined are from 1 to 3 centimetres in diameter. They are built up of concentric zones sometimes with radial fissures ; spherical coatings easily peel off, but the central part is more compact. Two nodules are sometimes joined ; in other cases they bear the marks of small depressions. Except for their rather large size, analogies are not wanting with certain pisoliths or globular forms sometimes assumed by volcanic ashes. These globules are not generally very coherent, but the third variety differs in this respect. In it the concretions are more irregular, assuming discoidal, cylindrical, even coral-like forms ; the surface alone is earthy, the internal part being compact, and so hard that steel will hardly scratch it. All the particles which make up the interior zones are strongly cemented, and coloured brown by iron. We may add that some of these nodules bear a great resemblance to some flint concretions of the chalk. A summary analysis showed that the material contained about 87 per cent. of silica, and that the loss by heating was 6 per cent.

The various forms of this siliceous substance have the same microscopic composi-

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[1] Ehrenberg, Ueber einen bedeutenden Infusorien haltenden vulkanischen Aschen Tuff (Pyrobiolith) auf der Insel Ascension (*Berichte d. k. Akad. d. Wiss. Berlin*, 1845, p. 140). Taking account of the name (Pyrobiolith) which Ehrenberg gives to the deposit, and the conclusions he expresses in his memoir on the infusorian volcanic tufas of the Rhenan country (*loc. cit.*, Bd. vi. p. 133), it is evident that he considers these deposits as of internal origin, and brought to their present position by eruptions.

tion. The dust of the earthy variety, and the slices of the concretionary, are filled with elongated colourless forms, more or less rounded, and slightly curved; these are undoubtedly organic and siliceous; they are the débris of the organisms which Ehrenberg discovered and determined. These particles are enclosed in a pale yellowish isotropic matrix without definite outline. When this opaline ground-mass is more coherent, one sees that the rods and colourless organic forms appear as partly dissolved; the ground-mass is more homogeneous, and the interstices are lined with microscopic grains of quartz. Splinters of glass, lapilli, or minerals of volcanic origin are rarely seen.

Ehrenberg's explanation does not seem to apply here; there is nothing to indicate an eruptive origin for the siliceous earth and its nodules. It seems more reasonable and more probable to admit that the cavity containing the deposit in question was formerly a crater-lake, in which the remains of fresh-water organisms accumulated; part of the constituent silica was dissolved, perhaps under the influence of thermal springs, and cemented the particles which in aggregating took in some cases the form of nodules.

Calcareous Rocks Forming on the Coasts.

Darwin describes calcareous rocks in process of formation at several points on the coast of the island.[1] The shore is covered with immense numbers of minute rounded particles of shells and coral, white, yellow, and red in colour, mixed with rounded volcanic minerals and splinters. At a depth of some feet the particles are cemented, and form a compact rock, the softest kind of which is used for building, while some varieties are too hard for this purpose. One of these calcareous masses was observed divided into horizontal layers half an inch thick; it gave a ringing sound like flint under the hammer. The people of the island believe that one year suffices to cement the calcareous sand into stone. The sand is united by a calcareous cement, and one can always observe, even in the most compact varieties, a zone of crystalline calcite around every fragment of shell and each volcanic grain. Lyell[2] states that turtles' eggs deposited in this calcareous and volcanic sand are sometimes subjected to the same process, and are found enclosed in the mass. He has figured some eggs containing the bones of young turtles that were included in this way in these recent calcareous rocks. Darwin treated a specimen of the rock of specific gravity 2·63 with acid, and found that it dissolved entirely with the exception of a little flocculent organic matter.

A great accumulation of calcareous particles takes place annually on the shore near

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[1] Darwin, Geol. Obs., pp. 49, 50.

[2] Lyell, Principles of Geology, Book III. chap. xvii., as cited by Darwin; in Lyell's edition of 1872, see vol. ii. chap. xlviii. p. 581.

the Residence in the beginning of October, the sand being driven towards the south-west. According to Lieutenant Evans, this is accounted for by a change in the prevailing direction of the currents. During this period the rocks exposed to the tide on the south-west are gradually covered by a calcareous incrustation, the thickness of which may attain half an inch. This coating adheres strongly to the rock, is white in colour, and at some points laminated, but after the lapse of a certain time it disappears; perhaps it is re-dissolved by the sea water, perhaps worn away by the waves. Lieutenant Evans, who communicated these observations to Darwin, had had opportunities of studying the phenomena during six years which he spent at Ascension. The thickness of the layer varied from year to year; in 1831 it was exceptionally great. When Darwin landed in June 1839, he could only see it at one point above a basaltic rock from which the quarrymen had raised a block of limestone. On taking into account the position of the rocks exposed to the tide, and the period at which they are covered with the calcareous coating, one comes to the conclusion that the sea water, continuously in contact with the particles of broken shells on the beach, takes up an excess of calcium carbonate, and then on evaporation deposits it upon the rocks over which the waves wash. According to information given to Darwin by Lieutenant Holland, this incrustation is found on the rocks of the coast in several parts of the island.[1] The formation of this deposit must be explained by the solvent action of sea water on the shelly formations of the shore, and the rapid evaporation of the water.

The specimens of these oölitic rocks which we have examined come from the west coast, and vary greatly in coherence. Some are scarcely compact, the fragments of shells and minerals being simply brought together without the aid of calcareous cement; others are massive, very coherent, and hard, showing a compact ground-mass in which the naked eye can detect the pink or white organic particles mixed with black volcanic grains.

Microscopic observation shows that the fragments cemented together by calcareous matter are all perfectly rounded, the elliptical form sometimes prevailing. They are composed of the remains of shells and other organic débris, and are distinguished from

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[1] Besides this deposit and the rocks formed of shell fragments, Darwin describes a calcareous incrustation presenting a special structure. It also covers volcanic rocks exposed to the tide. We have found nothing amongst the specimens to correspond to the description and figure he gives in his book on Volcanic Islands, p. 51. We refer to the passage where the author enters into very precise details on the subject of this layer, the form of which closely resembled an organic structure. He considers it due to the same cause as the cemented limestone and incrustations of the coast. In the analysis he made of the concretionary incrustation of Ascension, calcium sulphate was found; this might come from evaporated sea water. He adverts to Dr. Webster's description (Voyage of the "Chanticleer," vol. ii. p. 319) of beds of gypsum and salt, 2 feet thick, on rocks exposed to the prevailing wind. Fine gypsum stalactites, resembling those of carbonate of lime, may be seen there. In the caves of the centre of the island amorphous masses of gypsum are found, and in an old crater on Cross Hill the salt appears traversing the scoriæ. In this case Darwin considers the sea salt and gypsum as of volcanic origin (see Darwin, Geol. Obs., p. 53, footnote).

the calcite cementing them, by their internal structure, semi-opacity, and greyish tint. The internal structure of the fragments is generally well preserved; sometimes they present a spathic cleavage, and at others the calcium carbonate composing them is very fibrous. Yet, as examination in convergent light shows, it is impossible to refer these fibrous sections to aragonite. With the condenser, one arm of the cross of monaxial crystals may be seen. The rolled fragments of inorganic origin cemented together with the shell sand are the débris of volcanic minerals or rocks. The latter are most frequently represented by rounded spangles of plagioclastic felspar, often by grains of olivine, but augite is rather rare. The lapilli, or rolled fragments of rocks, belong generally to the family of basalts. They are scoriaceous, often vitreous, and transformed into palagonite with vesicles lined with zeolites. Rolled fragments of trachytic rocks rarely occur in this limestone; this may be accounted for by the fact that basalt chiefly occurs on this side of Ascension. The rocks and minerals enclosed in the calcite are all somewhat profoundly altered. The substance cementing these heterogenous fragments is always calcium carbonate, perfectly transparent and fibrous; this distinguishes it at the first glance from the included shell-particles. The fibres are so fine that it is impossible by optical means to determine whether they are calcite or aragonite; the polarisation colours and the irisation are the same as for calcite. The calcareous coat which envelops each of the rolled grains is sometimes fibro-radiated, the fibres spreading from one grain to the sides of the zone surrounding the contiguous fragments. The calcareous matter sometimes does not fill all the interstices, and the resulting little geodes, sometimes of triangular form, bristle with a fine lacework of rod-shaped crystals of calcium carbonate.

In conclusion, something must be said about a shining coating of calcium phosphate which clothes some of the rocks of Ascension. In his description of the rocks of St. Paul, Darwin drew attention to an enamel coating which covered the cliffs of that islet. We have described and analysed the material which Darwin found at St. Paul's Rocks, and compared it with the substance coating the rocks of Ascension. Darwin, describing this glossy incrustation, says: "Extensive portions of these rocks are coated by a layer of a glossy polished substance, with a pearly lustre and of a greyish-white colour; it follows all the inequalities of the surface, to which it is firmly attached. When examined with a lens, it is found to consist of numerous exceedingly thin layers, their aggregate thickness being about the tenth of an inch. It is considerably harder than calcareous spar, but can be scratched with a knife; under the blowpipe it scales off, decrepitates, slightly blackens, emits a fetid odour, and becomes strongly alkaline: it does not effervesce in acids. I presume this substance has been deposited by water, draining from the birds' dung with which the rocks are covered. At Ascension, near a cavity in the rocks, which was filled with a laminated mass of infiltrated birds' dung, I found some irregularly-formed stalactitical masses of apparently the same nature. These masses when broken had an earthy texture, but on their outsides, and especially at their extremities, they were formed of a pearly substance, generally in little globules, like the enamel of teeth, but more translucent, and so hard as just to scratch plate-glass. This substance slightly blackens under the blowpipe, emits a bad smell, then becomes quite white, swelling a little, and fuses into a dull white enamel; it does not become alkaline; nor does it effervesce in acids. The whole mass had a collapsed appearance, as if in the formation of the hard glossy crust, the whole had shrunk much."[1] Darwin states in a note that when he described this substance in his Journal he viewed it as an impure calcium phosphate.[2] We have tested some small fragments of the incrustation collected at Ascension; there remains no doubt as to this being the true interpretation. The coating gives the reactions of phosphoric and sulphuric acids, and the microscopical characters resemble those of the incrustations on St. Paul's Rocks.[3] It may therefore be admitted that it was formed, like the latter, by the decomposition of the excrement of birds. In his description of Ascension, Lesson was the first to lay stress on the accumulation of birds' droppings which covered the rocks of the island. The insoluble residue exposed to the rays of the sun and the action of waves has hardened, and forms the coating which clothes the rocks of the coast.[4]

VI.—NOTES ON THE ROCKS OF THE TRISTAN DA CUNHA GROUP OF ISLANDS.

Until the Challenger Expedition explored these islands, we had only very uncertain notions of the nature of the rocks that constitute the group of Tristan da Cunha. We have borrowed from the Narrative, vol. i., and the works of Sir Wyville Thomson[5] and Moseley,[6] and especially from Buchanan's report,[7] the local details that accompany these lithological researches. The following observations do not form a complete geological monograph of the Tristan da Cunha group; in general, they have reference only to the

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[1] Darwin, Geol. Obs., pp. 32, 33.

[2] *Ibid.*, p. 33.

[3] See A. Renard, Report on the Petrology of the Rocks of St. Paul, p. 18 (*Narr. Chall. Exp.* vol. ii. Appendix B). We give there a micrographic description and analysis of these layers and veinules of calcium phosphate. The incrustation Darwin saw at St. Paul's, which he compares to that at Ascension, is described on p. 21 of our memoir. On analysing a specimen we found phosphoric acid (P_2O_5), 33·61, and lime (CaO), 50·51, besides traces of iron, manganese, and sulphuric acid. This incrustation can thus be viewed as tribasic calcium phosphate with calcium sulphate, and perhaps carbonates of lime, magnesia, and iron (see Darwin, Voyage of the Beagle, chap. i. p. 8; Buchanan in Thomson, The Atlantic, vol. ii. pp. 107, 108.) For phosphates very like those we describe, see also Phipson, *Amer. Journ. Sci.* vol. xxxvi. p. 423; Julien, *ib.* p. 242; Piggott, *ib.* 2nd Ser. 1856, No. 22.

[4] Lesson had observed this shining layer, but mistook its nature; he says, "a grey enamel-like obsidian clothes the rocks of the coast," *loc. cit.* p. 492.

[5] Wyville Thomson, The Atlantic, vol. ii. p. 152.

[6] Moseley, Notes of a Naturalist on the Challenger, p. 108.

[7] Buchanan, *Proc. Roy. Soc.*, vol. xxiv. p. 593.

rocks that crop out on the coasts. The difficulties of exploration prevented the naturalists from rambling out of sight of the ship. On considering the nature of the rocks collected, everything leads to the belief that similar conditions would have been observed in the central part of the island.

The group of Tristan da Cunha comprises the Islands of Tristan, Nightingale, and Inaccessible. On the strength of the relations of the flora, there ought to be added to the same group the small Island of Gough, lying 200 miles to the south. These islands form the summits of a great submarine chain, which traverses the middle of the Atlantic from north to south, and on which, in the southern part of that ocean, rest the St. Paul's Rocks and the Islands of Ascension and St. Helena.[1]

A. Rocks of Tristan Island.

Tristan, the most important of these islands, lies in the north of the group; it is situated in lat. 37° 2′ 45″ S., long. 12° 18′ 20″ W. (Herald Point); it is 1550 miles distant from the Cape of Good Hope, 2000 miles from Cape Horn, and nearly 1320 south of St. Helena. The area is about 16 square miles. The Island of Tristan is almost circular, an elevated peak occupying the centre. If a circle of 3½ miles radius be described with this mountain as centre, it will touch all the salient points of the coast, except those in the eastern quarter, where the shore projects about half a mile beyond the circumference. This island rises almost vertically from the bottom of the sea, the 100 fathom line occurring close to the coast; it is bordered by craggy cliffs, which render landing very difficult. The perpendicular rocks that encircle the island attain a height of 1000 to 2000 feet, and form a terrace or plateau, on which stands a conical peak, reminding one of the peak of Tenerife; its summit, covered with snow for nearly the whole year, attains a height of 7640 feet. According to the inhabitants of Tristan, the peak is a cone of black and red scoriæ, with a crater-lake on the top; the diameter of the crater is about a quarter of a mile. From the coast other eminences of less height are visible on the plateau that forms the centre of the island. These hills are very probably also secondary cones of eruption; several of them, like the central peak, have crater-lakes.

The cliffs are formed of nearly horizontal beds of basalt, alternately compact and scoriaceous, with intercalated layers of reddish volcanic tufa. The whole system of beds slopes slightly towards the shore, as can be seen to the east and west of the harbour. These beds are traversed by dykes, generally vertical and of no great thickness.

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[1] Starting from the meridian of 35° W., and a little to the south of the parallel of 35° S., the bottom of the sea begins to rise gradually, till it reaches the culminating point of the submarine chain of the South Atlantic. The ground rises to the height of the Islands of Gough and Tristan da Cunha, around which soundings of 1100 fathoms and upwards have been made. To the east of the islands the bottom sinks to 2200 fathoms, between long. 10° W and 15° E., and from lat. 30° to 50° S.

Torrents and atmospheric erosion have worn gullies in these walls of rock, and heaped together piles of débris, which have accumulated to a height of 100 feet at the foot of the cliffs. This circle of volcanic fragments is, in its turn, edged by a belt of gravel of the same nature, which is spread out on the narrow shore of the island.

There is perhaps no region in the world where atmospheric agencies exert their destructive action in so energetic a manner as here. For nine months in the year terrible tempests run riot on the island, and when the season of rains has ended, and the snow that has accumulated on the top of the peak begins to melt, the water rushes down in cascades, carrying an immense quantity of débris. These streams vigorously attack and demolish the less coherent and homogeneous of the layers that form the horizontal strata ; they lay bare the rocks of the dykes, and cut deep indentations in the ledge of the terrace. The transverse dykes alone resist the erosion, and stand up like walls.

The Island of Tristan da Cunha.

Mr. Buchanan observes that at Tristan, as at Nightingale Island, the dykes have, at their contact, made the volcanic breccia which they traverse more alterable ; whence it results that denudation acts by preference along their sides. These dykes of massive injected rocks also form the axis along which the coves and bends of the shore are hollowed out. On the Island of Tristan the gully lying behind the settlement, in the centre of which the spring rises that supplies the village brook, is formed in a similar way. It is banked by a vertical dyke, the thickness of which is nearly 180 feet; this injected rock has altered the encasing beds, which have become schistose and break down readily. A large number of similar dykes can be seen in the cliffs, but their thickness does not generally exceed one or two feet. The rocks of the coast, presenting as they do good natural sections of the island, have enabled Mr. Buchanan to establish at two points the existence of old vents, occupied now by volcanic materials, which seemed to him products of subaërial eruption, slowly deposited under water. This interpretation leads to the further admission, that certain parts of the Island of Tristan have, like several islands of the Atlantic, been subjected to upheaval.


Settlement of "Edinburgh," Tristan da Cunha.

In first describing the rocks that have been poured out as lavas, or projected as incoherent volcanic materials, and now constitute the nearly horizontal beds, we must point out, as one of the most important, a reddish yellow rock with large crystals of augite. According to the observations of Mr. Buchanan, it has undergone profound alteration under the influence of the dykes that traverse it. Some of the specimens of it are almost completely disintegrated; the augite crystals alone have resisted decomposition, and they can be extracted with ease from the almost earthy mass that encloses them.

Thin sections of certain less decomposed portions of this rock show that it ought to be referred to the felspathic basalts, passing, in some cases, to the augitic andesites. The following minerals—plagioclase, augite, mica, titanic or magnetic iron, and, in certain cases, olivine—give the rock a microporphyritic structure. The crystals of felspar give sections showing plagioclastic lamellæ following the albite type; sometimes they are twinned on the Carlsbad, the pericline, or the Baveno type. Fig. 13 shows a section of plagioclase observed in the rock in question.

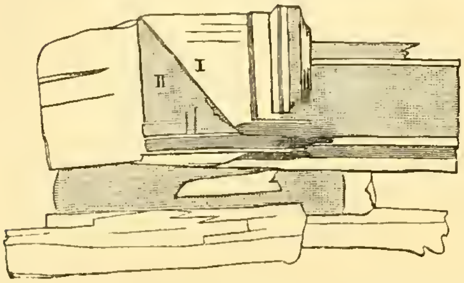


Fig. 13.—Felspathic basalt of Tristan da Cunha.
I. and II. twin of Baveno, the other twins following the pericline type, or some other analogous twinning. The plane of twinning (*n* or *e*) is at the same time the plane of composition.

The crystals of augite present no striking peculiarity. Those of olivine, which at first sight somewhat resemble pyroxene, are enclosed in a setting of small augitic crystals. The black mica plays a very subordinate part, but the ilmenite or hematite is, on the contrary, represented by large dark brown or almost opaque sections, furrowed by well-marked lines of cleavage intersecting at angles of 120°; these lines run throughout the whole extent of the section, and are often parallel to its outlines (see fig. 14). It is somewhat rare to find hematite with such clearly marked cleavage. Something analogous may be found in sections of ilmenite, but then, generally, there are needles of rutile, intercalated at constant angles. In the mineral we are describing, we have not been able to make out any inclusions of rutile.

Fig. 14.—Felspathic basalt of Tristan da Cunha.
Opaque section of ilmenite or hematite with cleavages intersecting at 120°.

The ground-mass is formed of microliths of the same species, especially of felspar and augite; between these small crystals lies a vitreous base, which plays a wholly subordinate part. At certain points a yellowish limonitic matter has been deposited as concretionary masses in the pores.

Some of these decomposed specimens pass almost without gradation into a more compact and harder rock. These compact zones are black with glassy lustre and brilliant fracture; they exhibit the vitreous modification observed on the contact faces of the dykes in the same island. These black bands resemble obsidian; they are only 2 centimetres thick, and may be looked on as the more quickly cooled surface of the basaltic sheet. This glass shows under the microscope a blackish brown and sometimes nearly opaque isotropic base; at certain points it passes into the reddish modification, with the resinoid appearance of the palagonitic tufas. In this base crystals of plagioclase are seen, some sections of which give extinctions of 42°, and consist of anorthite; as usual, this felspar is traversed by few hemitropic lamellæ. The augite sometimes contains granules of olivine, magnetite, and apatite as inclusions.

The beds formed by this altered felspathic basalt are overlaid by a basaltic tufa. The transition is effected through rocks that are richer in glassy materials, but belong, nevertheless, to the same lithological type. The tufa covering the sheet in question is formed of fragments in which the vitreous element predominates; they appear, under the microscope, to consist of a vesicular yellowish or brownish glass, passing occasionally into the hydrated, reddish, resinoid product of decomposition of certain basic volcanic glasses. The crystals that separate out from these vitreous fragments belong chiefly to greenish pleochroic augite, and are generally irregular in contour. The preparations show, besides, sections of the same mineral and of plagioclase of smaller size, with clean cut outlines embedded in the glassy matrix, and belonging to a secondary period of consolidation. Olivine and magnetite are relatively rare. Frequently the large crystals of augite and plagioclase are partly lined or entirely surrounded by a vitreous substance more opaque and blacker than the glass that forms the ground-mass.

This tufa is overlaid in its turn by a rock of the same kind, but of a coarser grain. It consists of lapilli, 2 to 3 centimetres in diameter, and is full of augite crystals visible to the naked eye. There also occur in it fragmentary crystals of olivine, which show their clastic origin very clearly under the microscope. The same remark applies also to some of the augites in this tufa. As is shown by fig. 15, the sections of these clastic minerals exhibit certain outlines which represent the crystallographic contours. These traces of faces are distinct and straight (a), and are bordered by black glass of varying thickness; but wherever this section shows fractures, this coating of black glass is absent. This furnishes evidence that the crystals in question were once entirely embedded in a dark or almost opaque glassy magma, from which they were projected as loose material; they must have been partially crushed, and wherever fracture occurred the glass was carried away, while where they remained unbroken the vitreous mass protected the faces of the crystal. The augite of the tufa we are describing has a great tendency to form twin-crystals as polysynthetic as those of some plagioclases. These lamellar individuals, intercalated in the principal crystal, are extremely distinct and remarkably regular; when large enough, they betray their presence by sections with reëntrant angles (see fig. 16) formed by the alternating faces of two adjacent individuals. Sometimes, too, the

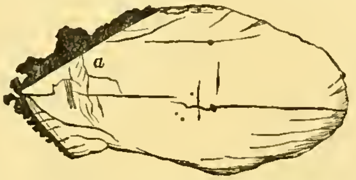


FIG. 15.—Tufa of Tristan da Cunha. Clastic grain of olivine crystal, certain outlines (a) exhibiting crystallographic contours bordered by black glass.

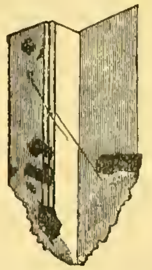


FIG. 16.—Tufa of Tristan da Cunha. Polysynthetic twinning of augite; reëntrant angles at the upper part of the section by the alternation of the faces of two adjacent individuals.

outlines of these reëntrant angles are replaced by a straight face, which restores these broken lines, as is to be seen in fig. 17, showing a polysynthetic augite from this tufa. In the upper, most clearly developed, part of fig. 17, we ought, considering the size of the polysynthetic lamellæ, to recognise the successive traces of the angles formed by the juxtaposition of the twinned individuals; but we find only one straight line whose direction corresponds to $\bar{P}\infty$ of one of the individuals. We often observe intercrystallisations of augite and plagioclase; sometimes the two minerals, embedded the one in the other, have their vertical axes parallel. The crystals of plagioclase, augite, olivine, and magnetite are often of somewhat large dimensions. Those of augite and plagioclase are corroded, and show the effects of the action of the base which surrounds them. In this matrix we find the same minerals, but of much smaller dimensions; the small plagioclastic crystals sometimes assume the shape of rhombic tables, often observed for the bytownite of recent eruptive rocks.

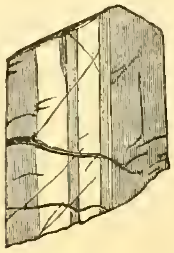


Fig. 17.—Tufa of Tristan da Cunha. Section of a polysynthetic crystal of augite with straight outline corresponding with $\bar{P}\infty$ of one individual.

As we have just seen, the superposed rocks that form the horizontal beds all belong to the felspathic basalts, with vitreous matrix. Among the specimens which we have examined, and which, according to Mr. Buchanan's notes, are to be regarded as lavas, we find some that show certain peculiarities of structure. They are more scoriaceous, but their mineralogical composition is the same. Among the scoriaceous rocks there are some of dark-greyish colour, having their vesicles studded with zeolites; they contain crystals of augite measuring a centimetre. Under the microscope large lamellar sections of plagioclase are seen, often twinned on the Carlsbad type; two simple twinned individuals give very different extinctions, 35° for one individual and 24° for the other, so that very probably we are dealing with a section parallel at once to both P and x. In the thin sections the augite is dark green, with a yellowish tint produced by incipient alteration; apatite sometimes occurs as an inclusion in the augite; the preparations also show olivine, magnetite somewhat rarely, and scales of hematite. These various minerals stand in a ground-mass in which are gathered very minute microliths of plagioclase, augite, and magnetite, with almost no intervening matrix.

Other specimens of lava exhibit transition towards the pyroxenic andesites. These rocks are compact, like the basaltic lavas described above; their microscopic appearance is identical, only we find no olivine in the preparation; the constituent minerals are plagioclase, augite, and magnetite, with the addition of biotite in small brownish lamellæ. These small crystals are all set in a matrix formed of faintly-coloured glass.

Hornblende is rare in the lavas of Tristan, only one rock having been found to yield it. This rock closely resembles the andesitic lavas in microscopical characters;

it is slightly more schistose, less compact, and not so dark in tint. Under the microscope it is found to be composed of the following minerals of the first generation: large crystals of plagioclase, augite, and hornblende. The sections of this last species are encircled by a zone of magnetite. These sections stand out from an almost colourless glassy matrix, containing microliths of plagioclase, augite, and magnetite.

Another specimen belonging to the bedded rocks consists of a fragment taken from a layer of loose volcanic products, overlaid by a sheet of lava. From the structure of the specimen, it is evident that it is composed of two layers, indicating successive deposits. The one has the composition and texture we have recognised in all the basaltic lavas of the island; the other is an agglomeration of glassy splinters, plagioclase, augite, and magnetic iron; all these minerals are fragmentary, and the layer in question ought to be regarded as a basaltic tufa.

We have given the lithological characters of the lava-streams and tufa that constitute the greater part of the rocks cropping out on the coast; it remains to indicate the nature of the transverse dykes injected into these superposed layers. The specimens procured from these dykes look to the naked eye like compact basalts of blackish tint, giving slight indications, also, of a columnar structure. One fragment which was contiguous to the encasing rock exhibits, to a depth of about a centimetre, the black vitreous modification with brilliant lustre, well known in basaltic rocks that have been subjected to sudden cooling.

To judge from the specimens we have examined, these dykes are felspathic basalts, presenting sometimes a transition into augitic andesites. The minerals of first generation are magnetite, olivine, and plagioclase. The last-named crystals are lamellar; the extinctions, measured symmetrically on two adjacent hemitropic lamellæ, are about 36°. This felspar, therefore, approaches labradorite. The ground-mass of this rock is somewhat remarkable (see fig. 18). It is almost entirely composed of augitic microliths, which are grouped in rosettes or twinned crosswise, and sometimes planted almost perpendicularly on the plagioclastic lamellæ or between the small prisms of augite, forming a fibro-radiating aggregate. Crystals of olivine with hexagonal or rhombic contours are frequent, and they enclose a nucleus of glassy substance. Magnetite, in more or less irregular grains, fills up the interstices between the various minerals that constitute the matrix. The other specimens from the injected dykes have the same mineralogical composition and the same texture.

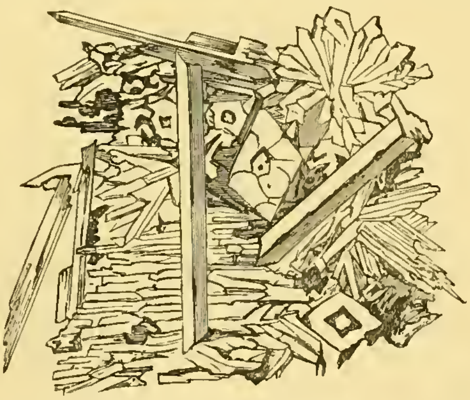


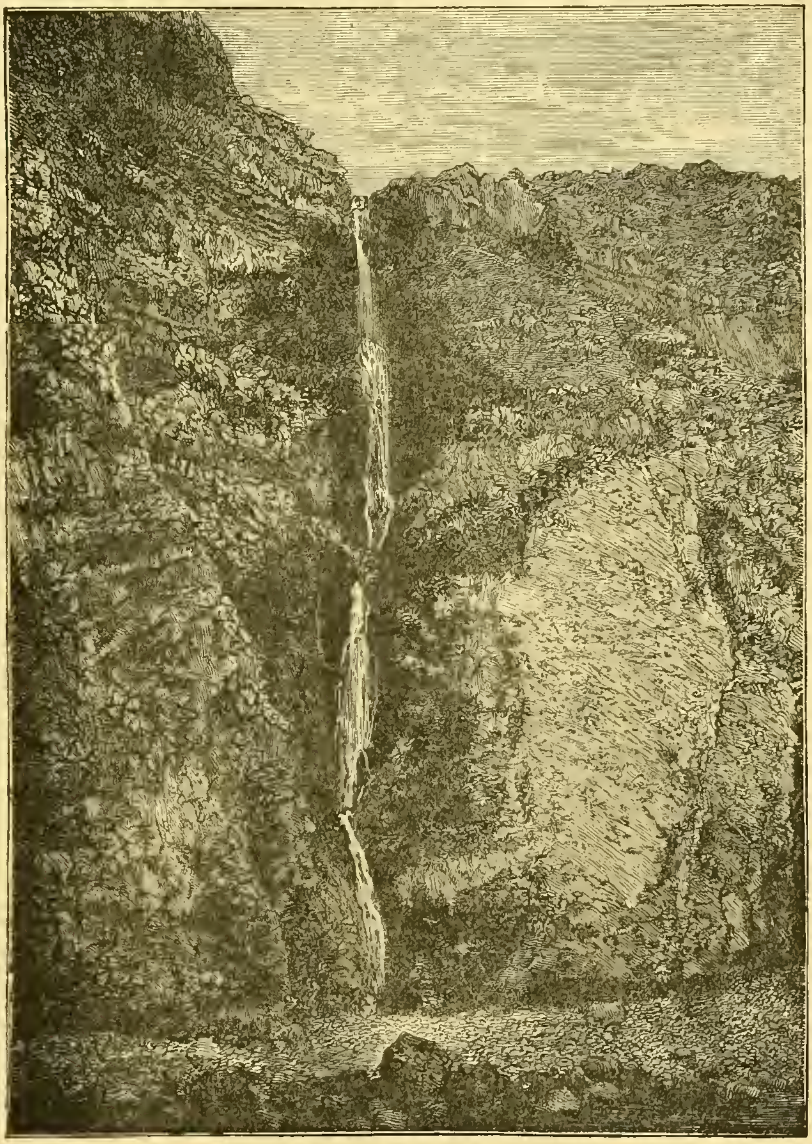
FIG. 18.—Dyke of felspathic basalt, Tristan da Cunha. Ground-mass composed of augite microliths in rosettes or planted perpendicularly on the plagioclastic lamellæ, and crystals of olivine with vitreous inclusions.

Among the specimens of rock from the Island of Tristan, there is a vitreous fragment, very compact, and with a slight reddish reflection, which the inhabitants use for striking fire. This rock when examined under the microscope is seen to have a very dark vitreous matrix; in some parts it is slightly transparent and brown. The minerals developed in it are augite and plagioclase. This latter mineral is present in lamellar sections, somewhat large at times, and sometimes riddled with vitreous inclusions; the large plagioclase crystals are even visible with the lens; we observe also much smaller lamellæ of triclinic felspar, scattered sporadically in the ground-mass. The dimensions of the crystals of augite with magnetite inclusions are the same as those of the large plagioclase crystals; their forms are well marked, and a certain number among them are twinned like those previously described in the lavas of the island. There are also to be seen in the base a great many small sections of augite, as well as some microscopical sections of olivine. This rock, which one would at first sight place alongside of obsidian, ought to be referred to the felspathic basalts; it constitutes a very vitreous variety of that type.

The soundings of the Challenger around the Island of Tristan brought up samples of the sediments that are deposited near the island. The mineral particles that occur in these deposits are exclusively of volcanic origin. The fragments that enter into their composition are microscopical fragments of the rocks which we have just described, or of the minerals that form these rocks. One dredging (18th October 1873) brought up a fragment of hard, black, massive rock, weathered on the surface; microscopical examination showed that it belonged to the basalts; it greatly resembled the rocks forming the dykes in Tristan. We find in it microliths of plagioclase elongated in a direction parallel to P/M, and giving extinctions of about 30°; and, still further, small sections of olivine and apatite. The black pigment of the ground-mass is concentrated at certain points. All the characters of this rock go to show that it came originally from the Island of Tristan. The same statement does not hold good of the fragments of pumice collected in the same dredging. The ubiquity of pumice in pelagic deposits is a well-known fact, and Mr. Murray has shown how these volcanic products may come to be deposited at points far removed from their place of origin. We are thus led to regard these fragments of pumice as in no way appertaining to the rocks of Tristan. Macroscopic examination shows the presence of sanidine in this pumice; under the microscope the same mineral is seen in splintered crystals, without either regular outlines or hemitropic striæ. Plagioclase, with the twinnings of albite and pericline, is also present.

B.—*Rocks of Inaccessible Island.*

Inaccessible belongs to the same group as Tristan da Cunha. It lies to the west of the other islands, and is a little smaller than Tristan, from the summit of which its centre is about twenty-three miles distant.[1] Abrupt cliffs, fringed with a line of breakers girdling the island, appear at first sight to make landing impossible, but there is a narrow beach at the base of the vertical rocks. Inaccessible Island is nearly quadrilateral in outline, the angles being directed towards the cardinal points. The highest part of the island is towards the west, where the cliffs rise to the height of



Waterfall, Inaccessible Island (*from a Photograph*).

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[1] For the physical description of Inaccessible see Wyville Thomson, The Atlantic, vol. ii. p. 156; Moseley, Notes of a Naturalist etc., p. 115; *Narr. Chall. Exp.*, vol. i. p. 254. Buchanan has given geological details on this island in *Proc. Roy. Soc.*, vol. xxiv. p. 614.

1840 feet above the sea level, the average elevation of the rocky wall being about 1100 feet. A crag 1140 feet high occupies the southern angle, and a conical mound of 700 feet rises on the south-west, the two heights being separated by a V-shaped ravine, probably produced by atmospheric erosion.

The geological structure of Inaccessible is identical with that of Tristan, and the appearance of the two islands is consequently similar. The vertical cliffs present a series of good sections, which show the island to be built up of successive horizontal beds of eruptive rocks, traversed by oblique or vertical dykes. As at Tristan, the coast cliffs terminate in a plateau. Boulders, broken off by the waterfalls from the lava-beds and dykes, have collected at the base of the rocks, passing on the seaward side into a belt of rounded basaltic pebbles. The rocks dip almost vertically into the sea, and there are very few places where they can be climbed in order to reach the central plateau. Soundings of from fifty to ninety fathoms occur a few yards from the cliffs.

Sir Wyville Thomson was so struck by similarities in the physical geography of Tristan and Inaccessible as to hazard the opinion that these eruptive masses, now separated by twenty miles of water, had once been united. According to the description of the naturalists of the Challenger, the rocks of Inaccessible very closely resemble those of Tristan, and they have the same arrangement. We will first describe the rocks forming the lava sheets and the tufa.

Almost all the specimens from Inaccessible are felspathic basalts; the differences between them are chiefly in texture, and sometimes in the development of a vitreous base. A porphyritic basalt, which appears to take an important place in the structure of the island, has given rise by decomposition to a yellowish earthy substance, to be described further on. This basalt is a black scoriaceous rock containing many crystals of augite, sometimes a centimetre in length, olivine, and felspar. Felspar is the least abundant constituent, and its crystals are the smallest. Microscopic preparations show that the ground-mass in which these porphyritic crystals are embedded is formed by a yellowish or altered base, which penetrates all the fissures of the larger minerals. This ground-mass contains small augite sections, some of them star-shaped, showing penetration twins; these microliths are associated with minute plagioclase sections and with magnetite. The large porphyritic crystals of augite are zonary, and have a somewhat pale pink colour; the regular sections of olivine are a little smaller, and have been slightly altered at the edges; a yellowish zone surrounding this mineral shows that it is being decomposed into hematite. It contains numerous inclusions of magnetite, and shows traces of twinning. If there were no small crystals of plagioclase in the base this rock would be classed with limburgite, which it resembles macroscopically in several ways.

This basalt decomposes into a yellowish earthy substance, from which crystals of augite may be easily separated. The following analysis of these crystals was made by Dr. Klement; it shows that this pyroxene is akin to chromiferous diopside.

I. 1·2557 grammes of substance dried at 110° C. and fused with sodium and potassium carbonate gave 0·6504 gramme of silica, 0·0485 of alumina, 0·0071 of chromic oxide, 0·0888 of ferric oxide, 0·2815 of lime, 0·5476 of magnesium pyrophosphate and traces of manganese.

II. 1·1195 grammes of substance treated in a sealed tube with sulphuric and hydrofluoric acids required 7·2 cubic centimetres of potassium permanganate solution to oxidise the ferrous oxide (1 c.c. = 0·005439 gramme FeO)—

Silica, SiO_2,	51·80
Alumina, Al_2O_3,	3·86
Chromic oxide, Cr_2O_3,	0·57
Ferric oxide, Fe_2O_3,	3·19
Ferrous oxide, FeO,	3·50
Manganese,	traces
Lime, CaO,	22·42
Magnesia, MgO,	15·72
	101·06

Another rock, which was labelled as a lava, and must have been poured out in sheets, closely resembles that just described. It contains rather large crystals of augite and lamellæ of plagioclase, which sometimes measure two or three millimetres, but olivine is not common. The rock is vesicular, and has a bluish grey ground-mass. Microscopic examination shows that the fine-grained paste is formed of small aggregated plagioclastic lamellæ, with augite and magnetite, but free from any vitreous constituent. Sharply crystallised olivines stand out from the ground-mass; some of them are twinned, most probably following a dome. There are also zonary crystals of augite, each of the zones extinguishing at different angles; these are twinned, following the orthopinacoid, and the twins are frequently repeated polysynthetically. The lamellæ of microporphyritic plagioclase are often twinned according to the Carlsbad, pericline, and albite laws. Sections almost perpendicular to *P/M*, showing very thin and sharp periclinic striæ, extinguish at angles between 35° and 39°; this felspar, therefore, approaches anorthite.

Other basaltic lavas show no porphyritic structure, the only element visible to the naked eye being lamellæ of plagioclase of three or four millimetres in size, which have lost their glassy sheen. The mass is bluish grey and scoriaceous; augite and grains of olivine may be distinguished by the lens. Under the microscope the ground-mass is seen to be devitrified by trichites, and to contain augite and magnetite microliths, as well as very slender crystals of plagioclase, sometimes assuming a stellate form. Olivine is one of those first-generation minerals which determine the microporphyritic structure. This mineral occurs in rather large sections with sharp crystallographic outlines; sometimes the form is hexagonal; two of the sides belong to the vertical zone, and are perpendicular to the plane of the optical axes. Others form an angle nearly of 77°, these being thus traces of the face $\bar{P}\infty$ (*d*). These sections show cleavages perpendicular and parallel to the vertical axis, and a third rather indistinct cleavage parallel to *d*. This olivine has a light greenish colour, but is transformed into a red hematite-like matter along the cleavage planes and fractures, and on the edges of the sections. It may also be penetrated by a network of dendritic oxide of iron. This formation of hematite may be connected with the accumulation of grains of magnetite on the edges of the olivine. This mineral has been subjected to corrosion and dislocation, and is often enclosed in augite. The large zonary crystals of plagioclase have been deformed by mechanical strain, and exhibit undulating extinction. They are much lengthened and lamellar, being twinned according to the Carlsbad, albite, and pericline laws. Extinction takes place at a large angle, sections more or less parallel to *M* extinguishing at 43°; the plagioclase is thus to be grouped with anorthite. Augite is the third microporphyritic element, but its sections show few noteworthy peculiarities; they are feebly pleochroic, the differences in absorption being scarcely perceptible. Sometimes these sections are twinned and exhibit a zonary structure, the inner part approaching to violet in tint, while the outer layers remain almost colourless. This augite is filled with vitreous inclusions, magnetite, and sometimes patches of olivine. In the vesicles are seen groups of small acicular crystals, probably some zeolite.

Judging by the specimens at our disposal, doleritic basalts are not common in Inaccessible, only one instance of a dolerite occurring in the collection, and its characters appear most plainly when the rock is examined microscopically. To the naked eye it is scoriaceous, with large vesicles; the ground mass is bluish grey, speckled with irregular white spots of altered felspar. The microscope shows that all the minerals are approximately of equal size. In this rock also olivine has crystallised first, and it exhibits several of the peculiarities already described, being coloured yellowish by alteration, and often surrounded by a zone of delessite. Lamellæ of felspar, somewhat drawn out, surround grains of augite. Sometimes these two minerals are oriented with their axes parallel, at other times they cross each other at various angles; both belong to a secondary stage of consolidation.

Another rock, resembling in structure the dolerite just described, differs from it by the absence of olivine and the presence of a base, in which the minerals giving the rock a doleritic structure are embedded. The base, which is devitrified by trichites, surrounds crystals of augite, appearing to play an unimportant part, and large zonary sections of plagioclase. These felspar sections are more basic at the centre than in the outer zones. Sections of the zone $P:k$ give symmetrical extinctions of 28°–27° for the inner, and of 21°–17° for the external zones. The central parts thus approach anorthite, while the outside comes nearer to labradorite. Notwithstanding the absence of olivine in the microscopical preparations, this rock cannot be classed with the augite andesites, and its structure presents fewer resemblances to that type than to the dolerites.

We may note in passing some slightly vesicular rocks, the ground-mass of which is close-grained, and contains no macroscopic minerals except a few whitish grains of altered felspar. The specimens resemble ordinary basalt in every respect, and show no microscopic features meriting special attention.

Related to these rocks there are some vitreous masses altered into palagonite. They are scoriaceous like pumice, and are coloured yellowish by limonite, but do not show well the resinoid aspect of palagonitic rock. They contain small heterogeneous fragments, indicating the tufaceous origin of the deposit. Under the microscope this substance shows, between crossed nicols, in certain parts of the preparation, phenomena of polarisation like those of altered sideromelane; the vitreous mass is, however, isotropic. The base contains numerous small crystals of augite, which are sometimes capillary and of a green or brown tint. Plagioclase microliths are neither abundant nor well formed; they are often hollowed out on both extremities, and are usually present as skeleton crystals. Olivine is rare or altogether absent. Some patches seem to be made up of heterogeneous fragments; these lapilli are characterised by an obvious difference in the texture and by their mineralogical composition, as they are formed of rather large crystals of plagioclase mixed with grains of augite. The vesicles scattered through the rock contain no zeolites, remaining vacant in the centre although their walls are lined with a light transparent green layer of a secondary mineral.

Having dealt with the lavas and tufa of the island, we have now to describe the transversal dykes. The rocks forming these dykes are generally massive or finely alveolar. The porphyritic basalt with large augite crystals, described above, is traversed by a vein composed of a compact, bluish grey, slightly vesicular mass, containing macroscopic crystals of augite and olivine. This basalt when examined microscopically presents a microporphyritic appearance, produced by rather large zonary crystals of augite and olivine. The ground-mass is an aggregate of minute crystals of three minerals, plagioclase, augite, and magnetite, without interposition of any base. Another dyke, resembling the first in colour and microscopic structure, differs from it in being perfectly compact. Here also augite and olivine can be seen by the naked eye, but under the microscope the ground-mass appears composed of minute plagioclase and augite crystals, and contains a little vitreous matter. Large sections of augite and olivine stand out from the paste; the former are zonary and pleochroic:—

$\gamma >$	$\beta >$	α
pink.	yellowish pink.	yellowish green.

As at Tristan, some of the dykes of Inaccessible show the alteration well known in massive basalt when suddenly cooled: at the contact with the encasing rock it is altered into a brilliant black vitreous coating a centimetre thick. This glassy modification affords a beautiful example of devitrification by trichites of ilmenite, and shows a tendency to perlitic structure. The glass itself is yellowish, and depolarises light at certain points, usually near the edge of the small crystals or in the outer zone of the vesicles, a phenomenon due to molecular tension. Small skeleton crystals of plagioclase and augite microliths are abundant, but black dendritic structures predominate, resembling those described by Zirkel in tachylite.

The following analysis of the black vitreous coating of one of these dykes produced at the contact of the encasing rock has been made by Dr. Klement:—

I. 1·0648 grammes of substance, dried at 110° C., and fused by Sipöcz's method with alkaline carbonates, gave 0·0071 gramme of water, 0·5120 of silica, 0·2028 of alumina, 0·1028 of ferric oxide, 0·1003 of lime, and 0·1035 of magnesium pyrophosphate.

II. 1·1578 grammes of substance treated with hydrofluoric acid gave 0·1621 gramme of sodium and potassium chlorides and 0·1718 gramme of potassium chloroplatinate.

III. 1·0733 grammes of substance treated in a sealed tube with hydrofluoric and sulphuric acid required 11·1 c.c. of potassium permanganate solution (1 c.c. = 0·005405 gramme FeO) to oxidise the ferrous oxide.

IV. 1·6478 grammes of substance treated with hydrofluoric acid gave 0·0722 gramme of titanic acid.

Silica, SiO_2,	48·09
Titanic acid, TiO_2,	4·38
Alumina, Al_2O_3,	19·05
Ferric oxide, Fe_2O_3,	3·44
Ferrous oxide, FeO,	5·59
Manganese,	traces
Lime, CaO,	9·42
Magnesia, MgO,	3·50
Soda, Na_2O,	5·06
Potash, K_2O,	2·88
Water, H_2O,	0·67
Total,	102·08

The non-altered basaltic mass adjacent to these vitreous black bands is filled with arborescent trichites of ilmenite, which appear slightly brownish in transmitted light;

most of them are grouped round a perfectly colourless prismatic crystal of plagioclase, to which they are attached. Many crystals of magnetite and ilmenite are to be seen, and plagioclase is more abundant than in the vitreous zone, although the crystalline form is embryonic; augite occurs in rosettes of little crystals. The shining black part of the vein is perfectly compact, but the internal portion is slightly vesicular, the pores being lined with a transparent coating of green secondary matter which also penetrates the microscopic fissures of the rock. The whole mass of the dyke must have been cooled rapidly. Olivine is scarcely to be found in this rock.

All the rocks from Inaccessible dealt with so far conform more or less strictly to the basaltic type. A rounded pebble picked up on the shore is a bronzite and biotite andesite. This specimen shows that eruptive masses different in composition from those of the coast must exist in the interior of the island. The appearance of the pebble shows at once that it differs from the ordinary rocks such as those described above. It is much lighter in colour, being whitish grey. The texture is fine-grained, the fracture nearly plane, and no constituent minerals appear to the naked eye. Under the microscope a colourless ground-mass is seen, formed chiefly of curved and twisted crystals of plagioclase of indefinite outline, and all matted together. Mixed with these there are some violet-coloured augite microliths, with irregular outlines, but evidently of the same stage of consolidation. Some scales of biotite also appear. All these minerals are of approximately uniform size, and have crystallised simultaneously. Small yellowish crystals appear in the paste as isolated short prisms, with flattened summits, and worn on the angles. Sometimes these occur as irregular grains with fractures, but they are too minute to permit their forms to be definitely ascertained. These small sections give straight extinction, and so far as they could be examined by convergent light it has been proved that the plane of the optical axes is parallel to the brachypinacoid. These crystals ought to be considered as bronzite, and the rock as a bronzite andesite.

C.—*Rocks of Nightingale Island.*

Nightingale is the smallest island of the Tristan da Cunha group, lying towards the south. It is surrounded by rocks, amongst which are two islets measuring one-half by one-sixth of a mile. One of these, Middle Island, 150 feet high, with an undulating summit, is situated in lat. 37° 25′ 50″ S., and long. 12° 29′ 45″ W. The second islet, which also lies to the north of Nightingale, is Stoltenkoff Island, and has a height of 325 feet. Nightingale Island is a mile long from east to west, and about three-quarters of a mile broad.[1] A channel ten miles wide, and over 465 fathoms deep,

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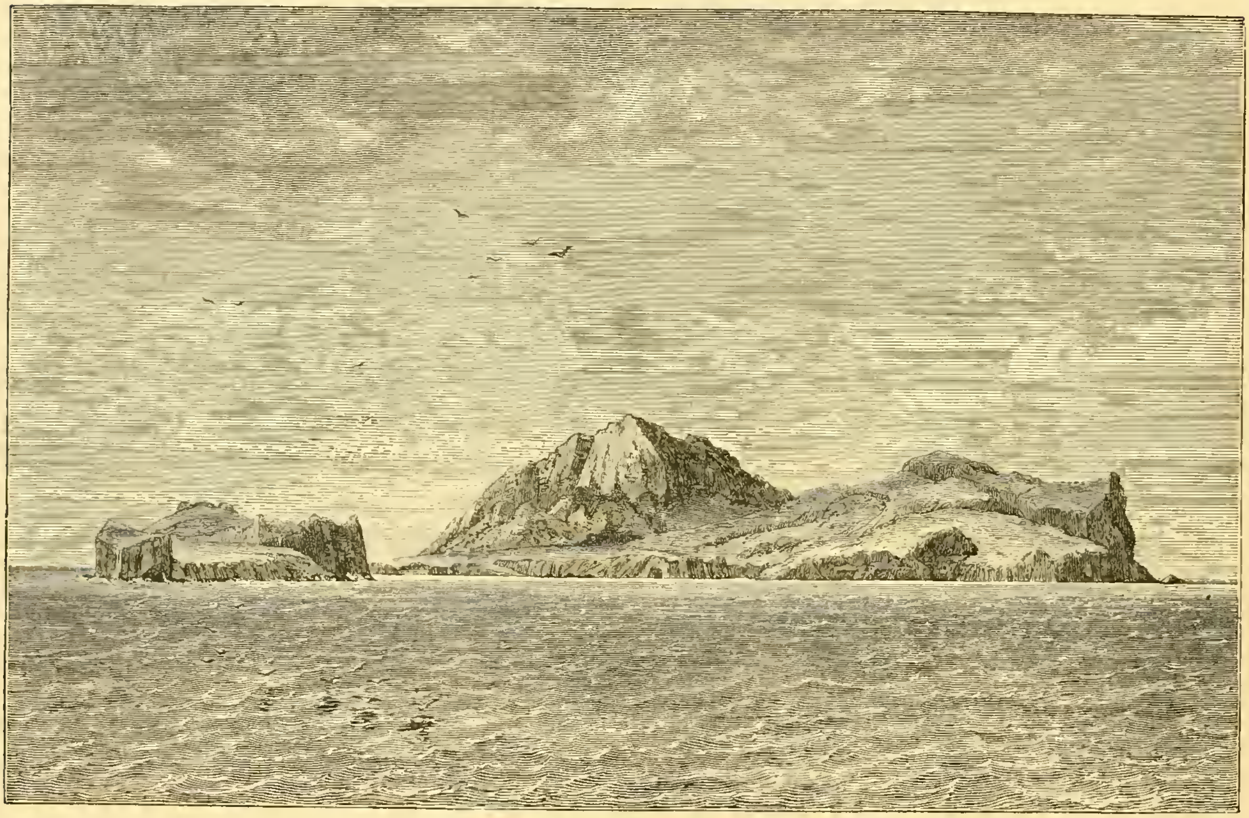
[1] For the natural history of this little group, see Thomson, The Atlantic, vol. i. p. 185 (with a map); Moseley, Notes of a Naturalist on the Challenger, p. 126; *Narr. Chall. Exp.*, vol. i., pp. 262 *et seq.* For its geology, see Buchanan, *Proc. Roy. Soc.*, vol. xxiv. pp. 614, 615.

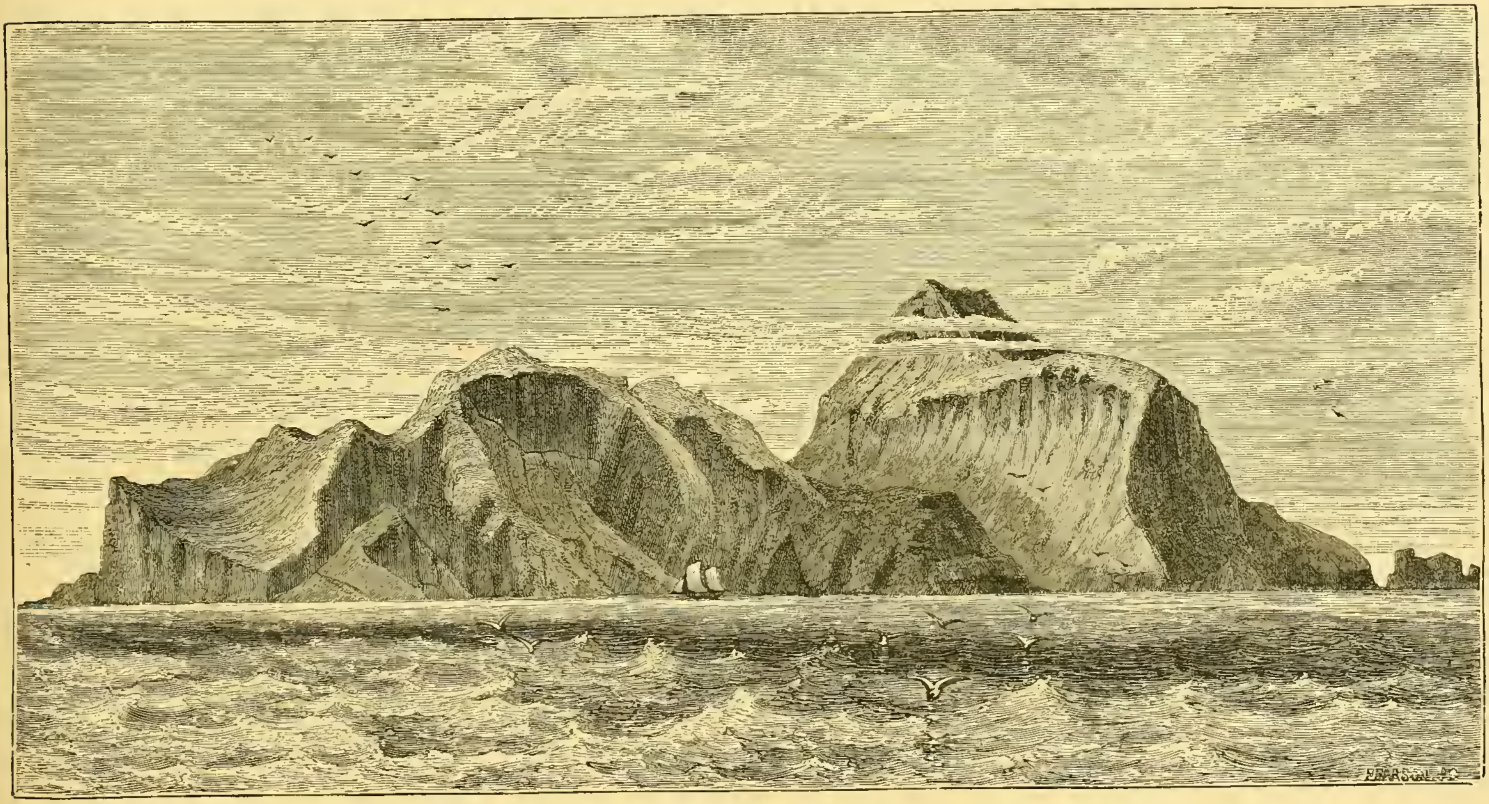
separates Nightingale from Inaccessible, while depths beyond 1000 fathoms occur in some places between Nightingale and Tristan.

On account of the weather and the difficulty of gaining access to the interior of Nightingale, the Challenger naturalists had to limit their geological collections to the rocks which cropped out near the shore. Nightingale differs greatly in appearance from the other islands of the group, being more varied in outline and surrounded by cliffs only thirty or forty feet high, and often less. The southern part of the island is more picturesque, the ground rising by successive crests to a peak 1105 feet high, one side of which is almost vertical for half its height. Mr. Buchanan was unable to ascend this hill, but he describes the rock as being greyish in colour, and of a sub-columnar structure. The rest of Nightingale is undulating, and the rocks, except at a few isolated points, are covered with verdure. No traces of recent volcanic activity are to be seen. The rocks of the coast are chiefly a conglomerate or breccia of doleritic fragments embedded in a whitish felspathic mass. Here and there the conglomerate is surrounded by beds of volcanic rock probably of more ancient origin. Marine erosion has hollowed the cliffs girdling the island into innumerable caves, formerly the refuge of seals, which


Nightingale Island, from the North.

have now been driven elsewhere by indiscriminate slaughter. The fact that the caves are situated a little above sea-level, proves that the island has been recently elevated. A raised beach on the top of the cliffs confirms this supposition.[1]

The stratum of volcanic conglomerate at the base of the shore cliffs is, so far as can be determined from the specimens examined, a phonolitic tufa. The bluish grey rock is speckled with white kaolinised patches; the ground-mass is waxy and considerably altered, and is impregnated with limonite in some places. Under the microscope, the mass is composed of minute sections of nepheline, usually as grains, but frequently in the form of parallelograms or hexagons. The nature of this mineral is also proved by the microchemical reaction of sodium. These crystals are arranged in line, and like the other mineral constituents show well-marked fluidal structure. Microliths of augite are associated with the nepheline; these are brownish, show no evident pleochroism, and extinguish at angles large enough to prevent confusion with hornblende. Small sections of sanidine are also present. Several minerals give the rock a microporphyritic appearance, plagioclase being the most important. The felspar crystals are often twinned


Nightingale Island, from the South.

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[1] The above is a summary of Mr. Buchanan's geological observations at Nightingale (*loc. cit.*, pp. 614, 615)

according to the Carlsbad law, and at the same time traversed by polysynthetic lamellæ after the albite law. Hornblende occurs associated with the plagioclase; the crystals of both species are deeply hollowed and corroded. Rather large brownish hornblende sections are seen surrounded by a zone composed of little green grains of augite with granules of magnetite, biotite, and titanite. In this phonolitic mass are embedded heterogeneous clastic fragments, which prove the tufaceous origin of the rocks forming almost the entire explored portion of the island.

Dr. Klement has obtained the following results from an analysis of this tufa:—

I. 1·0676 grammes of substance dried at 110° C. and fused with alkaline carbonates, by Sipöcz's method, gave 0·0116 gramme of water, 0·6102 of silica, 0·0285 of titanic acid, 0·2142 of alumina, 0·0535 of ferric oxide, 0·0421 of lime, and 0·0459 of magnesium pyrophosphate.

II. 1·0339 grammes of substance treated with hydrofluoric acid gave 0·1875 gramme of sodium and potassium chlorides, and 0·241 of potassium chloroplatinate.

III. 1·1143 grammes of substance treated in a sealed tube with hydrofluoric and sulphuric acids required 4·0 c.c. of potassium permanganate solution (1 c.c. = 0·005439 gramme FeO) to oxidise the ferrous oxide.

Silica, SiO_2,	57·16
Titanic acid, TiO_2,	2·67
Alumina, Al_2O_3,	20·06
Ferric oxide, Fe_2O_3,	2·84
Ferrous oxide, FeO,	1·95
Manganese,	traces
Lime, CaO,	4·41
Magnesia, MgO,	1·55
Soda, Na_2O,	5·84
Potash, K_2O,	4·52
Water, H_2O,	1·09
	102·09

Some specimens collected by Mr. Buchanan in a gully prove the presence of eruptive masses of the andesite type at Nightingale. The rock in question is black and massive, with a plane fracture and rather schistose. Crystals of felspar, about three or four millimetres in diameter, and of hornblende of nearly equal dimensions, shine out from the mass. Microscopically there is a glassy ground-mass containing porphyritic minerals of the first generation. Plagioclase is the most noticeable, and its sections are remarkable in that instead of the usual lengthening along the edge *P*/*M*, they show a great extension following *yM*; in fact many sections take the form of disymmetric hexagons (sections nearly parallel to *M*) in which the shortest sides correspond to the edge *P*/*M*; this is confirmed by examining the best-marked lines of cleavage which run parallel to the short sides of the hexagon. The trace of T/M is indicated by its parallelism with the prismatic cleavage, which is rather less distinct than that just spoken of. It frequently happens that all the outlines of these sections are not equally distinct, or only appear clearly for part of the section, the rest being terminated by a fracture nearly parallel to the prism. These hexagonal sections show that the plagioclase is zonary, and that the extinction is negative. The angular value is greater for the centre than for the outer zone, being from 14° to 10° for the former, and 10° to 3° for the latter. This felspar is thus probably composed of mixtures intermediate between oligoclase and labradorite. Sections following M show the lamellæ after the pericline law almost parallel to the edge P/M; this, according to M. Schuster, is the case for plagioclases approaching andesine. These sections are full of vitreous inclusions, which have no definite arrangement, but are specially numerous near the centre of the crystal, and sometimes follow the external outline and planes of cohesion. The included vitreous matter, which also occurs in the large crystals of augite and hornblende, is of a less deep brown colour, and sometimes contains microliths similar to those of the ground-mass. This fact, taken together with the corrosion of the crystals containing these inclusions, proves that they have been penetrated by the magma in which they were immersed.

Hornblende plays an important part in this rock. Its crystals are prismatic, much elongated, corroded, and fragmentary; this mineral is generally decomposed, its cleavages being as a rule indistinct. Magnetite often encircles the sections as an external zone; probably these small opaque crystals were attracted around the hornblende even before alteration commenced. Inclusions of apatite sometimes occur. The pleochroism is—

α	$<$	β	$<$	γ
yellow.		brown.		dark brown.

Augite of the first generation appears in corroded crystals of the ordinary form and pleochroic—β, bright yellow; α and γ, green. The polarisation colours are whitish yellow, and the tints are brilliant in sections more or less perpendicular to the vertical axes. The mineral is often twinned following the orthopinacoid. It is zonary, and gives larger extinctions for the central parts than for the peripheral layers (34° for the former, 30° for the latter). Patches of augite formed of agglomerated grains are also sometimes seen. Biotite is not common in the rock, but small crystals of magnetic iron are extremely abundant.

The ground-mass embedding the minerals described above is composed of an almost colourless base containing minute lamellæ of plagioclase extinguishing at very small angles, and nearly colourless augite microliths distinguished sharply from the felspar by their more brilliant polarisation colours.

Some specimens of rock forming the floor of "Bromley's Cave"—one of the cliffcaverns on the coast examined by the Challenger naturalists—were collected. This rock, an augite-andesite, is black and massive like a compact basalt; the fracture is plane. No constituent minerals can be detected either by the naked eye or with a lens, but the microscope shows some microporphyritic sections. Amongst these there are a very few plagioclastic lamellæ giving large extinctions, and some sections which, from the absence of polysynthetic twins may be referred to sanidine; the latter are traversed by two cleavages at right angles, and give straight extinction. The augite of this rock is of a light violet colour, its outlines are irregular, and large crystals seldom occur. Corroded hornblende sections are also found as microporphyritic elements, sometimes twinned according to the ordinary law; they show the pleochroism —a, yellow; β, brown; γ, brown. This mineral is sometimes quite decomposed, being invaded by augite microliths and magnetite. The ground-mass of the rock resembles that of basalt in some respects; it contains numerous plagioclastic lamellæ and microliths of several minerals. Those of augite are almost always twinned, the sections appearing to be divided in two longitudinally; the summit is terminated by a low dome, and transverse sections appear as irregular, slightly-coloured grains. Hornblende is present in small pleochroic fibrous prisms which might be taken for biotite, but the extinction is oblique. The rock has been slightly altered with formation of delessite.

An intrusive vein of amphibolic andesite crops out on the floor of Bromley's Cave. It is a black rock with a plane, more or less schistoid, fracture. A very few drawn out vesicles are to be seen, and to the naked eye only some fine needles of hornblende appear, while the lens shows a mass composed of crystalline grains. Microscopical preparations show that microporphyritic crystals of plagioclase, hornblende, augite, and magnetite are embedded in the ground-mass. Under a low power the paste appears brownish and homogeneous, but when more highly magnified it is seen to be made up of an aggregation of plagioclase, augite, and hornblende microliths, the last named being present in greatest number. The crystals of the first generation which produce microporphyritic structure are generally corroded.

Large sections of plagioclase are sometimes lengthened following the edge P/M, sometimes flattened parallel to M; this mineral also occurs as grains. The felspar is related to anorthite, the maximum angle of extinction in the zone $P:k$ being about 39°; two adjacent hemitropic lamellæ gave a maximum extinction of 31°. The structure is usually homogeneous, but when the sections are zonary the centre is more basic than the outer layers. There is nothing remarkable about the large ill-defined sections of augite which are identified by their pale greenish colour, characteristic cleavages, crystallographic outlines, and the angles of extinction. Hornblende is more important, and often appears in irregular corroded grains, although the form is sometimes fusiform, or that of a much-lengthened prism. The sections are almost always twinned according to the ordinary law, and this twinning is shown in the most slender crystals, where it appears in the sections as two extremely thin lamellæ that give the mineral a fibrous aspect. The colour is brown, and the pleochroism is very well marked—

$$\underset{\text{deep brown.}}{\gamma} \quad > \quad \underset{\text{yellowish brown.}}{\beta} \quad > \quad \underset{\text{pale yellow.}}{\alpha}$$

These crystals extinguish at a less angle than is usual for hornblende. Magnetite occurs in the preparations as irregular grains or sections of octohedra.

The ground-mass is composed of crystals of secondary consolidation showing distinct fluidal structure. When examined under very high powers the paste is seen to contain sections of plagioclase usually much lengthened following the edge P/M, and twinned according to the albite law; the little crystals are often grouped in rosettes. A series of extinctions measured from the trace of M gave values between 16° and 32°, the polysynthetic lamellæ giving for one side 20°, for the other 30°, 26°–30°, 13°–16°, 36°–44°. These crystals accordingly differ little in composition from the felspar of first generation. Microliths of augite are also present in the form of greatly lengthened prisms, sometimes broken in several pieces and of a very pale green colour; 40° is the maximum angle of extinction. The part played by hornblende in the ground-mass ought to be noted here. From the minute dimensions and brownish colour of its crystals this mineral might be taken for a glassy base devitrified by microliths, and interposed between the larger sections of plagioclase and augite. A high power, however, brings out the individual crystals as small, fibrous, brownish prisms, sometimes lying in parallel lines or grouped in bundles, sometimes interwinned so as to form a network. They often show distinct pleochroism and extinguish at small angles, while their fibrous structure and elongated form complete their analogy with the larger individuals of the same species. Magnetite appears in very definite sections of octahedra. A network of trichites is occasionally observed closely resembling that of hornblende crystals referred to above; the trichites may perhaps be magnetite, but more probably they are altered hornblende.

All the rocks seen on the coast of Middle Island, which lies a little to the north of Nightingale, are composed of the tufaceous mass now to be described, and according to Mr. Buchanan's observations the entire islet is probably an accumulation of the same formation. The rock is a yellowish, pumiceous, almost earthy, substance, enclosing lapilli and very distinct hornblende crystals. Microscopic examination shows that it is formed of cemented fragments. The most important rock occurring in this tufa will be briefly described. Under the microscope it shows a very compact ground-mass surrounding fragmentary microporphyritic crystals of hornblende, plagioclase, sanidine, and augite, the splinters of the last-named mineral being smaller than those of the others. The largest crystals of plagioclase are corroded; they are sometimes zonary, and show the twins of albite and pericline; from its extinctions the felspar may be classed as labradorite. Sanidine, which is frequently associated with the former, is distinguished by the absence of hemitropic lamellæ, and by the very small angles of extinction in almost all the sections examined. These are sometimes twinned according to the Carlsbad law, and in one case that of Baveno was observed; the extinction is almost always undulating.

The grains of augite are corroded like the felspar, and when little altered their colour is green without pleochroism; their structure is zonary; the centre, which is darker in tint, extinguishes at 36°, the outer zone only at about 45°. Augite is sometimes entangled in brown hornblende sections, the two uniting with parallel axes, and it often forms irregular inclusions in the hornblende along with apatite. Hornblende is a much more important constituent than augite; its sections, which are always brown and strongly pleochroic, are surrounded by an altered zone where magnetite has accumulated. The only other constituent of any size appears in irregular, dirty-brown patches, scarcely transparent, and standing out in marked relief; it is evidently titanite, and is sometimes transformed into calcite.

The paste enclosing the minerals mentioned above is formed of a network of nearly colourless microliths showing fluidal structure. Amongst these may be seen very minute sections of sanidine with indistinct outlines fibrous in appearance, and with straight extinction; they exhibit the Carlsbad twinning, and in ordinary light appear almost as a homogeneous mass. Equally minute microliths of augite occur amongst the foregoing, and may be distinguished by their colour, the chromatic polarisation, and the angles of extinction. Magnetite is present in the ground-mass, but to a very unimportant extent. Finally, there are small, clear, colourless splinters of quartz. The preparation is traversed by veins in which ferric oxide has been deposited.

Thin slices of this tufa show the true characters of a microscopic breccia. Alongside the fragments of the trachytic rock just described, and the splinters of which play the most important part in this tufa, there are small lapilli of an entirely different lithological nature, rich in plagioclase and similar to basalt. Other fragments of rock related to vitreous masses of the same family are frequently changed into palagonite.

VII.—ROCKS OF THE FALKLAND ISLANDS.

A. *Rocks of the "Rivers of Stones."*

The Falkland Islands are connected by their geological character with the American Continent, thus presenting a marked contrast to the oceanic islands of the Atlantic, most of which are formed exclusively of volcanic rocks. The Falklands, on the contrary, are made up of sedimentary strata—schists, sandstones, and quartzite of Silurian and Devonian age—and archæan rocks. We shall here limit ourselves to the consideration of those remarkable "stone rivers" which form one of the most interesting features of these islands, and we propose to describe the lithological nature of some of the rocks of these "streams." Both Darwin and Wyville Thomson examined them with close attention, and described them. Combining their descriptions,[1] we may obtain an idea of the origin of these stony accumulations.

At the east end of the principal island in the Falkland group the valleys present a most striking appearance, being filled with masses of pale grey rocks, which glitter in the sun, and form tracks of from a few hundred to more than a thousand metres in breadth. From a little distance the effect is that of a gigantic glacier, descending from the neighbouring heights and gradually increasing in volume, as if it were fed by lateral streams up to the point where the main "river" reaches the coast. The stones, which vary in size from 30 centimetres to 7 metres, are not piled up irregularly, but extend in great level beds varying from 100 to 1900 metres in width. Thomson showed that the width of the stream is always in relation to that of the shelves of rock which crown the hills. Deposits of peat are constantly encroaching on the flows, and even form islands, when the fragments are near enough to afford a basis. Immense masses of rock on the hills seem to have been stopped in their course, and fragments, bending over like arches, are piled upon each other like the ruins of an ancient cathedral.

All those who have visited the Falklands agree in saying that the stones in question are not water-borne, but are angular, like the fragments of a breccia, and piled up irregularly one above another. They are not decomposed, except to such an extent as might be due to ordinary atmospheric agencies; the angles are generally worn, with a shining, slightly-polished surface. A thin coating of whitish lichen covers the stones, giving them quite the appearance of ice from a little distance. The thickness of the layer of stones is not easily determined, but the sound of running water may be heard evidently a few feet beneath the surface. At the mouth of the valley the sec-

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[1] Darwin, Voyage of a Naturalist; Thomson, The Atlantic, vol. ii., p. 216. See also Narr. Chall. Exp., vol. i., p. 892.

tion of the mass, as shown on the shore, exhibits an enormous accumulation of stones, and the river flows out from beneath an archway of piled-up blocks. As we have said, the interstices of the heaps are carpeted with moss.

The inhabitants view these "stone-rivers" as one of the marvels of their island, and explain their formation by the most improbable hypotheses. Darwin seems to have accounted for them by great earthquakes in the region, but does not consider this a sufficient interpretation. Thomson suggests another explanation. The blocks of quartzite filling the valleys may come from the shelves of rock which appear on the surrounding hills (Darwin remarked that they might come laterally from the nearer slopes as well), and these piled-up blocks certainly show great lithological analogies with the higher beds. The difficulty of the problem comes in when we try to explain how the stones should descend in a close mass along a valley, the slope of which, according to Darwin, is not steep enough to hinder the passage of a coach. The slope in fact does not exceed 6° or 8°; usually it is only 2° or 3°, and it is never great enough to allow the stones to roll, or even slide, down. According to Thomson, the quartzite shelves of the hill-tops do not all resist disintegration equally, the softer parts weather into sand, and the harder, being left without support, break off into irregular blocks. This explanation is equally applicable to the crystalline rocks, the presence of which we are about to show amongst the débris. When the fragments break off vegetation rapidly covers them up, and many of the little mossy heaps are only stones covered by a thin layer of vegetation. Once enclosed in this mass they are, as it were, pushed over the slope. We may mention, amongst other causes that act as well as gravitation, the expansion and contraction of the moss as it takes up more or less water. The dilatation of the moss moves the blocks, and the superficial layer of stones is in some degree drawn towards the declivity. Rain washes off the sandy débris; this erosion prepares the way for the larger blocks, while on the other hand the adjacent vegetable matter decomposes and is washed away. It is to the slow removal of vegetable and mineral matter, and to the movement of the superficial layers—of which Thomson gave numerous examples observed by him in Scotland—that he attributes the accumulation of stones in the valleys.

Neither Thomson nor Darwin have called in ice-action as a means of transport, although it has been alleged that the Falkland Islands were covered by glaciers at an epoch not very far removed from our own. No certain proofs of glaciation are to be seen in the islands, and the stones of these streams bear no marks of glacial striæ. Only a detailed study of local conditions would enable us to say whether Thomson's theory gives an adequate explanation of all the facts. None the less is it true that this theory seems preferable by its simplicity to that which Darwin demanded, when he wrote, forty years ago, on the subject of "stone rivers:"—"The progress of knowledge will probably some day give a simple explanation of this phenomenon, as it already has of the so long thought inexplicable transport of the erratic boulders which are strewed over the plains of Europe."[1]

The specimens collected by Thomson show lithological characters of some interest. One of these blocks is in the form of a quadratic prism, measuring about 40 centimetres by 10; the fracture is regular and polyhedric; the edges hardly show a trace of weathering, but the surface is covered by a less coherent layer of slight thickness. Beneath this thin altered surface the rock remains remarkably fresh. To the naked eye it appears to possess a granitoid structure with grains of medium size; with the lens a plagioclastic felspar can be seen, associated with a black mineral of the amphibolic or pyroxenic group. This rock belongs to the type occurring in the eruptive masses often embedded or injected amongst palæozoic strata, such as those of the Falkland Islands. Microscopic examination shows that the fragment in question must be classed as a diabase, and it also reveals that the rock possesses peculiarities of some interest, and of a kind to which the attention of lithologists is specially directed. This diabase is composed of plagioclase, augite, hornblende, biotite, and magnetite. Of all these minerals, that which at present plays the most important part is unquestionably hornblende; but this constituent is of secondary origin, and can only take a subordinate place in classifying the rock lithologically. The sections of felspar are remarkable on account of the very great number of fine plagioclastic striæ which they present. In exceptional cases only the Carlsbad twin is apparent, but in others the section shows, at the same time, lamellæ twinned according to the albite and pericline laws. These plagioclase sections do not present definite crystallographic outlines, but microscopic examination shows that they are generally elongated following on the edge P/M. It is somewhat rare to find a section parallel to M which would suffice to determine the sign and the angle of extinction. This was possible only in one case: a section presenting two cleavages, parallel to P and to T, crossing at an angle of more than 60°, gave a negative extinction of about 30°. This observation shows that the plagioclase in question approaches closely to a mixture analogous to that of bytownite. These sections of plagioclase are remarkably clear, and the phenomena of chromatic polarisation are sharp and brilliant; the decomposition, so often found in the felspars of granitoid rocks, has, as yet, only affected the plagioclase lightly. This mineral has been subjected to mechanical deformation; some of the lamellæ are laminated, showing an undulating extinction; they are strained, curved, and split up into numerous slices.

The augite of this rock presents some noteworthy features. Like the felspar it has no definite crystallographic outline. In the sections perpendicular to the axis c a net-

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[1] Darwin, Journal of Researches, 1879, pp. 198, 199.

work of cleavages appears, crossing at angles of about 87°; the extinction on the face ∞Ꝑ∞ is more than 35°. The position of the optic axis being in the plane of symmetry, this mineral cannot be mistaken for a rhombic pyroxene; while, if the phenomena of pleochroism only were to be taken into account, there would be no hesitation in viewing these sections as allied to hypersthene, all the more because, like the latter mineral, they have a certain fibrous structure. It is very probable that this monoclinic pyroxene has often been confounded with hypersthene, but in the present case, the angle of extinction, and the phenomena in convergent light, make the determination as augite quite certain. The intense pleochroism is—

β	$>$	$\gamma = \alpha$
reddish.		sea-green.

Hornblende in large greenish sections is much more widely diffused through the rock than augite, and it is only formed at the expense of the latter. In examining more minutely the relations connecting these two minerals, we observe phenomena of alteration and pseudomorphism, more magnificent examples of which than those of the Falkland Islands it would be hard to find. Augite grains can rarely be seen without a surrounding zone of greenish amphibolic matter. Decomposition commences in the microscopic fissures which furrow the surface of the augite; these become covered with a yellowish coating, making them clearly visible. If the optical properties were not taken into account, one might confound the augite, altered in this way and surrounded by the secondary product, with some sections of decomposed olivine. The colour and relief are the same, and the roughened surface and products of alteration present the same microscopic appearances in the two minerals. At a more advanced stage of decomposition the fissures appear wider, the secondary product spreads out, sometimes entirely surrounding a nucleus of nearly unaltered augite. The mineral formed in this way at the expense of the augite passes from its yellowish colour to green, takes on a finely fibrous texture at the place of contact with augite, becomes filled with opaque, blackish, ferruginous grains, and unites laterally with patches of clearly characterised hornblende. These, as we have said, always surround a fragment of augite, which remains as a nucleus in the middle of the hornblende.

The hornblende appears in large yellowish brown sections, with the optical characters and cleavage of this species, but never surrounded by crystallographic contours. The large amphibolic patches are moulded on the neighbouring minerals, and do not present the more or less prismatic form which augite preserves in spite of the granular texture of the rock. In a word, the characters of the hornblende mark it out as having been formed after all the other minerals in the rock, and its relation to augite shows that it has developed from the latter. We have thus a perfectly clear case of amphibolisation of pyroxene. It is interesting, besides, to note that although no uralitisation can be strictly said to be observed, there exists, none the less, an orientation of the hornblende upon the augite nucleus. In fact, it is noticeable that a section of hornblende enclosing several nuclei of augite differently oriented (which could not therefore be parts of one individual) is a unique crystalloid. The cleavages are common, and so are the optical properties for each point of the section. It is thus possible to follow one of the crystalloids of hornblende a long distance from the augite nuclei which gave rise to it. The pleochroism of this hornblende is—

$$\underset{\text{yellowish brown.}}{\gamma} \quad > \quad \underset{\text{yellowish.}}{\beta = \alpha}$$

Biotite must also be mentioned as a constituent mineral of the rock. It is often enclosed in hornblende, and may be considered as a secondary product. Rather large sections of magnetite also occur. The grains of magnetite are also surrounded by a very narrow greenish zone of hornblende, as if the matter which gave origin to the latter had permeated the entire rock.

From the foregoing description it appears that some of the rocks from the "stone rivers" of the Falkland Islands are amphibolised diabases, of which they present a very remarkable type.

B.—*Notes on some other Rocks from the Falkland Islands.*

The following description relates to other crystalline or clastic rocks collected at the Falkland Islands. One of the most remarkable displays large scales of hornblende, which may measure as much as a centimetre, and between them grains of felspar and quartz occur. In structure and mineralogical composition it is a diorite. It contains large patches of felspar, which appear under the microscope as sections of irregular outline. In some cases no trace of twinning is perceptible, and then the felspar resembles orthoclase; but other examples, where decomposition has also reached a more or less advanced stage, show polysynthetic lamellæ, although usually not many. This characteristic would serve to class the felspar with albite; it is always difficult to determine the magnitude of the angle of extinction, on account of the small number of sections presenting hemitropic lamellæ, still, by measuring the double angle, values of about 6° to 10° were found. These large felspar patches are altered into kaolin, and penetrated by rows of epidote grains along the lines of cleavage. The hornblende, the large crystals of which are irregular in outline, shows the characteristic extinctions of this species. The pleochroism is—

$$\underset{\text{yellowish brown}}{\gamma} \quad > \quad \underset{\text{dirty green}}{\beta} \quad > \quad \underset{\text{yellowish}}{\alpha}$$

Black mica occurs as inclusions in the hornblende, and grains of epidote also appear in the interior of these sections. Titanite presents whitish grey sections; these are very sharp rhomboids with traces of a cleavage parallel to two sides of the figure. These cleavage lines should be parallel to the face *r* (℞ ∞) or *l* (∞ *P*); the two other sides may be, in the first case, *P* (*0P*), in the second *y* (Ꝑ ∞). There are also large sections of magnetite often surrounded by a slight zone of chloritic matter, which also penetrates to the interior of the hornblende.

A specimen, which may be viewed as related to the preceding rock, is essentially composed of pyroxene and hornblende. It is granular in texture, with rather large grains, and shows biotite as an accessory element. In spite of the analogy with the diorite just described, there is no felspar in the specimen in hand, and it may be viewed as resulting from a more basic concretion such as often occurs in the ancient massive rocks. Hornblende exhibits the same characteristics as in the preceding rock, but is intercalated amongst the minerals; at other times it is enclosed in augite, and oriented like the latter. The crystals of augite generally show a better preservation of the crystalline form than the hornblende, and have more or less prismatic outlines in the sections, contrasting with the more irregular appearance of the amphibole. This mineral appears to be secondary, resulting from the decomposition of augite. It contains lamellæ of biotite, and besides these minerals magnetite is also to be found.

Some fragments of rock belonging to the series of crystalline schists were collected at Port Sussex. One of these, which to the eye appears covered with ferric oxide, is fine-grained, breaking with a plane fracture pierced with perforations. The ground-mass, when viewed microscopically, is seen to be formed of lamellæ of mica—apparently altered biotite—lying in all directions and associated with an amorphous mass. Some sections with indistinct outlines are visible as a microporphyritic mineral; these sometimes resemble hexagons, and we may have to deal here with altered garnets; in other cases the sections are prismatic, and they may then be classed as felspar. These sections are often filled with a light greenish secondary material resembling chlorite. Little quartz is to be seen, and finally there are rhombic sections which represent an altered rhombohedric carbonate.

We may mention amongst the clastic rocks of Port Sussex, a specimen formed of a greenish fine-grained mass, in which no crystalline elements are visible, and enclosing a granitic fragment, of which we shall speak later. The microscope shows this rock to consist of clastic fragments cemented by a ferruginous argillaceous mass. The broken crystals which are to be seen come from the disaggregation of ancient eruptive or schistose rocks. Amongst these minerals, quartz, plagioclase, microcline, orthoclase, and some splinters of almandine garnet are particularly visible. This rock agrees very well with the composition of an arkose, although we have not ascertained the presence of mica.

The fragment of included granite is a rolled pebble, large grained and very micaceous. Grains of plagioclase, orthoclase, quartz, and mica are to be seen in it. The felspathic sections are altered into micaceous matter. From the smallness of the angle of extinction of this plagioclase it may be classed as oligoclase. Alteration has, one might say, effaced the original characteristics of the mica which is transformed into a greenish matter filled with secondary products. It also happens that fibro-radiated chloritic plates have taken the place of the micaceous mineral. Colourless sections polarising with blue tints are also observed; these are lengthened and coated with mica, and are perhaps cordierite. The quartz has the characters of that mineral in granitic rocks.

Another clastic rock from the same locality presents the appearance of a fine-grained felspathic sandstone, penetrated by oxide of iron, and breaking with a plane fracture. Microscopically it is an aggregation of grains of felspar and quartz with heterogeneous particles of rock. Some of the last named are mica schist, formed of grains of quartz ranged in lines with lamellæ of muscovite between. Other fragments are of a vitreous nature, the glass being altered, having been originally vesicular. In this base there are numerous plagioclase microliths; no bisilicates are to be seen. These splinters may, all things considered, be referred to porphyrites; sometimes a glance is obtained of micaceous lamellæ. Finally, there are found amongst this débris of ancient rocks some grains which seem to be splinters of the paste of a red porphyry. The broken felspars are principally plagioclase; some of the sections being very finely striated, and giving small extinctions, are probably oligoclase; others have few hemitropic striæ, and by this character may be taken as albite; finally, there are others presenting considerable resemblances to microcline. The titanite occurs as an inclusion in a grain of felspar, the latter being perhaps albite. This idea is suggested on taking account of the frequent association of both minerals in the more or less schistose ancient rocks. Orthoclase only plays a subordinate part, sections of felspar being, in fact, rarely seen without hemitropic lamellæ. Titanite is, on the contrary, somewhat common, and it tends to show that the original rock, the disaggregation of which furnished the constituents of that we are considering, contained probably hornblende. The quartz is in irregular fragments, which occasionally, though not often, show undulating polarisation. Their crystalline outlines, which are discovered in certain cases in the form of the sections, or in the arrangement of the inclusions, seem to indicate that this mineral is more likely derived from a porphyritic rock than from a granite. Amongst the minerals formed *in situ*, and developed in the interstices, we may mention certain small greenish scales resembling chlorite.

Some schistose rocks from Port Sussex are of an earthy grey-blue colour, with a homogeneous ground-mass with darker blackish bands, recalling the appearance of an argillaceous schist. The microscope shows that these are formed of white or reddish mica in lamellæ or fibres having the structure of sericite. Numerous grains of quartz may also be seen, and some débris of monoclinic and triclinic felspars. The colouring matter is iron, in the state of limonite, or a graphitic material. Other schistose rocks resemble true slates; the slabs are slightly shining and blackish. In the microscopic preparations only small groups or threads of quartz, and an opaque graphitic or carbonaceous mass, can be distinguished, all the other elements being concealed by these.

From the same locality we may also mention a black fine-grained quartzite, with a subconchoidal fracture, resembling basalt in appearance. The rock is composed in greater part of small grains of quartz with irregular outlines, fragments of granite, and particles of ancient volcanic rock. Besides the quartz, calcite and decomposed mica are to be seen, also some grains of felspar, and very rarely epidote.

Finally, we have to mention a grey schistoid rock in which a few felspathic grains can be made out with a lens. The microscope shows the clastic origin of the specimen, the cement which unites the constituent minerals being chloritic. In this rock fragments of diabase with epidote, grains of plagioclase, of microline, and of quartz, have been noticed.

VIII.—ROCKS OF MARION ISLAND.

Marion Island[1] and Prince Edward Island belong to the same group. They were discovered in 1772 by the French navigator Marion du Fresne, who named Marion Island "l'Ile de l'Espérance," in the hope that this island should prove an outlying sentinel of the Antarctic continent. In 1776 Cook sailed between the two islands, and, not knowing the names given by du Fresne, called them "Prince Edward Islands," which designation is still retained for the northern and the smaller of the two. From that time to the present both islands have been much frequented by whalers and sealers. Sir James Ross, in his Antarctic voyage, passed in view of these rocky islands, and described the black volcanic peaks of Prince Edward Island.

Marion Island, the larger of the two, and on which alone an opportunity of landing was afforded to the naturalists of the Challenger, is 33 miles round; its shape is an irregular parallelogram, about 11 miles in length, 8 in extreme breadth, and about 80 square miles in area. The highest point is about 4,250 feet above the sea level. It

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[1] For the natural history of this group, see Moseley, Notes of a Naturalist, p. 163; *Narr. Chall. Exp.*, vol. i.; Buchanan, *Proc. Roy. Soc.*, vol. xxiv. p. 388.

lies between the parallels of 46° 48′ and 46° 56′ S. latitude, and the meridians of 37° 35′ and 37° 54′ E. longitude.

The island seems to be entirely volcanic. The highest land is in the centre, and irregular slopes lead down to the sea on all sides. These slopes are of very moderate inclinations, and are broken in numerous places by shallow valleys bounded by cliffs where the more ancient flows of lava have suffered denudation. These valleys are now occupied by more recent lava-flows, which still retain their rough pinnacled upper surface. Further, all over the slopes and summits are scattered irregularly numerous small cones, formed mostly of conspicuously red scoriæ. The lava presents in many places in the cliffs a columnar structure. Some sand gathered on the shores of a small fresh-water lake near the sea was full of augite and olivine crystals.[1]

In attempting to reach the actual upper limit of vegetation, Mr. Buchanan made some geological observations, and collected some specimens of the rocks which will be hereafter described. The ascent was up the bed of a small stream, which lay at the verge of one of the modern lava-flows, where it abutted on a low cliff exposing a more ancient flow in section. The more recent flow had a very gradual inclination of not more than 8°. The stream was found to flow over an apparently very recent stream of black cellular lava, the ripples and eddies in which were still perfectly fresh, except in the very centre, where they had suffered some slight abrasion. This lava was basaltic and contained much olivine. Close by the bed of the stream rose several red conical hills. One of these, the highest within reach, consisted of a heap of loose scoriæ disposed in layers, dipping away on all sides at a regular and very steep angle. Few of these pieces of scoriæ were more than six inches in diameter. At the top was a perfectly conical pit, and slightly below the summit, on the north side, were three smaller and similar pits. The scoriæ of which the hill is made up consisted of a highly cellular red ground-mass, with indications of augite, without, however, any perfect crystals being discernible. Besides the red scoriæ, there were some of a chocolate-brown colour, with frothy exterior and compact kernel, resembling almond-shaped volcanic bombs. Besides this hill, there were five or six others precisely similar in appearance and rising out of the same valley. From the top of the hills this valley or depression could be seen to be bounded, towards the interior, by a semi-circular cliff of rocks, in some parts columnar, and open to the sea. Above this cliff rose the snow-covered cones and peaks of the interior, which seemed to be similarly formed to those of the lower ground. On leaving the stream-bed and returning to the eastward over the spur of the mountain, the cliff was found to consist of a light-grey compact doleritic rock.[2]

All the rocks which were collected at Marion Island by Mr. Buchanan, and which

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[1] Moseley, Notes of a Naturalist, p. 164.

[2] Narr. Chall. Exp., vol. i. pp. 300, 301.

we have examined, belong to the felspathic basalts; the various specimens differ only in colour, or in the more or less vesicular texture. We will describe first the rocks forming the volcanic cones near the small stream already mentioned. Amongst these, red or black scoriæ are the most frequent. Their surface is very vesicular, the interior part more compact, and having a somewhat waxy lustre. With the naked eye, crystals and grains of olivine are seen scattered through the rock. Microscopical examination shows a vitreous fundamental mass, with lamellæ of plagioclase, the extinctions of which are about 40°, indicating a mixture near anorthite. There are large sections of olivine without any noteworthy peculiarity, the characteristics of this mineral being those which it generally presents in the basaltic rocks. These sections show a perfect cleavage following the base, and are often crowded with trichites. What seems to characterise the crystals of augite is that they very often occur in groups of several individuals, joined with their vertical axes; this is one of the most striking peculiarities of this mineral in the rock under description. Magnetite is present here as in all the specimens from Marion Island. The base is speckled with globulites and trichites; this vitreous matter is often partially decomposed into a brownish palagonitic matter.

The black lava forming the bed of the little stream explored by Mr. Buchanan is generally compact in some places, however vesicular; its grain is that of dolerite. This rock is spotted with white points, and contains macroscopic olivine. Under the microscope it shows the structure and the composition of a felspathic basalt, and resembles in every particular the rocks already described. Augite is present only in very small grains, which are not always easily distinguished from olivine. However, the crystals of this last mineral, even when very small, contain almost always vitreous inclusions of hexagonal or rhombic shape, their outlines being parallel to those of the section; these regular inclusions are not to be observed in the small sections of augite.

A rock labelled "recent lava" has the same macroscopic characters as that just described, but contains even less augite than the preceding specimen. There must be some augitic microliths in the ground-mass, but it is difficult to give any definite determination on account of the opacity of the base. The plagioclases are lamellar, and extinguish under large angles. Very often these plagioclase crystals surround the olivine sections, and are parallel to the outlines of the latter. Olivine does not show the prismatic faces; the sections are always rhombic.

A volcanic bomb collected near the conical hills already mentioned is 10 centimetres by 5, its shape being elliptical; this bomb is reddish brown, rather compact. With the naked eye crystals of olivine and augite are seen embedded in the ground-mass. Microscopical examination shows that this rock is a felspathic basalt. In a brownish base are embedded crystals of plagioclase, olivine, and augite. These minerals are almost always porphyritic; microliths of felspar and of augite are hidden in the ground-mass. Some crystals of plagioclase are Carlsbad twins: two individuals, tabular following *M*, are elongated following the edge *P*/*M*, the outlines of these sections being the traces of the faces of *p* and *x*. The two individuals are joined on the face *M*, the trace of *p* of one of the individuals coinciding with the trace of *x* of the other. Other sections show at the same time twinning following the albite, Carlsbad, and Baveno laws. The extinction, measured from the trace of the polysynthetic lamellæ, is about 45°,—thus this felspar is a mixture very near anorthite. Large sections of augite are slightly greenish; they do not present any noteworthy peculiarity. Olivine has rarely crystallographic outlines; in some cases the sections of this mineral show the traces of a very obtuse and large dome, and the outlines are very like regular hexagons, but generally the sections present a very corroded aspect.

IX.—NOTES ON THE ROCKS OF KERGUELEN ISLAND.

These notes on the rocks of Kerguelen Island are intended to be essentially lithological, but geological and topographical features will require notice in so far as they throw light upon the lithological description of this volcanic island. We do not require to touch upon the history of early explorations of the island, a history centring round the name of the illustrious navigator Cook, to whom we owe the most exact, but by no means complete, data regarding the island up to the visit of Sir James C. Ross in 1840. The numerous visits of the South Sea whalers added nothing to definite knowledge, and to Ross we owe the first geological observations on the island. MacCormick at the same time devoted himself to the natural history of the region, while the flora was studied by Hooker.

Sir James Ross landed at Christmas Harbour, explored the neighbouring region, and greatly increased our knowledge of it. On the north-west coast also Hooker and MacCormick made their observations. After this memorable cruise many years passed away before another expedition landed on the island. The Challenger touched there in 1874 in order to make arrangements for the British astronomers who were to establish themselves in that locality to observe the transit of Venus. Almost at the same time the "Gazelle" landed the German observing party, who were stationed there for three and a half months for the same purpose. Shortly afterwards the "Volage" arrived with the party of British astronomers under the charge of Father S. J. Perry.

To this party we owe some observations on the south coast, but to the present day the west coast is unexplored, and the centre of the island almost unknown. This ignorance is due to the difficulties of exploration in the marshes and peat-bogs of the interior, amongst the fogs and snows, the torrents and ice-fields, and the terrible storms which burst upon the western coast. Add to these the extremely rigorous climate, and some idea may be formed of the difficulties opposed to the scientific investigation of a land the climatological conditions of which have justly earned for it the name of "Isle of Desolation."

In addition to the early geological work of MacCormick and Hooker, already incidentally alluded to, we only possess a very few contributions to the lithological constitution of Kerguelen. The rocks collected by the German expedition have been made the subject of a detailed description by Professor J. Roth.[1] The topography of the peninsula on which the German observatory was erected has been studied by Dr. Th. Studer,[2] and he has given geological details of the rocks described by Professor Roth. Mr. Buchanan[3] published his geological notes, taken during the Challenger's visit, and Mr. Moseley[4] described the natural history of the island. The chapter devoted to Kerguelen in the Narrative of the Cruise[5] may be held as reasonably complete with regard to the fauna and flora of the island, and the geology of those parts visited by the Challenger's staff.

These notes are specially devoted to the description of the numerous rock-specimens collected by Mr. Buchanan and others at various points in the island. We have also thought it advisable to condense here all the more important statements regarding the geology of Kerguelen scattered through the writings cited above.

Like most oceanic islands, Kerguelen is essentially of volcanic formation. Sedimentary strata, properly so called, are hardly represented at all. The accumulation of erupted material forms, one might almost say, the entire mass of the island.

Before proceeding to the description of the rocks, we will sketch out those physical features of the island which have a bearing on the facts to be considered.

The Kerguelen group is composed of 130 large and small islands, and 160 rocks. They are grouped round the central island, and are situated in the centre of the South Indian Ocean, nearly half-way between Africa and Australia, and some hundreds of miles south of the route of the clippers which round the Cape of Good Hope on the Australian passage. Its position is approximately 50° S. and 70° E., thus corresponding

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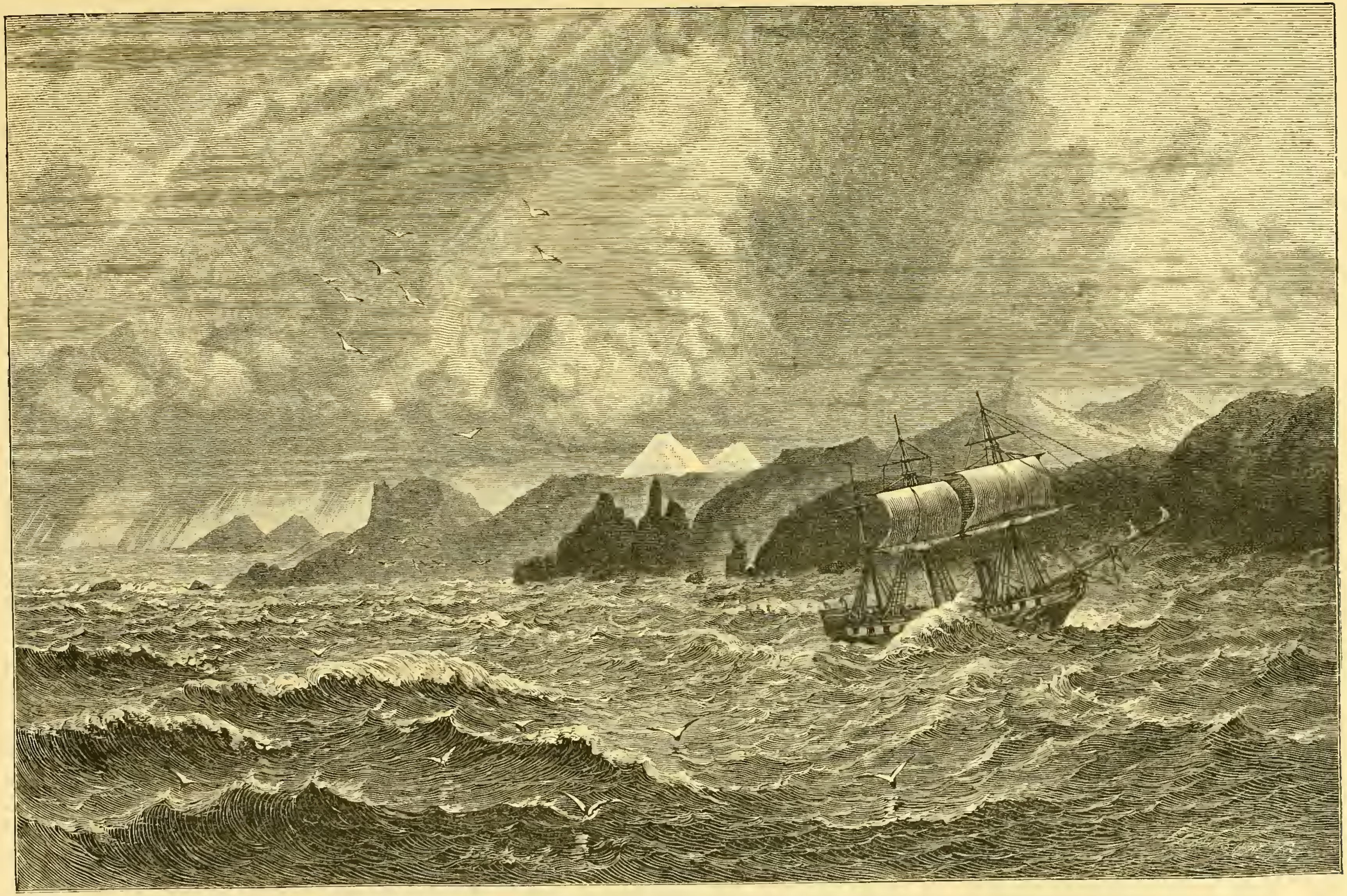
[1] J. Roth, Ueber die Gesteine von Kerguelenland, *Monatsber. d. k. preuss. Akad. d. Wiss. Berlin*, 1875, pp. 723–735.

[2] Th. Studer, Geologische Beobachtungen auf Kerguelenland, *Zeitschr. d. deutsch. geol. Gesellsch.*, 1878, pp. 327–350.

[3] J. Y. Buchanan, On Chemical and Geological Work done on board H.M.S. Challenger, *Proc. Roy. Soc.*, vol. xxiv. pp. 617–622, 1876.

[4] H. N. Moseley, Notes of a Naturalist on the Challenger, pp. 184–215. The author cites several memoirs on the natural history of Kerguelen.

[5] Narr. Chall. Exp., vol. i. pp. 332–360. See also Relation de deux voyages dans les mers australes, par M. de Kerguelen, Paris, 1782; J. C. Ross, Voyage in the Southern and Antarctic Regions, vol. i. chap. iv., 1847; Die Vermessungsarbeiten S.M.S. "Gazelle" an die Küsten der Kerguelen Inselgruppe (*Ann. des Hydrogr. und Marit. Meteor.*, 1875, pp. 354–365); Rev. S. J. Perry, Report on the Meteorology of Kerguelen Island, 1879; Account of the Petrological, Botanical, and Zoological Collections made in Kerguelen's Land and Rodriguez during the Transit of Venus Expedition, London, 1879, *Phil. Trans.*, vol. clxviii.



Cape Challenger, Kerguelen Island, with Mount Ross in the distance.

closely in longitude with the island of Rodriguez, the Maldives, and Bombay. The greatest length of the island is about 85 miles, its maximum breadth 79, but its area does not exceed 2,050 square miles. This small extent of area may be understood on taking into account the deep indentations of the coast; there is perhaps no other place on the globe where the coast-line is so extended compared with the area. Fifteen great peninsulas run out from the main portion of the island, and numerous deep gulfs penetrate it, cutting the coast-line into long narrow fjords. These are similar in all essentials to those of Norway; they are bounded by cliffs rising perpendicularly, and shutting in an arm of the sea often narrowed at its opening. Royal Sound and Rhodes Bay present classic examples of these extraordinary sinuosities of coast-line.

The actual island is only the skeleton, one might say, of a great region on which the phenomena of oscillation and denudation have left a profound imprint. The deep-sea soundings in the neighbourhood of the land lead inevitably to this conclusion, as they show the portion above water to be the summit of a great submarine plateau. Sir J. C. Ross got soundings of 70 to 80 fathoms for a distance of over 100 miles to the north-east of Cape Francis; the Challenger found no depths exceeding 50 or 60 fathoms for 45 miles to the north of Cape Digby; and between Kerguelen and Heard Island the depth ranges between 80 and 150 fathoms. The "Gazelle" obtained 125 fathoms 40 miles west of Cape Bligh and also 80 miles north of Swain Island. From the results of soundings, it seems probable that Heard Island is the terminal peak, situated at the southern extremity of the chain of submarine table-lands which connects it with Kerguelen. A glance at the chart also shows that the mountain chains of this land are directed north-west and south-east, and that the lofty summit of Heard Island is 260 miles south-east of Mount Ross, the culminating point of the lines of hills which traverse Kerguelen. Taking all these details into account, we must conclude that the two islands belong to the same topographical system, the connecting links being hidden by the waters. The erosion, which has left its traces everywhere; the glacial phenomena, marking their destructive action on the rocks; the oscillations of the ground, testified abundantly by the strata; the action of atmospheric agencies, and even biological facts, combine to give support to the view which presents Kerguelen as the relic of a great land.

A chain of mountains with elevated plateaux traverses Kerguelen from north-west to south-east, and at its southern extremity Mount Ross, the highest peak in the island, rises near the sea. The terraces in the centre, rising to 1500 or 2000 feet, are covered with snow-fields, and glaciers, of less extent now than formerly, are found in several parts of the island. At Mount Richards, for instance, both slopes are covered with them; here the glaciers come right down to the sea, while at other places they do not reach the water, showing rather a tendency to recede. This is the case at Whale Bay and also at Deutsches Bucht, but on the west coast there are several which come down to the shore. The volcanic manifestations, which gave birth to Kerguelen Island, have now entered on a stage of repose. According to the fishermen, an active volcano still exists on the west coast, and in this region also mineral oils and thermal springs are found.

Low plains are absent, as in all volcanic islands, and valleys with a flat bottom are uncommon. The heights run in lines forming chains, and the small extent of plain is also covered with rocks or mounds connected together. The tabular form is most common for the eminences with which Kerguelen is, in a certain sense, covered. These heights are cut into perpendicular-walled terraces. This arrangement is almost always observed in the case of ranges of hills not exceeding 1000 feet in height. The mountains are sometimes formed by the superposition of five or ten terraces, in other places as many as twenty have been counted. The terminal plateau and the terraces are covered with the débris and alteration-products of the volcanic masses, geodes from amygdaloidal rocks, and nodules of olivine, such as are found in basalt. What has been said applies particularly to the mountains near the coast. The less explored heights of the interior attain an altitude of about 1500 feet, and are composed of solid rocks carved and terraced like those of the coast. Mount Ross, with its double peak, and Mount Crozier belong to the mountains of the interior. According to Professor Roth, these jagged summits are formed of two kinds of rock,—dolerite and trachyte.

We shall now proceed to describe the different localities of the island from which specimens have been collected, indicating at the same time their principal topographical features and the local observations relating specially to the rocks under description. As we stated before, the north-east coast is the only one which has hitherto been explored. In the descriptions we shall follow the coasts, from Christmas Harbour at the northern extremity to Greenland Harbour on the south-east of the island. Describing in succession the rocks of each locality, we will specially lay stress on those parts of the island where the Challenger collected specimens. These localities are designated in our description by the names adopted in the chart of Kerguelen, accompanying this Report (Map V.).

Starting from the northern extremity and going eastwards, Christmas Harbour is the first place we meet with. This bay was named by Cook, who anchored there on Christmas Day, 1776. It is a fine example of a Kerguelen fjord on a small scale, a deep indentation surrounded by mountains with perpendicular cliffs. On each side the land runs out in narrow precipitous promontories. At the northern part of the bay the ground falls more gradually, so that it is possible to land from a boat. At the point of the southern tongue of land stands the well-known Arch Rock, which was formerly united to the island. Now the waves have perforated the central part of this wall of rock, while its base and summit remain connected with the land, forming a natural arch leading to a pile of rocks surrounded by the waves. Above the precipitous cliffs of the southern side of the bay an enormous mass of black basalt rises with perpendicular walls. As one can judge from the frontispiece to the Narrative of the Cruise, Christmas Harbour as a whole is a magnificent spectacle. The appearance is made particularly remarkable by the imposing mass of the rocks, and still more by the sharp contrast of the straight black cliff and the yellowish green vegetation covering the lower slopes.[1] Christmas Harbour was examined by Ross and the naturalists who accompanied him on his Antarctic expedition. The well-known fossil woods of Kerguelen were discovered here in an excavation named "Fossil Wood Cave," where Ross found a tree trunk 7 feet in circumference. The fossil wood is silicified or calcified, and appears in the form of splinters or blocks, varying in colour from yellowish white to chocolate-brown and black. They are found in beds forming nearly horizontal layers of only a few feet thick, and composed of a soft, whitish, clayey matter filled with black particles resulting from the decomposition of vegetable matter. The fossil wood is sometimes found in trunks measuring a foot and a half in diameter. It occurs in different states of fossilisation; sometimes it is silicified, at other times the bark is transformed into a brownish mass of greasy appearance, but crystalline in structure and effervescing with acids. Crystals of pyrites are sometimes found in the fossil wood. Tree trunks have also been observed, the interior of which is penetrated by the eruptive rocks with which this vegetable débris is associated, but the exterior preserves a fibrous appearance as in silicified wood, although the layer is very thin. With this clearly characterised vegetable débris, the genera of which can readily be determined,[2] layers of vegetable origin are found transformed so completely into carbonaceous matter that it becomes difficult to recognise the vegetable tissue; at the utmost some forms resembling *Chara* can be made out. According to Moseley, the intimate structure does not even appear with the microscope. These carbonaceous deposits are unsuited for burning, being mixed with a great deal of earthy matter, and often found associated with clayey deposits. Hooker stated long ago that these vegetable remains at Christmas Harbour did not belong to the modern epoch. We shall refer again to the geological conclusions to which the facts observed with regard to these deposits lead, and may mention here some other localities where they were found. Professor Roth speaks of their presence on the slopes of the basaltic terraces of Mount Havergal which closes Christmas Bay. Above the doleritic basalt a rock of the same nature is found altered into a reddish argillaceous matter, and a layer of palagonitic tufa. This is overlaid by layers of one to two yards of schistoid material, decomposed into a whitish substance. These are formed of a matter resembling lignite and of fine grains of palagonite; they are not

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[1] For the very interesting vegetation of Kerguelen, see the works of Hooker, and for that of Christmas Harbour and Table Mountain, in particular, Moseley's Notes of a Naturalist, pp. 193 *et seq.*

[2] According to Professor Carnoy, who has been good enough to examine the microscopic preparations, the fossil woods are certainly coniferous.

calcareous, and contain fossil wood enclosing crystals of calcite and analcime. Professor Roth, following Bunsen,[1] explains the presence of calcite by the decomposition into palagonite of the volcanic materials associated with these fossil plants. Another layer rests on this, formed also of palagonitic tufa, and containing fragments of fossil coniferous wood. In the zeolitic basalt, forming a cliff toward the south of Christmas Harbour, two beds of lignite occur at a height of 30 or 40 feet above sea level; they are several feet thick, and stretch towards Arch Rock. Silicified tree trunks were seen, according to MacCormick, in the interior of this natural bridge. The lignite is schistoid, of a brownish black colour, and varies much in composition. In some places it is earthy and brittle, but in others it resembles the lignite of the Alps both in colour and fracture. According to Captain von Schleinitz, quoted by Professor Roth, quite similar lignite is found in Breakwater Bay to the south of Cumberland Bay.

To return now to the volcanic rocks of Christmas Harbour. From the position of the Challenger's anchorage the naturalists could easily make themselves acquainted with the disposition of the eruptive masses that border the bay. These form horizontal layers and beds that may be followed along the whole extent of the vertical cliffs which wall the fjord. Here, as in almost all the other parts of the island, the eminences are terraces with flat summits. The plateau extending to north and south of Christmas Harbour is broken by two mountains which rise above it; to the north there is Table Mountain, to the south a hill not yet possessed of a special name; it appears like an enormous block resting on the plateau. A part of these heights has been named Mount Havergal, but it is evident that they are all formed of superimposed layers of basalt. The rocks rising above the horizontal beds of basalt and forming the highest points of the series of mountains, are of phonolitic nature, and similar to those which we shall describe in detail when speaking of Greenland Harbour. They traverse the horizontal beds of basalt, from which they differ in mineralogical character. Their eruption does not seem to have modified the arrangement of the beds which surround them. The latter, forming the principal massif of the region, are basaltic, and the beds are from 10 to 20 feet thick. These basalts are massive, but by climbing the heights one comes to certain layers, the rocks of which are vesicular and filled with zeolites (analcime and prismatic zeolites). These zeolitic minerals are very common in this part of the island, where they are often found as rounded grains in volcanic sand, with which their white colour affords a marked contrast. From base to summit a regular alternation may be traced of beds of compact sub-columnar basalt, and layers of the same material of a vesicular structure. These amygdaloidal rocks appear in two chief forms: one has very small and numerous vesicles, now completely filled with zeolites, the other has large cavities only lined by

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[1] *Ann. Chem. Ph.*, 1862, p. 53.

crystals. These zeolites are also frequently found in small veins in the rock. We may say that generally the vesicles are filled with analcime, while a prismatic zeolite predominates in the fissures.

The chain of hills on the south side of Christmas Harbour is higher than that to the north, and as the southern coast is much indented the stratification is clearly shown, and the superposition of basaltic layers in successive terraces becomes very apparent, especially in the promontories.

It is noticeable that all the hills are about the same height, and the general impression left is that the whole formerly consisted of a great plateau which has been deeply trenched by valleys descending towards the sea. This plateau is surmounted by high peaks, so closely resembling recent volcanoes in form that Mr. Buchanan thought they were volcanic cones until a closer examination showed them to be formed of horizontal strata like the plateau on which they stand. This seems to indicate that these peaks are nothing but portions of a higher plateau which have escaped the erosive action of the ice.

The greater number of basaltic rock specimens from Christmas Harbour are characterised by a doleritic structure. To the naked eye they are black, with crystalline grains, homogeneous in appearance, and with a plane fracture. The lens shows felspar. Sometimes they are a little scoriaceous, and show a tendency to assume an amygdaloidal texture, half-formed crystals of olivine and augite standing out. When the vesicular texture is more pronounced, the ground-mass retains the same appearance, its very numerous geodes being filled entirely with compact zeolitic matter of which the species cannot be clearly distinguished. The globules of zeolites generally vary from some millimetres to half a centimetre; they sometimes attain the size of 1 or 2 centimetres, but in this case they form true geodes, and the crystals lining the cavity are generally fibro-radial or prismatic.

Microscopic examination shows that these dolerites are formed of plagioclase and olivine enclosed in grains of augite, which are moulded upon the other constituent elements. These rather large crystals of olivine are often serpentinised, and sometimes give rise to a microporphyritic structure. The crystals of plagioclase are twinned according to the albite law, less often to that of pericline, and more rarely still they show the twin of Baveno. Extinctions of about 30° have been measured on sections which clearly present the striæ of the pericline and albite twins. The augite sections interposed between the felspathic lamellæ are large, but very seldom bounded by crystallographic contours, and usually very pleochroic. When the colour is less deep, the augite at first sight is difficult to distinguish from olivine, but as the latter mineral is usually altered, it is easy to distinguish it from the intact augite. Magnetic iron is represented by small sections derived from the octohedron, or by little rods.

These dolerites are rarely free from alteration; microscopic sections show that they are almost always penetrated by delessite, which even invades the crystals of plagioclase, and they are further often covered with hydrate of iron; grains of red hematite, also, are often seen. As we said when speaking of the macroscopic characters of these rocks, they are often amygdaloidal and filled with zeolites; chabasite is the most important of these, either completely filling the vesicles or lining their walls.

Fine-grained felspathic basalts were also collected at Christmas Harbour. The specimens examined were taken from a bed above sea-level in the northern part of this locality. Viewed by the naked eye these rocks are black, very compact, breaking with a plane fracture, and sometimes presenting large crystals of felspar and olivine. In some cases the rocks are altered, and take a greyish tint; the olivine decomposes into a greenish substance like steatite, and the felspar into kaolin. These altered rocks are often clothed with a thick coating of fibrous zeolite. Under the microscope these rocks are seen to be felspathic basalts; olivine is the only microporphyritic constituent. The larger sections of this mineral are transformed internally into a fibrous greenish dichroic matter, which is perhaps chlorite, possibly even a mica; a brownish frame surrounds the olivine crystals. The ground-mass, in which quadratic sections of magnetite abound, is formed of small grains of augite and opalised felspar microliths. The microscopic vesicles are bordered with fibro-radial delessite, the centre being filled with analcime, and in certain cases by a fibro-radial zeolite.

The olivine of a fine-grained basalt from the same place, and closely resembling that just described, presents interesting peculiarities. It appears in grouped granules, imitating to some extent the peridotic chondres of meteoric rocks. Fig. 19 represents these groupings of olivine grains, which are numerous enough in this rock to form a characteristic feature.

FIG. 19.—Basalt of Christmas Harbour. Grouped granules of olivine, imitating the form of this mineral in the chondres of meteorites. $\frac{1}{20}$ crossed nicols.

Another basaltic rock, from a bed 400 feet above the coast, shows some noteworthy peculiarities. The ground-mass is black and compact; large crystals of felspar and olivine appear in it, and the fracture is irregular. Microscopic examination shows that it is a felspathic basalt like those already described, but while in the former case it was olivine which gave these rocks a microporphyritic structure, here large sections of plagioclase produce this feature. They stand out from a ground-mass of grains of augite, felspathic microliths, and granules of olivine. These large crystals of plagioclase present a character sometimes shown by anorthite and certain albites; their sections appear almost free from hemitropic striæ. It is well known that the felspars which form the beginning and the end of the plagioclastic series have generally less numerous striæ than the intermediate links. In the present case we cannot explain this rarity of polysynthetic twins by the fact of the sections being cut parallel to the face *M;* they are usually cut, on the contrary, perpendicular to the edge *P/k*, for cleavages following *P* and *M* may be observed. In some sections following *P* extinctions have been measured, their value varying from 38° to 42°; this felspar is thus akin to anorthite. The microliths of the ground-mass, on the contrary, must be referred to labradorite.

It is unnecessary to do more than allude to some partly decomposed basaltic rocks which exhibit the usual alteration of basalts; it may simply be noticed that the formation of zeolites often goes on simultaneously with a considerable deposition of siliceous matter, and that the latter, in some cases, takes the place of the plagioclase.

A volcanic conglomerate from the summit of a hill at the south of Christmas Harbour is formed of palagonitic tufa. The black, compact, shining splinters of basalt, varying from 1 to 2 centimetres in diameter, are enclosed in a brownish mass; small whitish layers of zeolites have formed around the lapilli. The brown material has the well-known resinoid character of palagonitic tufas. Opal is sometimes deposited on the rock, and often passes into cacholong. Microscopic examination shows that this tufa is formed of an aggregation of brown vitreous granules. These fragments frequently change to a yellow colour at the edges, without showing any alteration to red, or the characteristic fractures and the phenomena of polarisation, which often accompany the most advanced decomposition of the vitreous matter of these tufas. These amorphous patches are always isotropic. Plagioclase and olivine have crystallised from the magma; no augite is to be seen, the rapid cooling of the paste accounting for the absence of this mineral. The sections of felspar are often prismatic, showing the striæ of the albite twin, but usually this mineral crystallises in little lamellæ with rhombic outlines, and so thin that several of them are superimposed in the thickness of the preparation. These small rhombic tables show traces of the faces *P* and *x;* sometimes they appear as disymmetric hexagons; in this case the face *y* is added to the preceding. Olivine is generally well crystallised, and its sections usually appear with rhombic outlines and inclusions of vitreous matter at the centre. This species sometimes shows crystals joined with parallel axes so as to form groups of several individuals. Magnetite is rather rare, appearing as inclusion in olivine. Vesicles in the vitreous mass contain delessite. The zeolitic substance, cementing the lapilli, forms fibro-radiating layers, which might be classed as natrolite, but the brightness of the polarisation colours seems to indicate the presence of chalcedony penetrating this zeolite.

The rocks forming hills about Christmas Harbour are traversed by dykes, from which Mr. Buchanan collected several specimens. One of these represents a compact basalt in which the naked eye can only distinguish olivine in a blackish shining crystalline mass. Near its contact with the adjoining rock the texture becomes closer, and the basalt passes into the vitreous variety; to this portion of the rock are joined basaltic lapilli cemented by a palagonitic matter. The microscope shows that this zone of contact, which resembles tachylite, is essentially composed of a vitreous base containing olivine and small rhombic tables of plagioclase, similar to those just referred to as occurring in the palagonitic tufas. The vitreous part, resulting from the rapid cooling of the eruptive rock in contact with the surrounding mass, can be observed in the microscopic preparations joined to the rock forming the central part of the vein. This more crystalline zone is composed of the same minerals; the plagioclase crystals, however, take another form: instead of the tabular sections just referred to, they are prismatic, and often in the shape of skeletons forked at two extremities. Augite is not developed in it, but the brownish glass is darker, and it is filled with trichites and spherulites. Olivine often occurs in twinned crystals, which are sometimes sharply outlined by crystallographic lines in one part of the section, and in the other part shade off into worn and irregular forms. The large sections of olivine in this rock are often enclosed in felspathic lamellæ. On the other hand, the felspathic microliths are surrounded by sections of olivine, which, from this point of view, seems to play the same part as augite does in many basalts. To return for a moment to the rhombic tables of plagioclase, which are confined to the vitreous zone in contact with the surrounding rock. It is natural to suppose that the development of these tabular crystals is in relation with a particular state of consistence of the lava where they were formed. These tabular crystals of plagioclase show the faces *P* and *x*, and sometimes those of *y*. The angle of extinction measured on the face *M* is negative, and about 32°. This observation suffices to show that this felspar is allied to bytownite.

The coal-beds of this part of the island are associated with schistoid rocks, which resemble certain slaty rocks. At first sight one would mistake them for slates of slight fissility. Their colour is purplish, and the surface shines like some clays, but they are harder, and the streak is not lustrous. No constituents can be discerned by the naked eye. The microscope proves their volcanic nature, and that they belong to the eruptions which poured out trachytic lavas. In ordinary light small prisms of augite and grains of magnetite are seen in a colourless and homogeneous ground-mass. With polarised light a rather large number of sanidine sections are seen in the preparation. They sometimes assume the form of elongated lamellæ, but they are generally placed with their widest faces parallel to the cleavage of the rock. Sections parallel to *M* often show the Carlsbad twin with *k* as the plane of composition; sometimes the two twinned individuals are not entirely superposed over the whole extent of the face *M*. The crystals are generally broken up, and present undulating extinction, induced by the mechanical strain to which the schistose character of the rock is also due. The whole mass seems to have been penetrated by chalcedony.

The hills situated to the north of Christmas Harbour, and reaching an altitude of

1200 feet, are designated Table Mountain. Ross discovered at the top an oval crater-like depression, the long axis of which measured about 100 feet. These heights are formed, like the others already described, of horizontal basaltic layers, but in this case they do not make up the whole mass. Pre-existing hillocks of pale grey rock were surrounded by the lava-flows, contrasting in colour with the black encasing rock. When speaking of Greenland Harbour we shall describe with greater detail the relations and the aspect of these masses surrounded by the basalt, as in both localities the same state of things occurs, and the observations recorded by Mr. Buchanan in that region are more explicit from the present point of view than those available for Table Mountain. Here we limit ourselves to the consideration of the most interesting rocks of the latter region. According to Mr. Buchanan, the basalt assumes a columnar structure and contains great nodules of olivine. The summit of the hill is covered with fragments of basalt which are broken prisms.

All the specimens which we have examined from Table Mountain belong to the basaltic series. We will describe them in the order in which they were collected by Mr. Buchanan when he climbed the hill.

A doleritic rock is first found at the height of about 500 feet above the sea. This appears compact to the naked eye, but crystalline grains may be distinguished. Very small vesicles are scattered through the mass, which is furrowed by long cavities from one to two centimetres in diameter lined with clearly defined crystals of chabasite. Red oxide of iron penetrates the rock in certain points. Microscopic examination shows that this dolerite is entirely impregnated with a greenish secondary mineral. The crystals of olivine which formerly existed are now only recognisable by the outlines of the sections; the interior is entirely converted into this green matter. The plagioclase also is so much altered that it no longer shows polysynthetic striation between crossed nicols; it is so penetrated by delessite that only a very narrow frame of felspar surrounds the sections. The augite appears to have resisted decomposition better, as a rule; reddish sections of it, giving the optical reactions of this pyroxene, are to be seen enclosed between the plagioclastic lamellæ. It is sometimes partly covered by an opaque brownish matter which surrounds and accentuates the crystalline outlines. This opaque matter is formed of elongated or slightly-curved black filaments resembling trichites or crystallites of magnetite.

At the height of 1000 feet, about 10 feet below the terminal plateau, Mr. Buchanan found a specimen of a granular rock, in which crystals of felspar could be distinguished by the unaided eye; its colour is light green by alteration, and its fracture irregular. Microscopically it appears to be a much altered dolerite. As in the preceding rock, olivine has almost entirely disappeared, but plagioclase in large lamellæ and augite have better resisted decomposition. Spherules of chalcedony and chabasite are developed in the pores. Silica has also penetrated the felspar, and the plagioclase thus assumes brilliant colours of polarisation. A greenish secondary product covering a considerable part of the preparation appears, and sometimes assumes a vermicular form very like that of helminth.

Two specimens of basalt were collected on the summit of Table Mountain. One of these was taken from a bed the rocks of which showed columnar structure. It is a very compact bluish black basalt, with a plane fracture, and contains large inclusions of olivine. Under the microscope the rock is very fine-grained, and in the ground-mass greenish brown augite crystalloids predominate, embedded in plagioclastic lamellæ. Fragments of olivine detached from a large inclusion of a peridotic rock are also to be seen. Rather large patches, composed exclusively of augite grains, are sometimes to be observed. The bottle-green nodules of olivine, enclosed in this basalt, are formed by an aggregation of minerals which corresponds to lherzolite (see fig. 20). Olivine forms the principal mass of this inclusion, its grains appearing irregular, colourless, and split up without a trace of definite cleavage (*a*). A lamellar rhombic pyroxene is associated with this mineral; its colour is light green, and it is probably enstatite (*b*). Finally, transparent brown isotropic sections of picotite and greenish augite (*c*) are embedded without crystalline outlines amongst the minerals already mentioned, moulding themselves upon them.

FIG. 20.—Basalt of Table Mountain.

Microscopic section of an inclusion in this rock. The inclusion is formed (*a*) of olivine in cracked, colourless, irregular grains; (*b*) rhombic pyroxene, lamellated, and light green in colour; (*c*) greenish grains of augite. The inclusion also contains brownish sections of chromite or picotite, which are not figured. $\frac{1}{20}$ crossed nicols.

Another preparation from one of the peridotic nodules of the Table Mountain basalt shows a slightly different composition. In this case the rock appears to be formed only of olivine, the aggregated grains of which have experienced a slight serpentinisation along the cracks.

The second specimen from the upper part of the mountain is, like that briefly described above, an ordinary black, compact, fine-grained basalt, in which the eye can detect nothing but grains of olivine. The ground-mass is formed of small plagioclastic lamellæ, not much lengthened, and of brownish granules of augite with which magnetite is associated. Large fragments of olivine without crystalline outlines give the rock a microporphyritic structure. One cannot help recognising these fragments of olivine as foreign inclusions, and similarly a like origin must be admitted for the large sections of chromite which the rock contains. These may be as much as two to three millimetres in diameter; they are very irregular in outline, and often surrounded by a zone of magnetite.

A volcanic bomb from Table Mountain is formed of a medium-grained, greenish black rock, reddened on the surface, and furrowed with long hollows full of large crystals of chabasite. Under the microscope it is seen to be formed of a slightly transparent greyish mass speckled with grains of magnetite. This ground-mass, which cannot well be analysed even under the highest powers, has an indistinct structure which may be compared to marbling. Skeletons of felspar forked at both extremities appear in this ground-mass. These plagioclastic sections are sometimes larger, and in that case are almost always cracked in every direction, and appear in parts converted into chalcedony. The olivine is decomposed into serpentine, and augite does not appear to be present.

A fragment of altered vitreous basalt may be mentioned, finally, amongst the specimens from this locality. The rock has a reddish brown colour, is scoriaceous, and very much decomposed, some parts passing into palagonite, others being almost earthy. The rock is entirely impregnated with iron, and is transformed into palagonitic matter in the last stage of decomposition. The ground-mass is brownish and opaque, filled with colourless microliths of felspar which are aggregated in star-like groups. Like the larger crystals to be described, the microliths are entirely converted into zeolites. The larger sections of plagioclase have retained their form only, and give the optical reactions of zeolites. Some small and very distinct sections of olivine also appear, filled with zeolitic crystals, and the latter are developed in the cracks of the rock as well. Other sections of olivine are less profoundly decomposed, being only impregnated by ferruginous matter and products of alteration along the fissures. If augite exist in this rock, it must be entirely disguised by the products of its alteration. A few crystals of apatite have been observed.

A specimen from Arch Rock may be described before considering the rocks of Cumberland Bay. This natural arcade forms the extremity of the southern headland enclosing Christmas Harbour. The specimen examined is a black dolerite, coloured greenish by alteration, of moderately fine grain, and breaking with an unequal fracture. Its microscopic structure is that of a characteristic dolerite; lamellæ of plagioclase are enclosed in reddish grains of augite, which constitute, so to speak, the cement of the rock. Large crystals of olivine, retaining their crystallographic form, but largely altered into serpentine, are observable. Delessite has been developed at many points; its sections appear generally triangular, or with straight lines, the outlines of this green secondary matter being usually defined by the intercrossed lamellæ of plagioclase, which themselves are more or less penetrated by delessite. The latter mineral also lines the geodes, in the centre of which calcite has crystallised. Arch Rock has also yielded amygdaloidal specimens with fibro-radial zeolites closely resembling those of Christmas Harbour.

Cumberland Bay is the first important indentation of the coast to the south-west of Christmas Harbour, but as neither the Challenger nor the "Gazelle" Expeditions collected rock specimens from this deep and narrow fjord, our geological knowledge of it is limited to the observations of Ross. He states that a hill 300 to 400 feet in height, formed of a basaltic conglomerate and terminating in a crater, stands at the head of the bay. Veins of an amphibolic rock are injected through the mass. On the south there is a bed of carbonaceous matter 10 feet wide and 1 foot thick, covered by an amygdaloidal rock. A little farther south another bed of coal, two feet thick, appears. The schistoid rocks at the north of Cumberland Bay show impressions of *fucus*. Ross describes the rocks of the bay as "trap," an expression which may apply to basalt or to more or less amygdaloidal dolerite. Buchanan observed that, although geodiferous rocks are very common in this part of the island, the nature of the geodes differs in various localities. At Cumberland Bay the cavities are filled with quartz crystals; at Howe's Island, of which we shall speak presently, chalcedony and agate predominate; on the other hand, the amygdaloidal cavities of the basalt are lined or filled chiefly with zeolites. To sum up, quartz crystals seem to be confined to Cumberland Bay; zeolites are chiefly found at Christmas Harbour, while Mr. Buchanan observed none at Howe's Island or Betsy Cove.

The bay of Rhodes is shut in between Bismarck Peninsula and the large island of Prince Adalbert, and there amygdaloidal basalts occur, some specimens of which we have examined. The cavities are filled with chabasite, the rocks themselves much altered, of a greyish colour, and entirely impregnated with zeolites, the constituent minerals not being apparent to the naked eye. Microscopic examination shows that these fine-grained rocks are composed of plagioclastic lamellæ, augite, magnetite, and several black opaque elements; but they contain little or no olivine. The microscopic vesicles are filled with closely-packed grains of chabasite.

Professor Roth mentions the occurrence at Port Marie in Rhodes Bay, Prince Adalbert Island, of some amygdaloidal dolerites with nodules of quartz and chalcedony with coatings of the same minerals showing impressions of the rhombohedron of calcite—$\frac{1}{2}$ R. Calcite and zeolites are also observed in these rocks. At a height of 500 feet a doleritic basalt decomposing into a ferruginous red clay is found.

To the north, and almost at the entrance of Rhodes Bay, is Howe's Island, long supposed to be a peninsula. It was visited by the Challenger naturalists, who found amygdaloidal rocks in the north-east, the geodes of which were exclusively filled with agate. The hill summits were strewn with these nodules, which remained in their places after the containing rock had decomposed.

Amongst the rocks of this island, those may be described which form the top of the chain of hills visible from the Challenger's anchorage. The specimens which we examined must have been collected as fragments, as their contours are rounded. They are greyish in colour, somewhat coarse-grained, contain augite and felspar visible to the naked eye, also many zeolites, and greenish specks of a secondary substance, probably delessite. Microscopical examination confirms the macroscopical determination of this rock as a coarse-grained dolerite. The plagioclase is transformed into chalcedony and micaceous matter. The augite is purplish and without crystallographic outlines. Titaniferous iron is very abundant, appearing in the preparations as elongated or irregular rods. Olivine seems to have almost entirely disappeared, hardly any trace of it remaining. In the cracks of the rock colourless patches are to be seen which give scarcely sensible chromatic polarisation, and are obviously of zeolitic nature. These zeolites are usually framed by a zone of delessite which lines the cavities with a mammillated coating. Hematite is also a somewhat common mineral.

Fine-grained basalts were also found on the summits of these hills. These are black and compact, and crystals of augite, plagioclase, and olivine may be distinguished by the lens. Microscopically the rock appears to be a felspathic basalt, the ground-mass being made up of microliths of felspar, grains of augite, and magnetite. In this there appear large sections of olivine and augite, and broad lamellæ of much altered plagioclase. A second specimen of fine-grained basalt from the crest of the hills of Howe's Island shows a composition analagous to that described, only the microporphyritic element is almost exclusively plagioclase.

The basalts just enumerated are traversed by a dyke of bluish black rock, in parts vesicular, and of medium grain. Examined with a lens it shows augite, plagioclase, and olivine entirely transformed into an almost earthy serpentinous mass with a slightly greasy lustre. The microscope shows the dyke to be composed of a felspathic basalt, resembling all those of the island which we have examined. The ground-mass is made up of small plagioclastic lamellæ, microliths of augite, and crystallites of magnetite. Large sections of plagioclase, giving the extinctions of anorthite, appear in the mass. This plagioclase is finely striated, and is sometimes twinned according to the Baveno or pericline law; at other times it is zonary, and very rich in brownish vitreous inclusions. The sections of magnetite sometimes attain pretty large dimensions, and, with the augite, determine the microporphyritic structure.

We have mentioned that the summits of the hills of Howe's Island are strewed with geodes of agate. Mr. Buchanan observed that these nodules, derived from decomposed amygdaloidal rocks, are often worn on a part of their surface, as if they had been planed, while in other cases they are covered with very sharp striæ. The planing of part of the surface may be looked upon as the result of glacial action. As we shall see farther on, this action must have been formerly exerted at Kerguelen on a far larger scale than is the case at present.

Proceeding towards the south-east we meet Bismarck Peninsula, which runs out, indented by numerous fjords, between Rhodes Bay and Whale Bay. The rocks collected here by the German expedition were examined by Professor Roth. He speaks of a mountain formed of doleritic rock on a very narrow headland at the western extremity. This hill has the terraced structure so often to be seen in Kerguelen. Other specimens from this locality are altered doleritic basalts of a greyish colour, and fine grained. In these the microscope shows crystals of augite, magnetite, and olivine embedded in a vitreous ground-mass. The eastern coast is deeply cut into by the bays of Sontags Harbour, Successful Harbour, and Port Palliser. Mount Palliser rises to the north of Sontags Harbour, and its terraces incline gradually towards the north-west as far as Cape Neumayer. These heights and those situated between Sonntags Harbour and Port Palliser are composed of amygdaloidal dolerites with chabasite, calcite, analcime on calcite, heulandite, geodes of chalcedony, and crystals of quartz.

The great peninsula of Bismarck is bounded on the south by Whale Bay, at the head of which—named Kaiserbassin by the Germans—a river enters from the Lindenberg glacier. The bed of this watercourse is full of flat pebbles. The glacier terminates about six nautical miles from the shore in a wall of ice 75 feet high, the base being at an elevation of 350 feet above sea level. The whole valley was probably filled by this glacier at one time. Professor Roth enumerates amongst the stones of the valley, more or less altered doleritic basalts and amygdaloidal rocks, with brownish silica and geodes of zeolites, the latter being covered by a thin coating of delessite. Among the secondary minerals he mentions quartz, probably replacing natrolite, and also agate, calcite, and geodes of quartz. A trachytic rock, containing sanidine, augite, and magnetic iron, crops out at the mouth of the river, and at another place the same rock traverses doleritic basalt as a dyke from 180 to 250 feet thick.

The Roon peninsula runs out between Irish Bay and Winterhafen. The rocks of the hills on this promontory are doleritic, and contain geodes of quartz and agate with a little calcite. The same rocks with identical secondary minerals appear again at Winterhafen, and according to Professor Roth, a greyish sanidine rock also occurs. The hills of the extremity of Uebungs Bay—which is only the eastern extension of Winterhafen—are crowned with lakes, and the rocks are similar to those described above, yet one rock seems to contrast strongly with all others found in Kerguelen. Professor Roth says that in this locality the basalt traverses a greyish pyritiferous mass, which effervesces with acids, and contains much quartz and little felspar. The appearance of this rock recalled that of the dolomite of the schisto-crystalline series, but he acknowledged that there was difficulty in pronouncing as to its age. Professor Roth gives some details of the rocks of this part of Winterhafen, which enable us to recognise the same uniformity of lithological constitution as we have already had occasion to notice at other parts of the island. A little farther along the coast to the west is Irish Bay; it receives the river descending from the Naumann glacier, which stops at a distance of five nautical miles from the end of the bay. At the foot of the glacier doleritic basalts are found *in situ;* these are sometimes amygdaloidal, and marked with glacial striæ; a trachytic rock enclosed in the basalt may also be observed.

Foundry Bay succeeds that last mentioned. It is a fjord barely two-thirds of a mile wide at the entrance, with Gazelle Basin situated in its western angle, and Schönwetter Harbour at its eastern extremity. The rocks from the shores of this bay are doleritic basalts, with olivine and geodes of chabasite, quartz, and agate. Amygdaloidal dolerites, containing fine geodes of heulandite, quartz, and chalcedony, are found at Schönwetter Harbour. There are also fine-grained basalts, and tufas of the same lithological nature.

Continuing towards the east we reach the most thoroughly known peninsula in Kerguelen, that named Observations Halbinsel by the German explorers, and made the object of a detailed topographical survey by Captain von Schleinitz, who commanded the "Gazelle."[1] Dr. Th. Studer, naturalist to the German expedition, published a memoir full of facts regarding this part of the island. He remained for more than three months in the neighbourhood of Betsy Cove, and his work comprises a most complete set of observations on the topography and geological conditions. The latter are treated with special detail, comprehending the study of the basaltic and trachytic eruptive masses, the deposits formed by running water, glacial phenomena, erosion by sea and rivers, and recent oscillations of the ground. It is impossible to give an abstract of this work here, the reader must therefore refer to the original paper. We may, however, state the principal features of the physical geography of this peninsula, and summarise the chief varieties of rocks collected by Dr. Studer and determined by Professor Roth.

The Strauch hills, attaining a height of 1150 feet, and Castle Mount, with an elevation of 1550 feet, stretch towards the west, and farther in the same direction lies the valley of Cascade River, one tributary of which flows from Lake Margot, another having its source a little farther north. Mount Crozier rises to 3000 feet at the south of Lake Margot. The peninsula on the north and east is simply a plain about 30 feet above sea level, covered with rolled pebbles, and diversified by lakes and marshes. On this plain, to the south of Accessible Bay, are situated the Tafelberg (275 feet), and three isolated summits—Mount Campbell (about 460 feet) lying farthest north, Mount Peeper (650 feet) next it, and to the south of these the crater-shaped Mount Bungary.

In what follows we shall give special prominence to the observations of the British naturalists, which only refer to the special point of Betsy Cove, where the Challenger

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[1] See *Annalen der Hydrographie*, Bd. ii. No. 19, p. 220, 1875.

anchored, and on the shores of which the explorers collected specimens. Mr. Buchanan observed that the hills here have the same structure as in the north, the eruptive sheets appearing in the form of horizontal layers. The hills, however, are farther from the coast, and a plain, broken only by Mount Campbell, extends from their base to Cape Digby. Mr. Moseley has drawn attention to the glacial phenomena in the neighbourhood of Betsy Cove. A series of *roches moutonnées* appeared to the north of the port where the Challenger anchored. Betsy Cove and the neighbouring fjord of Cascade Reach are two deep indentions opening into the great basin marked on the Admiralty chart as Accessible Bay. Here there also opens a large valley, running far into the country between two lofty chains of hills. The hills near this valley are rounded on the summit, probably by glacial action. According to Moseley, the whole region has been subjected to great denudation since it was glaciated, and the striæ and moraines must consequently have been obliterated to a great extent. Everything seems to show that the hills were cut out of a continuous sheet of volcanic rock, which formerly spread over the whole region; the summits are capped with basalt, showing columnar structure in their sections.

We shall first describe the compact coarser-grained specimens of basalt from Betsy Cove. They are black, with an unequal fracture, formed by an aggregation of crystalline grains, amongst which yellowish patches of olivine, measuring half a centimetre, plagioclase, and augite may be detected by the unaided eye. Under the microscope large and sometimes very elongated microporphyritic sections of olivine appear. This mineral is decomposed into a yellowish matter, not showing the usual green tint of serpentine. The augite is transformed into a green substance, delessite or grengesite, which also tends to replace the felspar; it is found in every hollow, and surrounds all the constituent minerals. The plagioclase crystals show an angle of extinction, which classes them as anorthite or some very basic felspar. Large sections sometimes show at the same time the albite and Carlsbad twins. The larger minerals are embedded in a network of small plagioclase crystals, augitic microliths, and decomposed grains of olivine.

Other specimens from the same locality are finer grained, and also distinguished by a cellular structure. They are all greatly altered, some specimens so much so that they appear earthy, are covered with oxide of iron, and are frequently red, with whitish markings. The vesicles, from half a centimetre to a centimetre in diameter, are usually lined with well-formed crystals of chabasite. Doleritic structure does not appear when slices are examined microscopically; microporphyritic structure is very rarely seen, and, when observed, is due to a larger development of crystals of plagioclase. These large sections of felspar are traversed by cracks, pervaded by a light-brown substance, presenting the characters of silica in the state of chalcedony or opal. The silica sometimes partly penetrates the mass of the felspar, but it is not found in this mineral only, as it occurs in all the holes, where it assumes a purplish or brownish colour. The concretionary structure and brilliant polarisation colours distinguish it clearly from chabasite. Felspar alone is usually found retaining its natural colour; augite is transformed into delessite or grengesite, and the olivine is covered with oxide of iron, or even filled with hematite, or else serpentinised. Chabasite, the rhombohedric forms of which are visible to the naked eye, fills all the vesicles with closely-packed grains. These react feebly between crossed nicols; they show striations and twinnings, and the other phenomena which have been particularly studied by Professor Becke.

Professor Roth's lithological observations on the rocks of Betsy Cove go to show what a large part doleritic basalts containing zeolites play in the whole peninsula. We need refer to a few only of the rocks of another nature which he has determined from specimens collected by the German expedition. A rolled pebble of red porphyry was found at the foot of Mount Peeper, and this, according to our author, seems to prove the existence of ancient rocks in Kerguelen. We shall refer to this point again. The specimens from the eastern part of Mount Peeper have been found to contain half-fused fragments of sanidine rock. This clearly proves that the trachytic masses existed prior to the basaltic eruption. This conclusion will be confirmed by considering the relation between the sanidine rocks and the basalts of Royal Sound and Greenland Harbour.

Professor Roth records from the neighbourhood of Mount Crozier, besides the usual eruptive rocks of Kerguelen, fragments of a bluish grey sedimentary rock, the age of which cannot be determined. It is related to a labradorite-porphyry coming from the south-western extremity of Lake Margot. This rock is compact, and the greyish blue ground-mass contains triclinic felspar and grains of pyrites, its appearance recalling the rocks of ancient type. The specimen effervesced strongly with cold acids, and after treatment with hydrochloric acid the ground-mass appears lighter in colour, while the felspar crystals are much corroded. Microscopic preparations show that the ground-mass is much decomposed, and contains triclinic felspar, a chloritic mineral probably derived from augite, altered olivine, and magnetic iron. Another rock, coming from the series of hills in the Studerthal, to the north-east of Mount Crozier, has a granular structure, and contains chiefly triclinic felspar, plates of black mica, and an altered mineral possibly derived from hornblende. The rock effervesces slightly in acids. It appears to contain some crystals of orthoclase, and Professor Roth was led to class it with the ancient eruptive rocks such as micaceous diorites.

The great peninsula, the rocks of which have now been described, is bounded on the south by a large bay, Royal Sound, occupying the south-eastern extremity of Kerguelen. Here the British and American stations[1] were situated in 1874. Before

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[1] The American transit of Venus mission was established at Royal Sound, near Molloy Point. Dr. Kidder, the medical man of the party, has published his botanical and zoological observations in Nos. 2 and 3 of the *Bulletin of the United States National Museum*, Washington, 1876.

describing the rocks of this fjord, we may consider those from Prince of Wales Foreland, a long and mountainous promontory which stretches from the peninsula already described towards the entrance of Royal Sound; the northern boundary is Shoal Water Bay. According to Mr. Buchanan this high promontory is formed of columnar basalt, in some places weathering into spheroids. The rock contains large nodules of olivine. Flat-topped hills extend into the interior beyond this tongue of land with its serrated rocks. They in turn are of basaltic nature, and contain much olivine, but the columnar structure gives place to a bedded arrangement, which in some cases is schistoid.

Besides the basalts reported by Mr. Buchanan, we have found amongst the specimens from this locality a limburgite, a lithological type we have not yet noticed as occurring in the island. Externally it resembles a basalt, but the mass is more shining and bluish black in colour. Bottle-green grains of olivine are visible to the unaided eye; with the lens smaller crystals of augite become visible. Large sections of brownish olivine appear in the homogeneous vitreous ground-mass. As a rule they have sharp crystallographic outlines, sometimes, however, they are corroded; they present no peculiarity, except for some large transparent inclusions of chestnut-brown chromite. Augite occurs as well-developed light green crystals, showing distinct outlines, and often twinned polysynthetically. Numerous augite microliths, usually very elongated, occur in the ground-mass. Magnetite is abundant in the form of regular sections, but no felspar is to be seen. The cavities of the rock are lined with fibro-radial zeolites.

On doubling Prince of Wales Foreland one enters the great bay of Royal Sound, studded with islands and reefs to the number of more than a hundred. The gulf is wide and deep. All the islets and the hills of the neighbouring land terminate in tabular summits. The rocks forming islands in this fjord are strewn with erratic blocks, the number of these ice-borne fragments seeming to increase as we approach the bottom of the bay. The hills are the same as those of Betsy Cove; in fact, if the great valley there were filled by the sea, the numerous hills of the northern part would appear as islets, and give to the bay the appearance of Royal Sound in miniature. It is almost certain that all the islets and reefs were connected to begin with, forming part of a sheet of lava which descended with a slight slope from the land to the sea. The slope was covered by a great glacier shut in by the hills which now border the sound on the south and north. After having planed down the whole surface over which it flowed, the glacier hollowed out the deep channels between the harder rocks, that now form islands in the bay. During this glacial period, or at some subsequent time, all these islands were covered by the sea in consequence of subsidence; the icebergs, broken off from the glacier as it entered the sea, deposited the erratic blocks upon the summits of the islets of the Sound. At this time, also, moraines must have been carried away.

Hog Island is the only one in Royal Sound the rocks of which are known. Specimens were collected by the German expedition and examined by Professor Roth. He reports amygdaloidal doleritic basalts with geodes of quartz as the chief rocks of this island, which rises about 400 feet above the sea. Trachytic rocks covered with a brownish altered layer occur on the summit. In the ground-mass of this trachyte there are crystals of sanidine reaching 15 millimetres in diameter; crystals of a shining triclinic felspar also occur, but these are rarer, and, finally, there is augite, without crystallographic outlines. The microscope also shows magnetic iron and some lamellæ of mica. A trachyte resembling that of Kühlsbrunn is found in the same island. It is a greyish rock, of a scaly grain and slightly slaty. Under the microscope, isolated brown crystals of hornblende appear. Professor Roth could not recognise with certainty the presence of triclinic felspar.

Mr. Buchanan collected from the rocks cropping out near the shores of Royal Sound several specimens of amygdaloidal dolerites, the vesicles being filled with zeolites. One of these much altered rocks has large crystalline grains, and is penetrated with a great number of fibro-radial zeolites, and with limonite. Microscopically it shows the doleritic structure, but this is not developed here in a very characteristic manner. The crystals of olivine have too sharp crystallographic outlines; they lead rather to a transition of the doleritic structure to that of the basalts, properly so called. In thin slices of this rock the microscope shows large plagioclastic lamellæ, between which grains of augite are embedded. The olivine is impregnated with hematite, and sometimes transformed in the interior into a fibrous matter like serpentine. In certain cases the augite appears in large sections, generally much altered and charged with iron. There are numerous rods of magnetite or ilmenite, and calcite is much developed in the vesicles, where it is associated with zeolites.

Other rocks from the same district are identical with the preceding. We may, however, add to the foregoing description that microscopic examination shows the regular association of plagioclase and augite, the former being united to the pyroxene parallel to one of the pinacoids. Small yellowish transparent rods also appear, sometimes arranged in parallel series, and recalling the form and grouping of magnetite trichites. These little rods are entirely transformed into limonite, but the larger sections of magnetic iron have not been affected in this way except a little on the edges.

Finally, at Royal Sound greenish yellow light scoriaceous rocks are found, almost earthy from alteration. The only mineral to be seen is augite in large black crystals, which stand out from the decomposed rock. Thin slices show that it is formed of a green basaltic glass full of bubbles and partly decomposed into palagonite. This vitreous matter is stretched out in filaments, and passes in some places from brown to yellow. Its structure is sometimes as fibrous as that of pumice. The vesicles are not filled with zeolites, but limonite is found almost everywhere in the preparations. Besides the very numerous crystals of magnetite, there are sections of brown hornblende well characterised by their contours, their cleavages, and their extinction. Augite is present as greenish sections. These two minerals are rather uncommon as large crystals in the rock just described. They bear traces of fusion or corrosion, their outline being rounded by the action of the vitreous magma. By the use of the highest powers little microliths of augite are seen in great abundance; felspar is extremely rare.

There remain to be described some rocks collected in the bed of Channer River which flows into Royal Sound. The specimens are flat-rolled pebbles of augitic trachyte, which contrast by their grey colour with all the other rocks that have been described. Crystals of sanidine visible to the naked eye appear in a greenish grey ground-mass; small prisms of augite may be distinguished with the lens. These stones have an indistinct schistoid structure, and microscopic examination of thin slices shows them to be microporphyritic. This structure is determined by large sections of sanidine of irregular outline, and by an aggregation of little green crystals of augite, which imitate by their general appearance crystals of hornblende whose place they take. These augitic pseudomorphs of hornblende are accompanied by numerous grains of magnetite. The hornblende has, as a rule, entirely disappeared, and zeolites fill the spaces between the microliths of augite (fig. 21). Sometimes, however, at the centre of the aggregation there remains a brownish, very pleochroic remnant of hornblende. The ground-mass is composed of rather elongated lamellæ of sanidine, twinned according to the Carlsbad law, pressed against each other, but still exhibiting a certain linear arrangement suggestive of fluidal structure. The lamellæ are sometimes less regularly disposed, forming a network; the forms of the felspar microliths in the ground-mass are less distinct. Almost all the constituent minerals are surrounded by a zone of green microlithic augite. Titanite is often present. A fibro-radial zeolite, showing the black cross of spherulites, lines the hollows and penetrates the spaces between the minerals.

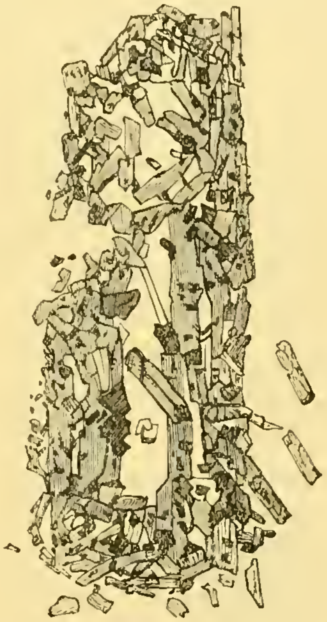

FIG. 21.—Augitic trachyte from Royal Sound.

Small grouped crystals of augite, imitating as a whole the form of a hornblende crystal, whose place they fill. This replacement of hornblende by augite has been accompanied by the formation of numerous grains of magnetite, and in the centre of the group of augites a small brownish pleochroic remnant of hornblende may be seen. Usually, as in the drawing, this mineral has quite gone, zeolites filling the interstices between the augite microliths. $\frac{1}{35}$ crossed nicols.

Mr. Buchanan describes a peculiar hill at the other entrance to the Sound, almost opposite Prince of Wales Foreland, which has a very similar structure to that of certain hills at Christmas Harbour. It has an embattled appearance like a castle, and is known by the name of "Cat's Ears." The rocks at the summit look like ruins; they are greyish, and contain fragments of scoriaceous lava, which also forms a layer immediately beneath the battlemented crags. The rock contains large crystals of augite, with sharp outlines, but they are always broken and rounded when observed in the volcanic sand formed by the decomposing rocks. The sand has been sorted out by the wind, the white grains, which are lightest, being carried away and only the black particles left. These crystals and the rocks themselves clearly show the erosive action of the wind, the former having lost all regularity, the latter being deeply cut into on the side facing the prevailing winds. Here, as in Heard Island, where the same thing can be observed in even greater perfection, the wind constantly blowing from the west carries along the sand and drives it with great force against the rocks, cutting and carving them in a characteristic manner.

From this hill Mr. Buchanan, from whom we borrow these facts, could see another very similar at the base of the Sugar Loaf. From a distance it resembled a druidical circle, but the short time at his disposal prevented him from examining it more closely or visiting the Sugar Loaf.

Amongst the rocks we have examined, there were no specimens from "Cat's Ears," nor from any other hillock of this part of the Sound, except Coronet Hill, near the south-western entrance. These rocks may be classed as augitic trachytes, trachytic tufas, and basalts.

Fig. 22.—Trachyte from Coronet Hill, Royal Sound.

Section of corroded sanidine with undulating extinction. $\frac{1}{20}$ crossed nicols. Polarised light.

The specimens of trachyte are greyish, rather compact, with an irregular fracture; only small crystals of sanidine can be detected with the lens. Thin slices, when examined, show that the rock is composed of an isotropic mass containing small crystals of sanidine, twinned according to the Carlsbad law, and also larger individuals of the same mineral. The latter are always much broken up, and exhibit undulating extinction (see fig. 22), as if they had been submitted to strain, a supposition which is strengthened by the linear arrangement of the augite microliths. These small prismatic crystals extinguish at nearly 40°, and are invariably bedded with their vertical axis in the plane of the preparation. Many sections of magnetite are to be seen; these are usually collected in the place occupied formerly by hornblende crystals, of which scarcely a trace remains. These crystals of hornblende are always surrounded by small green crystals of augite.

Other specimens of much-altered whitish trachyte readily fall into powder. They are as light as pumice, but of closer texture; they greatly resemble the preceding rock, except that the light vesicular vitreous matter, passing into a pumiceous structure, plays a more considerable part. Crystals of plagioclase, intimately associated with sanidine and apatite, may be mentioned as accidental elements.

These trachytes are accompanied by reddish pumiceous trachytic tufas. Irregular fragments may be seen by the naked eye embedded in a slightly scoriaceous paste. Thin slices show that these tufaceous rocks are composed of a greyish mass, which is isotropic in some places, and almost everywhere impregnated with iron. The little fragments of rock enclosed in this grey mass are trachytic; sanidine is the principal constituent in them, associated with green microliths of augite. There are also large splinters of very clear sanidine, which might be taken for quartz if they were not biaxial; finally, one observes large cracked crystals of green augite.

As everywhere else in Kerguelen, basaltic rocks occur at Coronet Hill, but here they are not very distinctly characterised. The specimens we class as basalts are scoriaceous, very vesicular, with drawn-out pores; in colour they are deep red, and nothing except lamellæ of black mica can be seen by the naked eye. Under the microscope the ground-mass appears almost opaque from the interposition of a black pigment, with numerous small green crystals of augite, and regular sections of olivine altered into hematite. Large fragments of augite, sometimes enclosing hornblende, also appear.

We have now to describe the rocks of Greenland Harbour. This fjord is situated to the south of Royal Sound, from which it is only separated by a narrow tongue of land. We may first recall the observations made by Mr. Buchanan in this part of the island. On entering Greenland Harbour he was struck by the appearance of the masses of grey rock which rise up boldly from the horizontal beds of basalt. The chain of hills near this fjord is composed of basalt, the greatest mass of grey rock being found on the summits in the western part of Greenland Harbour, and appearing from a distance like a heap of ruins. He was able to examine this rock in two places, at the summit of the hills west of the bay, and near the creek where he landed. He found the rock to be the same on both sides; it is a phonolite of a light greyish green colour, surrounded by basalt. The masses of phonolite are cylindrical and columnar on the outside, the columns being horizontal, and showing a radial arrangement. They do not penetrate the rock, but form a zone some feet thick around the central part, which remains massive. The prisms have been largely disintegrated by weathering, and lie broken up into a great number of blocks around the phonolite masses. The outer portion of the rock, in which the columns are horizontal, resembles a cyclopean wall, and resists atmospheric agencies much better than the solid centre. Were it not for these natural walls binding the whole mass together, the central part would form a *talus* of débris as it disintegrated; this the columnar arrangement effectually prevents. The upper part of the most remote phonolitic eminence, which crowns the summit of this chain of hills, rises to more than 50 feet. An accumulation of blocks covering the lower wall is scattered over the steeply inclined slope.

The basaltic rocks, which form the principal mass of the hills, and extend in horizontal layers at Greenland Harbour, as in all other parts of the island, will be described first. The rocks where the Challenger made a landing are altered felspathic basalts, black and massive, displaying no minerals to the unaided eye. The fracture is almost plane. With the lens one sees that they are formed of crystalline grains, amongst which triclinic felspars appear. In the ground-mass composed of microliths of plagioclase and augite are embedded larger crystals of plagioclase, and olivine which has been completely decomposed, only the form remaining; this mineral is replaced by limonite, which also penetrates the whole rock.

The horizontal beds extending to the south-west of Greenland Harbour are formed of a basaltic rock, the porphyritic structure of which is caused by the presence of large crystals of augite, felspar, and olivine. The mass is compact, but the whole rock is penetrated by oxide of iron. Large sections of plagioclase, cracked in all directions, are seen under the microscope. The cracks are filled with opal, and the whole appearance of these felspars resembles those we shall describe in the augite-andesites of Kandavu. Sections of augite and some small crystals of olivine are also seen, the larger ones being so much altered that they are destroyed in polishing the preparations. The ground-mass is formed of a network of small microliths of plagioclase and augite, with some magnetite.

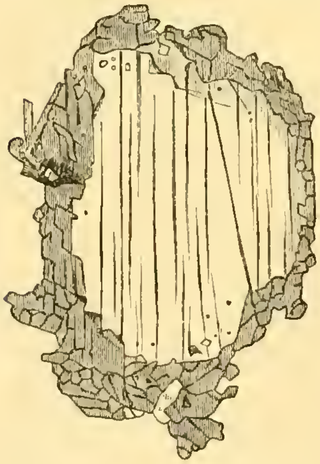

FIG. 23.—Basalt of Greenland Harbour. Section of augite showing the external green zone. $\frac{1}{35}$ crossed nicols.

The rock forming the greater part of the hills west of the bay is also spread out in horizontal beds, and, like the preceding, is a basalt, possessing the usual macroscopical character of this rock. Under the microscope this basalt appears with a ground-mass made up of small crystals of plagioclase and augite, and numerous grains of olivine. The most striking feature in these preparations is the great number of large crystals of olivine, which usually are formed of several individuals by direct grouping. These sections are sometimes bounded by curved lines showing the corrosive action of the magma. The olivine is usually decomposed on the edges, where the alteration is indicated by a slightly fibrous yellow border. Augite is less common than olivine, and shows as irregular colourless or pink sections in the preparation. On the edges it takes the same green colour as the small augites of the ground-mass (see fig. 23). These microliths surrounding the microporphyritic sections of augite give rise to this greenish zone. There is no plagioclase to be seen except the microliths of the ground-mass.

Other rocks of a reddish colour and much altered, which were collected by Mr. Buchanan at Greenland Harbour, are also basalts. Microscopic examination shows them to be fine-grained, with a ground-mass of microliths of plagioclase, and grains of augite and magnetic iron. In this are embedded large sections of triclinic felspar, traversed by cracks and in part opalised, like those we shall describe in detail in the notes on Kandavu Island. Augite and olivine also appear as microporphyritic elements; the latter mineral particularly is more or less penetrated with oxide of iron.

The horizontally-bedded basalts of which we have been speaking surround grey masses of trachyte and phonolite, projecting above the basalt and having a columnar structure. Their geological disposition and aspect have already been described from Mr. Buchanan's data. These rocks are hard and compact, their colour is greyish green, and although they present marked resemblances to many phonolites, they do not ring, as rocks of this type generally do. Specimens broken off the prisms are finer grained than those from the central mass, and have a distinct cleavage perpendicular to the length of the columns. This rock partially gelatinises in hydrochloric acid; the solution contains much soda and traces of sulphuric acid. From this reaction Mr. Buchanan concluded that these rocks contained at the same time nepheline and noscan. They may be classed as augitic trachytes; in some cases, by the addition of nepheline, they pass into phonolites, and then, finally, when sanidine is absent, pass into nephelinic rocks containing acmite.

We shall first describe the specimens taken from the wall of rock on the summit of the hills lying west of Greenland Harbour. These rocks, projecting above the masses of basalt, are phonolites. They are greenish grey, compact, with a slightly shining fracture and a rather indistinct schistosity. They are sometimes spotted with more or less circular black markings; large crystals of sanidine are to be seen, and sometimes milk-white microscopic sections of nepheline. Microscopic examination shows that the rock is essentially composed of numerous small crystals of nepheline closely packed together, but still preserving the general sharpness of their outlines. This mineral is sometimes seen in larger hexagonal or quadratic sections with zonary structure, standing out from the ground-mass formed by microliths of the same species. Sanidine is comparatively rare, and occurs in elongated lamellæ twinned according to the Carlsbad law. The green mineral is of quite small dimensions, and its outlines are vague; the angle of extinction measured for a great many crystals hardly ever exceeds 15° or 20°, hence the crystals are very probably hornblende. Titanite is rather common. Fibro-radiated zeolites often occur in the vesicles, and are also disseminated throughout the rock. A specimen of this phonolite has been analysed by Dr. Klement, with the following results:—

I. 1·0730 grammes of substance, dried at 110° C. and fused with the carbonates of soda and potash, gave 0·0387 gramme of water, 0·5887 of silica, 0·2322 of alumina, 0·0461 of ferric oxide, 0·0175 of lime, 0·0110 of magnesium pyrophosphate, and traces of manganese.

II. 1·0285 grammes of substance, treated with hydrofluoric acid, gave 0·2448 gramme of potassium and sodium chlorides, and 0·2130 of potassium chloroplatinate.

III. 1·2168 grammes of substance, treated with hydrofluoric and sulphuric acids in a sealed tube, was titrated with potassium permanganate and required for oxidising the ferrous oxide 2 c.c. of solution (1 c.c. = 0·005405 gramme ferrous oxide).

Percentage Composition.

Silica, SiO_2, ...	54·87
Alumina, Al_2O_3, ...	21·64
Ferric oxide, Fe_2O_3, . . .	3·31
Ferrous oxide, FeO, . . .	0·89
Manganese, ...	traces
Lime, CaO, ...	1·63
Magnesia, MgO, ...	0·37
Soda, Na_2O, ...	9·26
Potash, K_2O, ...	4·02
Water, H_2O, ...	3·61
	99·60

This analysis confirms the determination of the rock as phonolite, the large percentage of soda corresponding well with the important part taken by nepheline. The water present proves the alteration of the rock, which is also indicated by the zeolites disseminated throughout the whole mass.

Another nepheline rock picked up in the centre of the same creek differs considerably in mineralogical composition from the preceding. It is darker coloured, coarser in grain, marked with opaline points, less schistoid in structure, spotted with small deep green prisms, and sometimes speckled like the phonolite described above. A paler grey-green specimen is very massive, and nô mineral can be distinguished by the naked eye; it has a very distinct prismatic fracture. The greyish groundmass is formed exclusively of little crystals of nepheline. In this there appear distinct green lamellar sections which are pleochroic, as it were corroded, and including nepheline crystals. The mineral might be taken for hornblende were it not for its extinction. Almost all the sections extinguish parallel to their length, and in the case of an oblique extinction it never exceeds 3° or 4°. We consider this mineral to be acmite, the presence of which has been ascertained in rocks analogous to those now described. The outlines of the prismatic zone are fairly clear, but the crystals are corroded, and almost fibrous at the extremities. Terminal faces are never seen, except a rather low dome which is very rare. The pleochroism, as shown by these crystals, is dark green for rays vibrating parallel to *c*, and yellowish for those perpendicular to that direction (see fig. 24). Like the rocks encircling the creek, this nephelinic mass contains numerous patches of fibro-radiated zeolites.

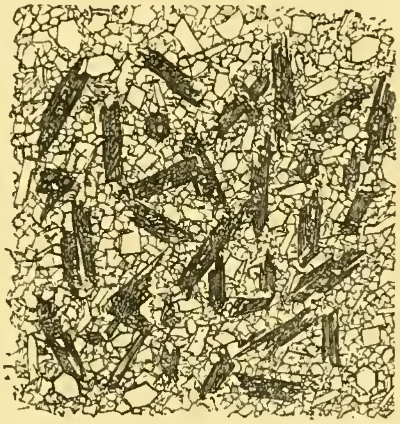

FIG. 24.—Nepheline rock with acmite from Greenland Harbour. The ground-mass is entirely composed of nepheline, numerous hexagonal or quadratic sections of which appear in the figure. In this there are greenish lamellar sections of acmite. $\frac{1}{33}$ crossed nicols.

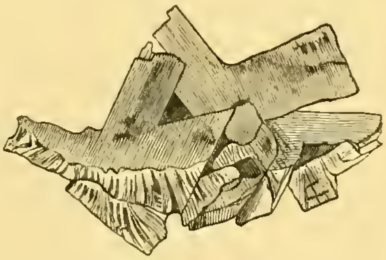

FIG. 25.—Basalt in contact with phonolite from Greenland Harbour.

Group of plagioclase epigenised into opal on the upper part, transformed into chalcedony on the lower. $\frac{1}{20}$ crossed nicols. Polarised light.

A specimen taken at the contact of the phonolite and the encasing basalt shows both rocks in juxtaposition, but quite distinct from each other. There is no gradual transition, but a sudden passage from one to the other: on one side the reddish almost spongy basalt, on the other the greenish grey compact phonolite. The latter is brecciated, as if the eruption of the basalt had produced a friction-breccia. The specimens of basalt taken at the contact are in some cases black compact tufas containing lapilli, which are identical in structure and mineralogical constitution with the basalt of Greenland Harbour. Fragments of phonolite are also seen, and sometimes vitreous lapilli altered into palagonite. Amongst the fragments of minerals in this tufa, olivine, augite, triclinic felspars, and large broken crystals of sanidine may be seen. Some of these, especially the plagioclases, are entirely penetrated by silica, which has converted them into pseudomorphs. A group of triclinic felspars is here figured (fig. 25), which shows that they are replaced in the upper part by opal, in the lower by chalcedony. The mass uniting the clastic elements of this tufa seems to be of a vitreous nature, but its characters are vague, and veiled by innumerable opaque grains, most probably of magnetite, which are scattered throughout the substance. The phonolite part of this specimen which is joined to the basalt does not present, from the point of view of micro-structure, anything to distinguish it from the normal phonolites already described, except, perhaps, that the sections of sanidine are somewhat larger.

Another hill situated at this part of Greenland Harbour is formed of a trachytic rock. It is a rounded eminence crowned by a mass of angular blocks, scattered about like the ruins of masonry. The rocks collected here by Mr. Buchanan are augitic trachytes, identically similar to those already described; they were obtained from the bed of a river entering Royal Sound. The rocks are compact, with a slightly greasy lustre, and a subconchoidal fracture. They are bluish grey in colour, sometimes with macroscopic sections of sanidine, sometimes marked with circular black spots, either extended in a zone or combined to form more or less continuous bands. The microscope shows broken crystals of sanidine and microliths of augite grouped round hornblende sections, only traces of which now remain. These augitic microliths combined with grains of magnetite tend to replace the amphibolic mineral, and in some cases do so completely. The sections of these minerals are embedded in a ground-mass formed principally of small lamellæ of sanidine. A specimen of these trachytic rocks from Greenland Harbour has been analysed by Dr. Klement with the following result:—

I. 1·1738 grammes of substance, dried at 110°C. and fused with carbonates of potassium and sodium, gave 0·0188 gramme of water, 0·6835 of silica, 0·2453 of alumina, 0·0065 of ferric oxide, 0·0380 of lime, 0·0126 of magnesium pyrophosphate and traces of manganese.

II. 0·9893 gramme of substance, treated with hydrofluoric acid, gave 0·2069 gramme of chlorides of sodium and potassium, yielding 0·2998 of potassium chloroplatinate.

III. 1·0507 grammes of substance, treated in a sealed tube with hydrofluoric and sulphuric acids, was titrated with potassium permanganate and 3·4 c.c. of solution were required to oxidise the ferrous oxide (1 c.c. = 0·005405 gramme FeO).

PERCENTAGE COMPOSITION.

Silica, SiO_2,	58·23
Alumina, Al_2O_3,	20·90
Ferric oxide, Fe_2O_3,	3·21
Ferrous oxide, FeO,	1·75
Manganese,	traces
Lime, CaO,	3·24
Magnesia, MgO,	0·39
Soda, Na_2O,	6·16
Potash, K_2O,	5·88
Water, H_2O,	1·60
	101·36

This analysis corresponds closely with the average composition of trachytes. The high proportion of soda may be explained by supposing the sanidine to contain that alkali;[1] possibly also there may be amongst the microliths of the ground-mass little crystals of plagioclase, the determination of which is impossible on account of their small size and their confused arrangement.

Let us now consider what are the stratigraphical relations between these phonolitic masses and the surrounding basalt. According to Mr. Buchanan, no derangement of the beds was found in any case at the contact of the two rocks. He was able to follow the line of contact easily to the highest mass and procure specimens of it. The basalt is much modified for some feet from the line of junction, the large crystals of augite and olivine disappearing near the contact with the phonolite. The line of contact is generally sharp, and many fragments of phonolite are seen enclosed in the immediately bordering basalt, which is very fine grained. The grain grows gradually coarser, until at a distance of 10 feet from the phonolite it reassumes the porphyritic structure which this rock shows in other parts of the island. These two facts seem to show that the phonolite rocks are the most ancient, and that the basalt has been poured out all round them. There is no evidence, on the other hand, that the phonolite has been erupted through the basalt mass.

We shall now describe some rocks from "Foul House Bay," and as this name is not on the chart we cannot follow geographical order in this case. They are coarser grained than the other specimens from the island, dark coloured, with a blackish tinge, and broken surfaces are shining and show a crystalline saccharoid texture. Macroscopical greenish yellow granules of olivine, augite, and plagioclase are seen in it. These rocks present obvious resemblances to certain peridotic diabases or coarse-grained dolerites; their microscopic characters also show the structure and composition of these lithological types. There is no distinct ground-mass, the crystals being entangled. Sections of plagioclase show that this mineral is elongated following the edge *P/M*, as is usual in the felspars of diabase and dolerite. This plagioclase shows extinctions of 44°, and is thus probably anorthite. Olivine occurs in large sections, rarely with crystallographic outlines, and is sometimes twinned, the two individuals seeming to be united parallel to a pinacoid. This mineral is altered, as is shown by the fissures being lined with an opaque black matter, and the sections penetrated by delessite; no serpentinisation, properly so called, is apparent. Delessite is largely developed in other parts of the rock in question. Large, reddish, zonary patches of augite fill the space between the other minerals. Magnetite or titaniferous iron is very common. Besides delessite, some grains of calcite occur as products of secondary formation. Another specimen, more decomposed, shows the same structure and composition, except that olivine has almost entirely disappeared, its place being

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[1] See Roth, Chem. Geol., vol. ii. p. 240.

taken by delessite with the addition of chalcedony, as is often seen in the volcanic products of Kerguelen.

Without knowing the stratigraphic relations of the rocks of Foul House Bay, a summary of the lithological characters of which has just been given, they might be equally well classed as peridotic diabases or recent dolerites, but the probabilities are in favour of the latter supposition.

Taking a summary view of the general observations given in the preceding pages, and those made at Kerguelen by the various naturalists who have explored the island, we see that the physical geography, the disposition, and the nature of the rocks all show the island to be of volcanic origin, and that the eruptive masses of basalt and trachyte belong to recent periods. The basalt formerly spread in vast continuous sheets far beyond the present limits of the land. The oscillations of the land, the erosive action of the atmosphere, of glaciers, and of the waves, have eaten into and carved out the coasts of Kerguelen, thus giving it its actual relief and remarkable outlines.

If we take into account all the observations of British and German naturalists, particularly those of Dr. Studer, it must be admitted that Kerguelen Island has been, in the main, built up by successive eruptions of basaltic masses spread out in wide outflows. At some points as many as twenty of these sheets can be counted one above another. All these basaltic rocks are felspathic, and are associated in a subsidiary way with palagonitic tufas and limburgite; they present great uniformity in structure and composition in all parts of the island. Dolerites appear to predominate, and amygdaloidal rocks with zeolites and geodes of quartz and chalcedony are very common amongst them. All the rocks of this series are connected together by their composition, and the different modes of structure they present may easily be explained. In fact, it is observed that the numerous basalt sheets are fine grained at the bottom and centre, but alveolar or even scoriaceous in the upper part, *i.e.*, the original surface of the stream. This surface is in its turn covered by a more massive rock. It must be admitted that, as in the case of lava-streams, the scoriaceous or amygdaloidal portion corresponds to the upper surface of the lava. Here the expansion of imprisoned gases was not counterbalanced by the pressure of the overlaying rocks, as was the case in the lower parts of the bed. The eruptions have been subaërial, at least in most cases. These facts, so far as they are exhibited in the neighbourhood of the German station, were observed in detail by Dr. Studer, and may be generalised for all other parts of the island; they are shown well at Christmas Harbour.

The terraced structure of these volcanic hills is due to the manner in which the masses composing them were erupted. One might suppose that the successive outflows were superimposed on beds of a former eruption without covering their whole surface, but it is much more probable that denudation has taken a leading part in the formation of these terraces, the limits of the erosion being determined by the alternations of massive and vesicular structure. We shall see that the surfaces of many of the superimposed layers have been directly exposed to atmospheric agencies, the influence of which has been most powerful on their scoriaceous parts.

The sheets of basalt contain masses of trachyte and phonolite, which are often associated, and form the escarpments crowning the heights of the island. These crests of trachyte or phonolite are shown in Table Mountain, in the region of Betsy Cove, at Royal Sound, and, above all, at Greenland Harbour. The stratigraphic relations of the basalts and trachytes, on which we have insisted in describing Mr. Buchanan's observations as confirmed by Dr. Studer, undoubtedly go to show that the phonolitic and trachytic masses were erupted before the outflow of the basalt sheets. In this connection we may recall an observation of Professor Roth which establishes this order of succession. He found that a trachytic rock from the neighbourhood of Mount Peeper had been exposed to the caustic action of basalt. On the other hand, we have stated that at Greenland Harbour, where basalt and phonolite are found in contact, it is the latter rock that has undergone the mechanical effects of the intrusion, which has formed a true friction-breccia. This necessarily implies the pre-existence of the phonolite.

Taking account, then, of all these observations, it is necessary to admit that in Kerguelen trachyte and phonolite have preceded the basaltic eruptions. There is also sufficient reason for the statement, based on the structure and composition of the trachyte and basaltic series as shown in the island, that their eruption is comprised within the recent volcanic period.

We may also recall the fact that all these rocks, generally altered, are filled with minerals of secondary formation, such as delessite, zeolites, quartz, chalcedony, agate, &c. This greatly complicates the question which must now be put, viz., Are there erupted rocks in Kerguelen which belong to more remote geological periods? Professor Roth and Dr. Studer were inclined to think so. The reasons which led the former to suppose that paleo-volcanic rocks were found there are as follows:—Amongst the specimens from near Mount Crozier he found a micaceous diorite and a fragment of red porphyry, from Lake Margot a labradorite porphyry, and at Winterhafen a rock was picked up which resembled certain dolomites of the crystalline schists. The existence of ancient crystalline rocks in oceanic islands appears incontestable, and we have shown their presence in many of them. Still, in the present state of our knowledge, we think it premature to state positively that outcrops of these ancient rocks exist in Kerguelen.[1] While freely admitting the correctness of Professor Roth's determinations, one may reasonably inquire whether the specimens he examined have not been con-

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[1] Mr. Eton says that limestone has been found near Foundry Branch; he adds that Mr. Stone of H.M.S. "Supply" showed him the cast of a fossil shell which a sailor picked up near Thumb Peak; *Phil. Trans.*, vol. clxviii. p. 2.

veyed to the place where they were found by icebergs, or brought up from great depths as enclosures by neo-volcanic eruptive masses. The former hypothesis seems very probable, and is confirmed by taking into account the changes of level which the land has undergone. During the periods of submergence the ice-packs detached from the Antarctic continent and driven towards the north, as at present, may have dropped the rock fragments which they carried. This is not a mere supposition; the Challenger dredgings between Kerguelen and Heard Island have brought up blocks of considerable size, which belong to the crystalline and schisto-crystalline series: granite, diorite, gneiss, &c. No one can doubt that these rocks have been carried by floating ice to the place where they were found, and we may add parenthetically, that they prove the existence of an Antarctic mass of continental land, to which Mr. John Murray has recently directed the attention of geographers. It may possibly be, however, that the fragments viewed as ancient rocks have been carried up by the trachyte and basaltic masses in their passage through the underlying strata. The typical volcanic outflows show many examples of similar facts, but nothing in Professor Roth's description enables one to decide this question. While fully recognising the care which he has taken to establish his diagnoses of the rocks in question, we may yet insist upon the great difficulties in the way of precise differentiation between the ancient and modern crystalline series. These difficulties increase with the amount of alteration of the rocks, and very often it becomes impossible to solve all doubts even with the microscope. Of this no further proof is required than the discussion still going on as to the true basis for a classification of eruptive rocks. This is not the place to carry on a controversy, but, confining ourselves to the subject in hand, we may remark that it is just in the case of rocks like those of Kerguelen, classed as of the ancient series, that the difficulties are greatest. In this way certain granular eruptive masses, which we have described, from Foul House Bay may be equally well classed as peridotic diabases or as dolerites, but their association with basalts gives greater probability to the determination we have thought it right to adopt. However it may be, we must acknowledge that in all the specimens from Kerguelen we have examined, there is not one which can be certainly referred to massive rocks of the ancient type.[1]

The superposition of basalt sheets and their scoriaceous surfaces show plainly that they have accumulated like lava in successive flows. They must have been spread one over another at intervals, this periodicity of the eruptions being shown by the alveolar structure of the surface of the beds. It is evident that if these basalts

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[1] Amongst the rocks from Kerguelen submitted to us there was one without any indication of locality, collected by Mr. Moseley. This at first sight resembles those of the ancient type. The microscope shows a greyish ground-mass very like that of porphyries. Silica predominates in irregular grains, and some sections are similar to altered felspar. It cannot, however, be classed with porphyry, for microscopic examination shows a section of vegetable origin filled with quartz and micaceous substance. Hence we believe this to be a trachytic tufa, the constituent elements of which were bound up with vegetable remains by an infiltration of silica, such as the amygdaloidal rocks of Kerguelen and the fossil woods exhibit so abundantly.

belonged to the same outflow, we should not see an alternation of compact and amygdaloidal rocks. The intercalation of beds of lignite and fossil wood also proves and gives precision to this interpretation. The beds prove that the upper layers of the sheets have been exposed to meteoric agencies, and that, thanks to their scoriaceous structure, they were readily disintegrated and transformed into argillaceous matter, on which vegetation could take root and develop. The growth of large trees proves that there were long intervals of rest between the eruption of the two basalt sheets which enclose these vegetable remains.

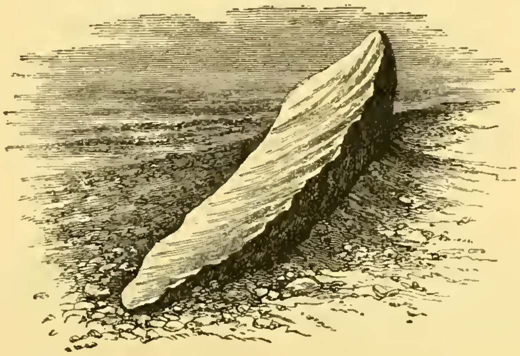
Accepting this view of the original arrangement of the basalt sheets, we must consider that Kerguelen formerly presented the aspect of wide basaltic plateaux broken only by escarpments of trachyte and phonolite. It is principally to meteoric agencies that the island owes its present shape. We have said that all the heights of one region come to about the same elevation, and that on both sides of the valleys the various strata occur at the same level. These topographical features show that the hills belonged at one time to a plateau extending over the whole region, and that these hills have been left when the valleys, which cut up and furrow the island, were carved out of the original plateau by running streams, glaciers, and atmospheric agencies. These agents, joining their powers with that of the sea, have formed the fjords and bays which everywhere run into the central mass. These ragged coasts, these cliffs and perpendicular crags and terraced mountains, in a word, the deeply trenched form of Kerguelen, are all explained by the extreme abundance of the atmospheric precipitation which beats on those barren rocks, almost destitute of vegetation. On the other hand, we have seen that glacial phenomena have left their mark everywhere, and added their action to that of running water and of the sea. The oscillations of the land, frequent elevation and subsidence, have also contributed to modify the shape of the island. Everything indicates that these great topographical movements and the epoch of the extension of glaciers have been subsequent to the last outflow of basalt. Finally, we must admit that the causes which have produced the vertical relief and outline of Kerguelen have extended their action beyond the present limits of the island and encircling rocks, and that the central mass is but the remains of a great denuded land. The present configuration shows this, and so does the development of vegetation in earlier periods. As Dr. Studer observes, even if we admit a higher mean temperature in order to explain biological facts, it does not suffice to explain the existence of a flora, for which a much larger land is required, in order to afford protection against the storms that now carry devastation to every part of the island. We are thus led to admit that in times anterior to our epoch Kerguelen was a vast mass of land. The topographical features that we mentioned at the beginning, and the results of soundings made by Ross, and on the "Gazelle" and Challenger, confirm this view, and point to a probable extension towards the south-west.

X.—ROCKS OF HEARD ISLAND.

After completing the exploration of Kerguelen's Land, the Challenger Expedition turned to M^{c}Donald and Heard Islands. The sea-bottom between these groups is very irregular and rocky. On the way to Heard Island the Challenger, on February 5, 1873, passed to the north of the almost inaccessible islands of M^{c}Donald. A landing was made on Heard Island, and Mr. Buchanan examined the coast and the rocks descending to the sea. This island, remarkable for its glacial and volcanic phenomena, was discovered in November 1855 by Captain Heard, in command of the United States ship "Oriental." According to the Challenger observations, Cape Laurens, the north-west point of the island, is situated in latitude 53° 2′ 45″ S., longitude 73° 15′ 30″ E.

Glacier, Corinthian Bay, Heard Island, as seen from H.M.S. Challenger.

The greatest length from north-west to south-east is 25 miles, its greatest breadth 9 miles, and its area about 100 square miles. The southern extremity, rising towards the east, forms a long and narrow promontory. The naturalists from the Challenger landed at the north of the island, in a bay designated on the chart as Whisky or Corinthian Bay. On approaching the place to the south-east of the ship the island was surrounded by great glaciers coming down close to the shore; the interior was veiled in clouds, entirely concealing the great mountain of Ben Big, about 7000 feet high, which crowns the island. The shore of Corinthian Bay is flat, and is covered with black volcanic sand, largely composed of magnetite; this sandy strip stretches for about half a mile from the sea to the head of the glaciers. The western side of the bay is formed of a continuous wall of magnificent glaciers. The island here is not wide, and a sandy plain extends across it from east to west. The volcanic sand, blown against the rocks by constant strong winds, gives rise by its mechanical action to remarkable phenomena of disintegration. Mr. Buchanan observed that the fragments of isolated rock, and glacier-borne erratics, lying on the sand of the shore, were so cleanly sliced by the particles of magnetite and augite, that they seemed to have been chiselled. The largest faces of the blocks on which the erosion has been greatest are always turned to the west, the direction from which the winds are most continuous and strongest.

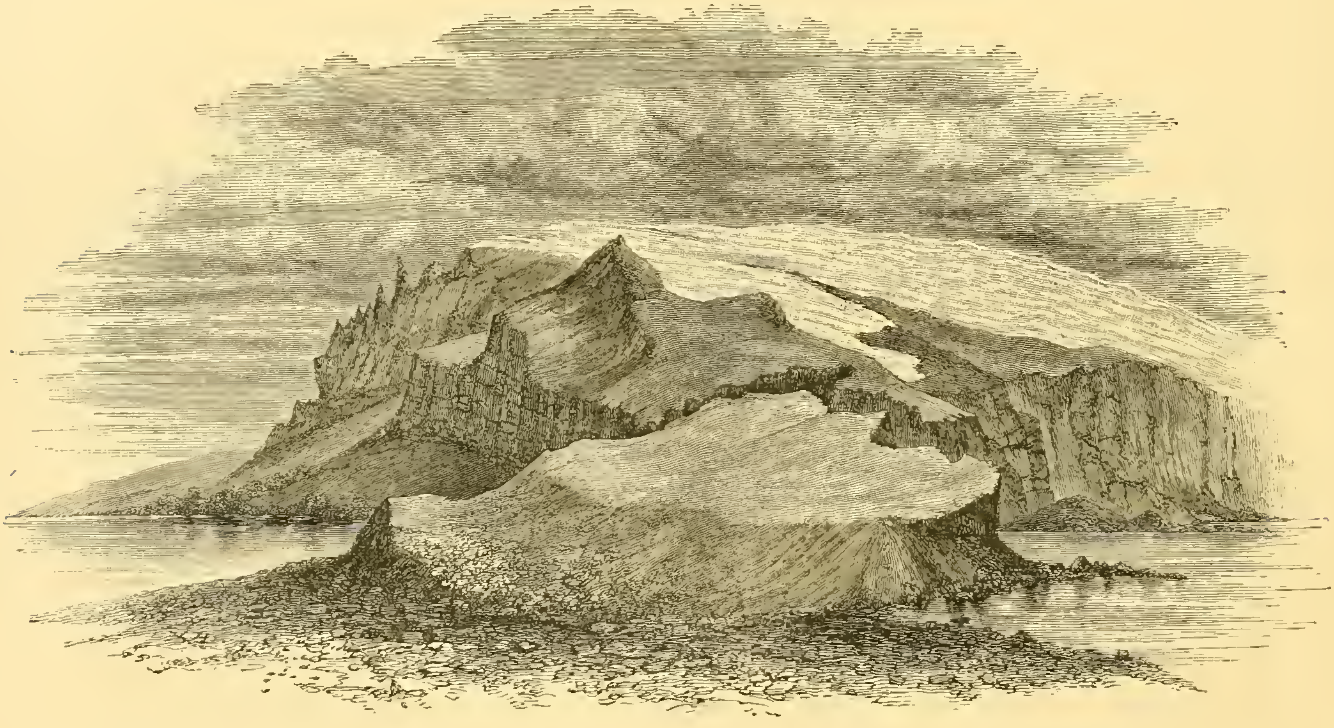


From a sketch by Mr. Buchanan, representing a rock embedded in the black sand. The side towards the west, with the high light on the woodcut, is being rapidly worn down by the sharp sand blown against it, which has cut an irregularly fluted pattern in it.

At the point where a landing was made, two promontories run out; that towards the west is formed of a high mountain rising up from the sea and cleft at the summit into two peaks, from between which a glacier descends to the cliffs on the north-west. Blocks of ice, breaking off, fall into the sea with an echoing roar. The other peninsula is covered with recent lava, the scoriaceous surface of which appears not to have been affected yet by erosive action. The flow extends from the base of a recent but greatly denuded crater, which is worn by wave action into three fantastic peaks, whose vertical walls show the successive lava-flows inclining from the centre outwards. This lava-layer spreads over the whole peninsula, and forms a row of cliffs cut out by wave-action along the northern part of Corinthian Bay. The glaciers covering the southern part have been stopped in their descent to the sea by a conical mound of scoriæ. When account is taken of the slight alteration of its surface, the lava appears relatively recent, and this fact, taken in conjunction with the great energy of denuding agencies at Heard Island, agrees well with the view of an eruption at no distant date.

All the rocks collected in the island are volcanic, and belong to the felspathic basalts. Some are massive, others vesicular; all may be viewed as derived from the lava-sheets which have spread over the island.

We shall first describe those specimens collected to the south-west of the solitary group of houses on the islands. In this place the rocks are spread out in beds, and present to the naked eye all the appearance of basalt, being black and fine-grained, with only olivine perceptible amongst the constituent minerals. Microscopically the rock is at once classed as a felspathic basalt, the minerals of the first generation being plagioclase, olivine, augite, and rather large grains of magnetite, embedded in a ground-mass of minute plagioclase and augite microliths and a vitreous base. The plagioclase sections have very sharp outlines, and can thus be determined with a precision rarely attained in the study of rocks of this nature. It is at once apparent that the plagioclase crystals occur habitually in groups of several, united more or less regularly, often parallel to *M*, and presenting all the peculiarities of certain macroscopic crystals of albite, those of Schmirn, for example, and of some crystals of labradorite. In many cases the sections of plagioclase have the form of a nearly rectangular parallelogram, with polysynthetic twins and symmetrical extinction; these sections are thus in the zone $P:k$, and, since they are approximately at right angles, we may conclude that the crystals are tabular, and terminated only by the faces of this zone. Sometimes, but more rarely, plagioclase sections are observed bounded on one side by angles of about 90°, and on the other by more or less obtuse angles formed by the trace of two edges, which may correspond to *T* and *l*, and are in general but slightly developed. The sections parallel to *M* enable the form of the crystals to be ascertained, and the optical properties determined. Sections parallel to this face appear as sharply outlined disymmetrical hexagons, which



From a sketch by Mr. Buchanan, representing the mountainous promontory forming the north-western end of the island. The top of the mountain was enveloped in cloud, below which the greater part of its sides were covered by a glacier descending to the edge of the precipitous rock cliffs, over which the ice-masses fell thundering. The sketch was taken from the shoulder of a red conical hill, against which the ice, descending from the main mountain of the island to the sea, splits and passes on both sides of it.

are bounded by traces of the faces *PyT*. That this is the case, is ascertained by the measurement of the angles and the direction of the cleavages, the latter exhibiting a line of cleavage parallel to *P*, and another, but less pronounced system, parallel to the prism. The angle of intersection of the trace of *P* and of the trace of the adjacent face is about 100°; this face is therefore *y*. The other side of the section makes an angle of about 64° with the trace of *P*, and is therefore *T*. The extinction for the section in question is negative, and takes place at 27°. The felspar accordingly approaches to bytownite. These observations have been made on a great number of sections of the rock, and each time the angular values were approximately the same. The symmetrical extinction of the sections showing albitic twins was about 40°; this value is another proof of the exactness of our determinations. The plagioclase has almost always crystallised according to the albite law, sometimes associated with that of the Carlsbad type. In some cases, also, this plagioclase is twinned according to the Baveno law. Thus two crystals of plagioclase, both twinned according to the albite law, can be observed grouped in such a way that the traces of *M* in the two individuals make an angle of about 90°. The extinction of the albitic striæ is the same for the two crystals, being about 40°, from which we may conclude that the section has been cut for both of the adjacent individuals in the zone *P* : *k*, and the fact that the extinction of the albitic lamellæ is the same in both confirms the supposition that they have a plane of this zone in common. The angular value of the extinction seems also to indicate that the section is approximately perpendicular to the edge *P*/*M*. The facts we have just mentioned thus prove the existence of the Baveno twin in some crystals of this rock, and that of pericline has also been demonstrated. Many of the plagioclastic sections show a zonary structure, especially those cut parallel to *M*, on which are observed a series of concentric zones, the inner ones being disymmetric hexagons, the outer quadrangular, representing traces of the faces *Py*. Thus the internal hexagonal zones show supplementary traces of *T*. At the beginning of their growth the plagioclases crystallised with the faces of the prism, which became smaller in proportion as the crystals formed, and finally disappeared when the last layers were deposited on the nucleus. This fact may be generalised and applied to all the plagioclases in the rock, as the prismatic faces are wanting in the greater number of crystals, or, if they are present, they play a very subordinate part.

In this basalt the felspar sections often show alterations due to the action of the magma; the angles are rounded off, the crystals often corroded, and penetrated by the vitreous mass in which they are embedded. We cannot, however, explain, by subsequent modifications, certain optical phenomena resembling the undulating extinction. At first sight one is tempted to ascribe these to the result of strain exerted on crystals already formed. But they are explained by the manner in which the hemitropic lamellæ are entangled. When observed in polarised light, a good many sections are seen to be traversed by black lines, with shaded borders, showing a certain parallelism. In other cases, when the section is turned round between crossed nicols, shadows are seen sweeping across. The difference between this appearance and that of undulating extinction does not appear at first, but, as we have just said, pressure cannot be called in, in this case. These phenomena are never seen in sections which show hemitropic striæ with great sharpness, nor in sections parallel to *M*. Sections of an intermediate zone, approaching *M*, show this peculiar extinction; on the other hand, when the sections are more in the zone $P:k$, the parallel black lines with shadowy borders appear. These observations lead us to conclude that this extinction is due to the fine lamellation of this plagioclase, the sections of which, cut more or less obliquely to the plane of twinning, must in polarised light show these undulations, or these traces of albitic lamellæ with indistinct borders. Olivine is somewhat uncommon in this basalt; it usually appears in grains, but occasionally the sections present crystallographic outlines. Amongst the latter there is one form which is hexagonal, with two parallel sides longer than the others. In ordinary light it appears quite homogeneous, but in polarised light it is seen to be divided into halves by a straight line perpendicular to the longer sides. The two halves in certain positions between crossed nicols show sharply different colours, although these are not very intense on account of the section being cut perpendicular to an optical axis. In convergent light this axis is shown to have the same position for the two halves, and to be eccentric. Everything indicates, however, that the plane of the optical axes is perpendicular to the direction indicated in the section by the trace of ∞P, which corresponds to the longer sides of the hexagon. The shorter sides should be traces of flattened domes. This section shows two cleavages: one parallel to the base, the other parallel to a pinacoid of the prismatic zone, and perpendicular to the former. More or less irregular fractures may also be observed parallel to the short sides of the hexagon, indicating a less distinct cleavage following the faces of flattened domes. The sections of olivine, sometimes little altered, are crowded with inclusions of magnetite.

The augite presents no noteworthy peculiarity, except that the crystals are often grouped. They are sometimes twinned in the ordinary way, or intercrossed with considerable regularity, although not clearly enough to show a law of twinning.

The ground-mass is chiefly composed of microliths of augite and plagioclase—the latter lamellar and giving great extinctions—and of a vitreous base, which surrounds all the minerals of the rock.

Another specimen from the same place closely resembles that just described, except that the colour is greyish, and rather large crystals of augite are visible to the naked eye. The microscope shows that it also is a felspathic basalt.

Finally, rocks from the same locality have a scoriaceous structure; they are black, and contain somewhat large vesicles. The ground-mass appears compact and fine-grained, but is sometimes altered on the surface, assuming a reddish colour, and is impregnated with limonite. Microscopic examination shows that, like the other rocks, it is a felspathic basalt. Rather large sections of augite and olivine predominate in the ground-mass, which also contains small microliths of plagioclase and of augite, with magnetite, and a vitreous base. The felspars do not attain the dimensions of porphyritic elements, and this rock presents few noteworthy peculiarities, except those due to the alteration of olivine. The sections of this mineral are, as a rule, partly filled with trichites; the spots not yet occupied by this secondary product appear clear and limpid, but in polarised light these apparently unaltered portions hardly show the colours of chromatic polarisation. We remark also that not only is the mineral full of trichites, but that while its external form remained unchanged, it was permeated by a secondary product, part of the original substance being removed. The mineral which has formed in the interior of the sections appears as groups of prismatic crystals, the summits directed towards the centre and the bases attached to the outer margins. These microliths are arranged in parallel bundles, and appear at first sight to be felspar, especially considering that we can detect in the same rock small plagioclases of undoubted secondary origin filling up cracks. Still it seems impossible to reconcile this interpretation with the crystalline forms and with the absence of polysynthetic twins, no traces of which are to be found in the prisms included in the olivine sections. The microliths in question present flattened angles at the summit, which may even appear like a terminal pinacoid. From this form, and the fact that extinction takes place almost parallel to the length, the microliths resemble certain zeolites, such as desmine and natrolite. They cannot be ascribed to the zeolites, however, for their outlines stand out too clearly, and the polarisation colours are identical, we may say, with those of the felspar microliths of the ground-mass. They might be identified perhaps with pilite. Olivine often forms in this rock very elongated crystals, which have sometimes been broken by movements of the magma.

A rock which is also scoriaceous, but contains better developed crystalline constituents, approximates in its texture to dolerite. Microscopic examination shows certain details in the structure of the plagioclase crystals which are worth noting. The sections not showing polysynthetic lamellæ are never perfectly homogeneous. They are speckled with more or less rectangular points, all of which extinguish simultaneously, and are similarly oriented. These inclusions are not isolated, as they seem, but must be united by a layer of slight thickness extending under the plane of the section. This is proved by the examination of sections of the zone $P:k$, in which polysynthetic twins appear. The polysynthetic lamellæ are not continuous, but interrupted at a certain distance, and the space left free is filled by the principal individual. Thus a section parallel to M ought to show these lamellæ in the form of quadratic inclusions; they ought to present different extinctions from the felspathic mass formed of the principal individual, and show themselves in the manner we have described. The sections of augite and olivine are in no way remarkable, except in being often corroded by the magma. Augite frequently occurs as inclusion in plagioclase. We may also mention, amongst the constituents of the rock, grains and crystals of magnetite, and a rounded fragment of hornblende surrounded by a large zone of magnetite.

Layers of volcanic conglomerate were observed near the fishermen's huts. The microscope showed this rock to be made up of basaltic lapilli, and more or less fragmentary minerals, with rather vague outlines, embedded in a light greenish mass. In the yellowish vitreous lapilli there are microliths of augite and small crystals of olivine. Plagioclase is not so common as the former minerals, but appears sometimes in the form of skeletons forked at both extremities.

A limburgite coming from the bed of a river in Corinthian Bay deserves description. This rock is greyish black, and the constituents are large enough to be recognised by the naked eye as crystalline grains of olivine and augite. The microscope proves the absence of felspar, and shows the ground-mass to be a brownish glass, enclosing crystals of olivine and augite. The forms assumed by olivine in this rock may be deduced from the microscopic sections. The hexagonal sections prove the existence of faces of the prismatic zone surmounted by a face of a sharply pointed dome. The angle between the traces of the dome is from 79° to 80°, and the value of k/k is 80° 53′. The sections are grooved with cleavages at right angles, parallel to the outlines of traces of the prism and to the base. The form of sections with a reëntrant angle shows that the olivine is often formed by juxtaposition of a certain number of crystals with parallel axes. They are often corroded by the magma. The examination of this rock tends to confirm an observation often made before in limburgites, that the best developed element in this lithological type is olivine; the augite is often in the form of microliths embedded in the vitreous mass. Another specimen of limburgite from Corinthian Bay, identical in composition and texture with the preceding, is somewhat rich in zeolites, as this kind of rock nearly always is.

The cliffs of the island contain layers of more ancient eruption. We have examined some specimens of these; they are greyer in colour and less scoriaceous in appearance than the rock last described. In one fine-grained mass the lens showed the felspathic element to predominate over the other constituents, and this was confirmed by microscopic examination. This rock is a basalt like all those of Marion Island. Microscopic preparations show large irregular or rounded sections of olivine and very numerous lamellar plagioclases, between which are embedded small irregular grains of augite. Magnetite occurs between the other constituents, and there are also a few small scales of biotite.

XI.—ROCKS OF KANDAVU, FIJI ISLANDS.

A PAPER by Professor Wichmann[1] has already made known a good many rocks collected in the Fiji archipelago by the naturalists of the Godeffroy Museum in Hamburg. He has shown that the whole series of paleo-volcanic rocks are present in these islands.[2] The more recent are especially represented by basalts and andesites. The latter, associated with fossiliferous volcanic tufas of tertiary age, compose by themselves almost all the small islands of the archipelago. According to the same author, the volcanic products of Kandavu are andesites. Professor Wichmann described some specimens taken from Mount Washington or Buke-Levu, which rises at the western extremity of Kandavu. Those about to be described came from a point to the north of the port of the island, where they were collected in August 1874 by the staff of the Challenger. All that is known about the geological nature of Kandavu is that the greater part of the island is a volcanic conglomerate of coarse structure, in which large blocks of lava are embedded. The island is covered with rounded hillocks, rising tier above tier. Mr. Moseley explains the regularity in form to the action of denudation. We may add that in Ovalau, the nearest island to Kandavu, the appearance is similar, and the rocks seem to be of the same nature.[3] According to Mr. Buchanan, all the rocks we are about to describe crop out near the port of Kandavu, and show a columnar structure.

We shall first describe those belonging to the amphibolic andesites. The naked eye distinguishes in a greyish ground-mass rather large, whitish, vitreous sections of plagioclase, and black specks of hornblende or biotite. The rock is rough to the

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[1] Beitrag zur Petrographie des Viti Archipels, *Min. pet. Mitth.*, Bd. v. pp. 1–60.

[2] It seems advisable to point out here, in connection with Professor Wichmann's paper, such geological details of the archipelago as we are acquainted with. Meinicke (Die Inseln des Stillen Oceans, p. 2, Leipzig, 1876) has summarised the mineralogical observations made on the Fiji Islands by Gräffe, Macdonald, Seemann, &c., and we may refer also to Horne (A Year in Fiji, pp. 163–170, London, 1881). According to these authors, the most abundant rocks are argillaceous and calcareous, also breccias and conglomerates, and in some places sandstone and clay slates, while basalts and trachytes form the highest summits, and more recent sedimentary rocks are deposited on the slopes. The island of Taviuni is the only one in the group which is exclusively volcanic, and this, according to Horne, is the only one of subaërial formation. But Professor Wichmann observes that the absence of tufas or of other rocks on the declivities of Buke-Levu in Kandavu seem to show that this island is not altogether of submarine origin. The rocks collected in Fiji by Gräffe (1862 and 1865), and by Kleinschmidt (1876–1878), showed that crystalline and schisto-crystalline rocks of the ancient series played a considerable part in Buke-Levu. The fossiliferous rocks there are of tertiary age. All the other islands visited by the explorers were found to be composed of andesites and basalts, and of tufas of these two lithological types. In some of them coral limestone, sometimes silicified, has been found. All these observations lead to the opinion that in the palæozoic and mesozoic epochs this archipelago formed a continent which became submerged about the middle of the tertiary period. Professor Wichmann made it evident that the data furnished by the study of the rocks of the Fiji archipelago present a great analogy from this point of view with those resulting from the examination of other Pacific islands. Contrary to the general opinion, held until very recently, that all the Pacific islands were of volcanic formation, it is now proved that several of them are built up of ancient crystalline and sedimentary rocks. In his paper on the rocks of the Fiji archipelago, Professor Wichmann has established very clearly the facts on which he founds this interpretation (see *loc. cit.*, pp. 1–8).

[3] Moseley, Notes of a Naturalist on board the Challenger, p. 301.

touch, and has a very irregular fracture. The microscope shows the ground-mass to be composed of a light yellowish or almost colourless base containing numerous felspathic and augitic microliths, and granules of magnetite. Brownish transparent scales of biotite are sometimes found.

The crystals of plagioclase are usually zonary, and twinned according to the albite and Carlsbad laws; they are generally formed of two large individuals enclosing a few extremely thin hemitropic lamellæ. In some cases one of the principal components, twinned following the Carlsbad law, is polysynthetic, while the other is simple, and presents traces of cleavages crossing at 90°. The outlines of those crystals, which are characterised by the rarity of hemitropic lamellæ, exhibit a face equally inclined to the traces of P and of M, which may correspond to a dome of the zone $P:M$ (n or c). Its trace makes an angle of about 45° with the traces of M and of P. That this plagioclase is a Carlsbad twin may be proved by the fact that in those sections where only the two principal individuals are seen, the projection of the vertical faces appears in an opposite direction in the two crystals; these twinned individuals have asymmetrical extinctions: one darkens at about 40° from the trace of M, and the other at 22°. The latter observation also proves that the plagioclase is a Carlsbad twin and is allied to labradorite. In the zone $P:k$ the angle of extinction for two adjacent plagioclastic lamellæ has been found to be from 17° to 20°, which confirms that this plagioclase is a mixture allied to labradorite. The sections of plagioclase often exhibit reëntrant angles, which in ordinary light are apt to be mistaken for indications of twinning, but examination between crossed nicols shows that the crystals are simply grouped without hemitropy, being united with parallel axes.

Hornblende plays an important part in this andesite. It has not only crystallised with the faces of the prism, but the two vertical pinacoids are often represented, and one of them even rather well developed. This mineral is frequently altered and surrounded by a black zone of magnetite; in other cases it is bordered by an aggregation of small prisms, which are also contained in the centre of the sections. This bacillary aggregate must be considered of secondary formation; the small prisms composing it are united parallel to their length, they are crossed by cracks parallel to the base, and are almost colourless, or exhibit a greenish tint. It is not easy to measure the extinction, but when this could be done it was found to be about 40°. Possibly this aggregation may be made up of small prisms of augite. They are arranged in such a way as to show a parallelism between their long axis and that of hornblende, and seem to behave almost like the fibrous hornblende which surrounds augite passing to uralite; here this paramorphosis appears to be reversed. The alteration of hornblende becomes visible not only by the zone of magnetite, or the surrounding groups of augite microliths just described, but it is accompanied by a development of biotite in the heart of the mineral. The manner in which this pseudomorphism is effected is as follows. The hornblende becomes darker in colour, the pleochroism more intense, the polarisation tints approach to dark-red tones, and the sections assume a lamellar texture, the lamellæ appearing undulated on the surface in polarised light. In fact we see all the characters of hornblende being exchanged for those we are accustomed to associate with black mica, but the form of the sections is unaltered. We shall show immediately, that biotite exists as a primary mineral in the rocks of Kandavu, and must point out the peculiarities which make it possible to distinguish this from the secondary product just described. In some cases the form of the sections gives no assistance, because both hornblende and black mica may appear in thin slices as hexagonal sections. Yet it is possible to demonstrate the secondary origin of the biotite, for, when this is the case, its hexagonal sections show lamellæ parallel to one of the sides of the hexagon; an observation sufficient to prove that the biotite is of secondary formation. A hexagonal section of biotite could not present this appearance; the lamellæ would not show themselves, and the section would appear uniform. Those lines which appear in the sections, and are caused by the union of lamellæ of biotite, cannot be mistaken for the cleavages of hornblende. Even if the characters of the mica were not so clear, this supposition could not be reconciled either with the outlines or with the direction of the supposed cleavages. The observations tend to prove that the lamellæ of biotite are piled up parallel to one of the pinacoids of the hornblende.

There is little to say of biotite as a primary mineral. At first sight it closely resembles hornblende, being surrounded, like the latter, by a black opaque zone; but its pleochroism, its pronounced lamellar structure, its reddish polarisation colours, its brilliant tints between crossed nicols, and the characteristic undulating shades on the surface of the section, prevent one from confounding this mica with anything else. It is recognised as a primary mineral by its sharp outlines, either hexagonal or in the form of a parallelogram, and by its always appearing isolated in the ground-mass.

Augite is rather uncommon; some microporphyritic sections of the mineral are of a green colour, such as it often assumes in andesites. Bronzite is of more common occurrence than monoclinic pyroxene. Olivine appears only in one of the specimens from Kandavu which were examined, where it is an accessory element. Its sections were of the usual rhombic or hexagonal form with worn outlines. It is a hyalosiderite converted into hematite, and full of trichites.

One of the specimens from Kandavu is an augite-andesite. It is a coarse-grained rock, showing to the naked eye a greyish paste, enclosing crystals of plagioclase, from 2 to 3 millimetres in diameter, and small grains of greenish augite, with a few points of black hornblende. Under the microscope this rock differs from that previously described by the predominance of a vitreous base and the presence of microporphyritic crystals larger than those of the amphibolic andesite just mentioned. Hornblende plays only a subordinate part, being substituted by augite. The microliths in the glassy base are not so numerous, but of the same species as in the preceding rocks.

Numerous and well-defined plagioclase sections are full of vitreous inclusions. Some of them show simultaneously the twinnings of pericline and of Baveno; that of albite is subordinate. The two series of polysynthetic lamellæ, which correspond in the principal individuals, cross at an angle of about 90°. The albitic striæ extinguish at 30°, a fact which indicates that we have to do with a mixture approximating to labradorite. When the sections present the lamellæ of pericline clearly defined, the extinctions for the latter are a little smaller than for the principal individual, being about 27° for the lamellæ in question and 30° to 31° for the polysynthetic lamellæ twinned following the albite law (see fig. 26).

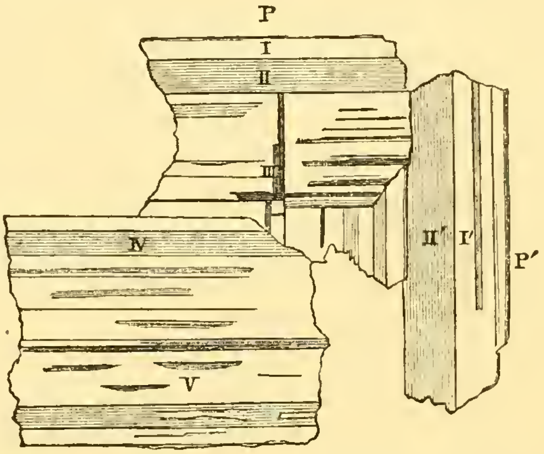

Fig. 26.—Augite-andesite of Kandavŭ. Section of twinned plagioclase.

I. II. . . .	Pericline twin.
I.′ II.″ . . .	do.
(I. II.) (I.′ II.″)	Baveno twin.
III. I. . . .	Pericline twin.
IV. V. . . .	Twinned with I. and II. having the face *P* common.

The augite presents its usual characters in augitic andesites. It is sometimes twinned polysynthetically; in other cases the sections show a fibrous structure causing them to resemble diallage. Augite contains felspar and magnetite as inclusions. Hornblende, which has a very small part to play in this rock, is represented by sections often twinned, with worn angles and surrounded by magnetite. The pleochroism of this hornblende is—

γ	>	β	>	α
yellow-brown.		brownish yellow.		pale yellow.

XII.—THE VOLCANO OF GOONONG API (BANDA ISLANDS).

THE whole Banda group, comprising twelve islands, with a total area of about 18 square miles, is of igneous origin. Volcanic activity is now concentrated in one of the two islets which protect the port of Great Banda on the north-west of the island. This volcano, Goonong Api (Malay = Fire Mountain), has been long known. The first recorded eruption took place as far back as 1629; another followed in 1690, when Goonong Api entered on a state of activity which lasted five years; and then followed the eruptions of 1765, 1775, 1816, 1820, and 1825. In November 1825 the eruptions were accompanied by earthquakes which ruined Great Banda and the islet of Pulo Neira.

The naturalists of the Challenger explored Goonong Api towards the end of September 1874, and observed a great number of facts, which will be summarised before commencing the description of the eruptive products collected up to the very summit of the volcano.[1] The mountain rises in a conical form to 1860 feet above sea-level. Neither the Dutch residents nor the native Malays attempt to scale the rugged heights save on rare occasions. M. Bickmore, one of the first to climb the mountain, has described his expedition, probably exaggerating the dangers of the ascent; the Challenger's staff, in order to study volcanic activity in the crater itself, climbed the volcano by the eastern slope. Up to within 700 or 800 feet of the summit the ground was covered with brushwood, which gave something to hold on by, and rendered the ascent, if not easy, at least practicable. On passing the upper limit of vegetation the naturalists came upon a vast accumulation of loose blocks, which rose up like a wall before them, and gave way when stepped upon. Above these heaps of broken stones the ground was firmer, the blocks of lava and volcanic ashes forming a solid foothold, but sharp angular pieces of lava piercing the bed of ashes made even this part of the cone troublesome to climb.

Exhalations of acid vapours escaped from all the cracks on the summit, and acted energetically on the lava, which was in some places entirely transformed superficially into a white substance looking like chalk. This action of the fumaroles is frequently confined to the outside of the rock, the interior preserving its fresh appearance almost unimpaired. The escaping vapours had a temperature of 121° C.; they were acid, and had a strong sulphurous smell.[2]

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[1] See Moseley, Notes of a Naturalist &c., p. 382; and *Narr. Chall. Exp.*, vol. i. p. 561.

[2] Reference will be made, in describing the volcano of Camiguin, to the high temperature at which algæ live in warm springs escaping from crevices in the lava. Analogous observations were made on Goonong Api; gelatinous masses made up of algæ were found attached round the mouths from which jets of vapour escaped. The vapour had a temperature of 121° C., and the plants were fixed to the rock where the thermometer marked 60° C. In a crack of the lava whence a sulphurous emanation escaped a plant was growing in a soil at a temperature of 38°; a foot and a half from this point the temperature of the rock was 104° C.

On the shore of the island, at the foot of the volcano, there is a girdle of coral easily accessible at low tide. The polyps are fixed to the volcanic rock, and the top of the bank rises a foot above sea-level. The island has thus at a comparatively recent period been subject to oscillations such as may be expected in a volcanic region. After these brief remarks on the geological phenomena of Goonong Api we shall describe the lithological characters of the eruptive products collected on the top of the volcano.

We shall begin with the less decomposed lavas, and afterwards deal with those which show in their altered appearance traces of the action of the acid vapours to which they have been exposed. All these rocks belong to the type of augitic andesites.

Some very slightly decomposed lavas are black, very lustrous, slightly scoriaceous, and spotted with felspathic grains. Microscopically they are formed of a yellowish base crowded with microliths of plagioclase and augite, and in this ground-mass are seen rather large sections of plagioclase, augite, magnetite, and, as an accessory mineral, olivine.

The microporphyritic crystals of plagioclase, which are vitreous, like sanidine, are sharply outlined, and are elongated following the edge, *P*/*M*, but in other cases they are less tabular, assuming the prismatic form. The most common types of twinning of these plagioclases are those of Baveno and of albite, but the hemitropic lamellæ are not numerous in the sections. The felspar sections often present the appearance of two halves joined together, resembling at first glance a Carlsbad twin, but closer examination almost always shows one or two hemitropic lamellæ—sometimes excessively thin—enclosed in one or other of the principal individuals. These striæ prove that this felspar is plagioclase. Fig. 27 shows a section of plagioclase from the rock we are describing. The section is parallel to the face *M* of one individual (I) and more or less parallel to the face *P* (zone *P*:*k*) of the other (II). It can be seen that (I) is traversed by cleavages parallel to *P*, which are parallel to the plane of union and to the plagioclastic striæ of (II). Cleavages parallel to *T* can also be seen. The angle of extinction approaches 40°. The individual (II) exhibits less regular fractures, resembling those usually seen in sanidine. It is noticeable that, as is almost always the case, only one of the cleavages following the prism is to be seen. The angle of extinction for the principal individual, measured from the intercalated polysynthetic lamellæ, is about 30°. The extinctions on *M* and *P* exceed those of bytownite, and are nearer to those of anorthite. The extinctions

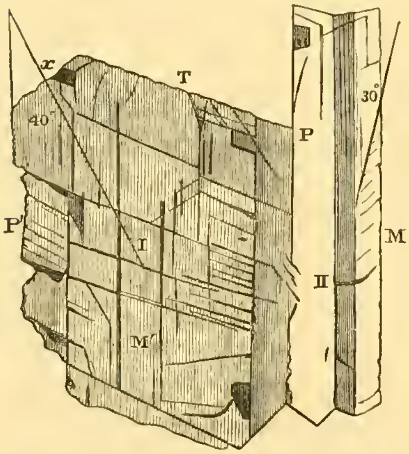

FIG. 27.—Decomposed lava of Goonong Api. Section of plagioclase.

observed between two hemitropic lamellæ in the zone $P:k$ are 32°, 21°, 19°, but in some cases they exceed 35°. These values agree with the determination just given. We see another confirmation of this in the fact mentioned above, of the rarity of hemitropic plagioclastic striæ ; it is well known that the extremes of the plagioclastic mixtures, albite and anorthite, are to a certain extent characterised by the rarity of these interpositions, or by the relative thickness of the hemitropic lamellæ.

The augite presents no very special characters ; it exhibits a tendency to form more or less irregular groups or nests, and is often twinned. The very rare sections of olivine, often occurring as inclusions in the plagioclase, are decomposed into red hematite. Magnetite is somewhat abundant. The microliths of the ground-mass, as observed above, are small crystals of plagioclase and augite, the former being often split up at the extremities.

The remaining rocks from the summit of Goonong Api have been altered by the action of fumaroles, as in the case of certain lavas from Ternate, but in those from Goonong Api decomposition is further advanced, and presents some phenomena worth describing. These lavas have the same aspect and the same lithological constitution as those just described, only they are much more friable, and covered in some places by a floury coating. One sees with the lens that the felspar crystals have lost their glassy lustre and appear porcellanous. Under the microscope the large sections of felspar show hardly any remaining trace of the original twinning, but their outlines are maintained notwithstanding the alteration that has destroyed the internal structure of the mineral. The sections are furrowed with a lacework of cracks lined with a colourless substance, in the same way as serpentinisation penetrates olivine. A few patches of the original mineral remain unaltered, but as a rule the entire section behaves between crossed nicols like an isotropic substance. The plagioclastic sections invaded by this secondary product rarely show the twins of plagioclase, one can only detect certain remains that react feebly with polarised light. These crystals often appear cracked (see fig. 28). The first explanation that offers itself to account for this strange phenomenon of decomposition is that the rock, being formed of anorthite—a plagioclase which lends itself very readily to the formation of zeolites—the alteration of the felspar would be due to a modification of this kind ; but chemical analysis proves that the substance penetrating the felspar is silica. In fact, the undecomposed augite-andesites of Goonong Api contain from 55 to 59 per cent. of silica, and when they exhibit the alteration which has been described the percentage of silica rises to 80 per cent., and, in the specimens trans-

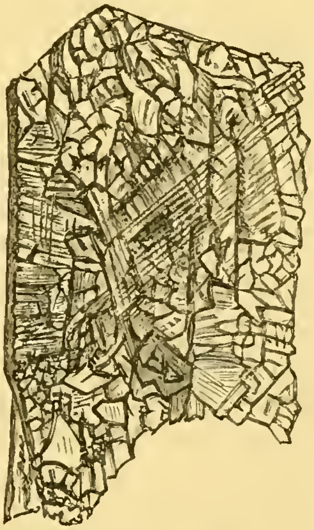

Fig. 28.—Lava of Goonong Api. Decomposed plagioclase partly replaced by silica.

formed into white material, it may even amount to 90 per cent. The substance which fills the crystals of plagioclase in this rock is thus silica. The augite sections even have not escaped this alteration; their margins appear corroded; a zone of silica, like that which we have observed in the felspars, surrounds them as with a frame, and sends ramifications through the crystals until, in many cases, the augite is transformed into a greyish isotropic mass. The augite can only be recognised by its external form, which is generally preserved, or by greenish or brownish fragments entirely embedded in silica. The vitreous ground-mass itself is subject to a similar modification in some cases, its usual yellow colour passing into grey. The outlines of the microliths are made indistinguishable, except perhaps in the case of magnetite, and all the constituent minerals seem to be embedded in the opaline mass. The siliceous matter rarely assumes the form of quartz, but here, as at Ternate, granules are sometimes seen possessing the optical properties of that mineral, or of tridymite. Quartz or tridymite is detected most frequently in the fragments covered with a coating of more or less powdery white material.

The alteration and displacement of these minerals by siliceous matter must be caused by the action of gaseous volcanic emanations, by jets of steam, and by high temperature. Amongst the vapours which attack silicates most energetically are those of hydrochloric and sulphuric acid. The latter, detected in the fumaroles of Goonong Api, can easily remove all the bases of this lava as soluble sulphates, which would readily be washed away. This is the case with the alumina and iron, while the silica, with which they were combined in the eruptive rocks, remains alone in the form of hydrate.

The alteration of felspar and augite into a substance resembling opal is a fact observed elsewhere. We may refer, for instance, to the investigations of Rammelsberg[1] on the pyroxene of Vesuvius in the lava of 1852, in which the amount of silica reached 85·34 per cent.; water was present to the extent of 5·47 per cent.; the mineral which had been altered by the action of fumaroles contained only traces of bases. Morawski and Schinnerer[2] showed that the sanidine of the trachyte from a solfatara near Pouzzolie contained 90·19 per cent. of silica and 4·19 per cent. of water. According to Blum,[3] the sanidine of Furnas is similarly changed into opal, the surface of the crystals remaining hard, while the interior is cellular and porous. Finally, Fritsch and Reiss[4] found the same modification in the felspar of a phonolitic rock of Pico de Teyde. These facts bear the most perfect analogy to those we have been describing, and they should be attributed to the same cause. The presence of quartz and tridymite, which were detected in some of the altered rocks, may be explained by their formation as products of sublimation, a mode of origin for these minerals too well known to require to be discussed here.

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[1] Rammelsberg, *Pogg. Ann.*, Bd. xlix. p. 388.

[2] Morawski and Schinnerer, Verh. geol. Reichsanstalt, p. 161, 1872.

[3] Blum, Die Pseudomorphosen des Mineralreichs, Bd. iii. p. 52.

[4] Von Fritsch und Reiss, Geologische Beschreibung der Insel Teneriffe, p. 423, 1868.

XIII.—ROCKS FROM THE VOLCANO OF TERNATE.

THE magnificent view at the entrance of Molucca Pass is well calculated to exhibit the great share which volcanic forces have had in building up the archipelago. The naturalists of the Challenger Expedition who explored these islands were greatly struck by the scene; when fairly in the straits they saw before them on the east coast alone ten volcanic cones, several being in an active state.[1] The volcano of Ternate was then in eruption, and is one of the most important in the group. It has been described in detail by Mr. Moseley, who made the ascent along with Mr. Balfour in October 1874. The rocks they collected on the summit are now to be described.

The island of Ternate, situated close to the equator, in latitude 0° 48′ 30″ N. and longitude 127° 19′ E., is separated by a narrow sound from the island of Tidore. It might be described as a huge volcanic mountain rising from the bottom of the sea and attaining an elevation of 5600 feet above its level, as determined by the Challenger Expedition. The ascent of this volcano is rarely attempted, and the nature of it was hardly known before Mr. Moseley's expedition, the results of which may be summarised thus:—

The island is formed of three superimposed cones, the highest, at the summit of which the actual crater is found, being surrounded by the second, which is in turn planted in the ancient crater that crowns the great basal cone of the mountain. After traversing the cultivated fields and woods which spread over the flanks of the mountain, one reaches the ridge of the ancient crater, at a height of 4800 feet. This crater is about 100 feet deep, and from it rises a second cone to a height of about 4850 feet, from which the cone of eruption springs. The second crater, which may be termed the intermediate, is encumbered with masses of lava thrown out by the crater of the superior cone. The solidified streams are formed of reddish lava cracked in all directions by contraction. The superior cone planted in the intermediate crater is destitute of vegetation. Its height from base to summit is 350 feet; the cliff-like slope rises at an angle of about 30°, and at the summit of the cone descends by a similar slope of 30° into the upper crater. The superior cone is not formed of volcanic ash, but of masses of basaltic lava; the blocks scattered over the surface appear very fresh, as if they had been recently ejected. Messrs. Moseley and Balfour vainly endeavoured

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[1] Amongst the volcanoes of the Moluccas we may mention, besides that of Ternate, the little cone of Hieri, an island situated in the north of the group. The cone is about 2200 feet high, circular, and about three-quarters of a mile in diameter at the base. The island of Tidore has the highest and most perfect cone (see Narr. Chall. Exp., vol. i. fig. 199, p. 594, for a view of this volcano). Its height is 5900 feet, and it is situated in latitude 0° 39′ N., longitude 127° 23′ E. The volcano of Mareh, from 700 to 800 feet in height, is formed by two peaks. The volcanic cone of Metir, in latitude 0° 28′ N., longitude 127° 23′ E., is 2800 feet high. The island of Mitara is also surmounted by a small cone, the form of which is remarkably regular. For the natural history and geographical details of these islands, see Narr. Chall. Exp., vol. i. pp. 592–600.

to explore this crater. They could only descend it to a depth of 60 feet, for the suffocating acid vapour which enshrouded them, and the difficulties of the ground, compelled them to return. They found deposits of sulphur in the crevices, and saw everywhere rocks profoundly modified in structure by the action of vapours exhaled from the volcano. The rocks about to be described were collected from the summit of this cone.

The rocks of Ternate belong to the augite-andesites, but in some cases, from the presence of olivine, they ought to be classed amongst the basalts. We shall first describe the andesitic lavas.

The most characteristic specimens are slightly scoriaceous, and of a dark colour; the naked eye and the lens only show some vitreous or white points which are crystals of plagioclase. Microscopically the rock is vesicular; the matrix, chiefly formed of vitreous matter, is devitrified here and there by spherulites, and numerous plagioclase microliths are scattered through the brownish glass.

The large sections of plagioclase are zonary, and full of vitreous inclusions; they exhibit at the same time the twins of the albite and pericline law. Sections, where the lamellæ are twinned following the albite and the pericline laws, appear clearly defined and intercrossing each other at right angles (also parallel to k), and give symmetrical extinctions of from 20° to 16°. These values show that we are dealing with a plagioclastic mixture which approaches labradorite.

Most of the augite sections are twinned polysynthetically. The lamellæ, often resembling those of plagioclase, are sometimes very numerous and closely packed, giving some sections of this mineral a fibrous appearance. The central part of the augite is often the most lamellated. Twinned lamellæ are sometimes noticed in the form of two triangles meeting at the apex, and thus resembling the well-known clepsydra structure which occurs in this species. A rather long augite crystal cut nearly parallel to ∞Ꝑ∞ showed these lamellæ closely packed in bundles at the centre, but spreading out by the addition of more lamellæ towards the extremities of the section. They thus present an appearance like a sheaf bound tightly in the middle, and show considerable analogy to the internal structure of augite just referred to. The pleochroism = γ greenish, β yellowish. This pyroxene has a great angle of extinction; the hemitropic lamellæ intercalated in the principal individual extinguish at 50°, and the large crystal itself at 44°. The cleavage is not well marked, doubtless because the slices cut off this somewhat scoriaceous rock are not so thin as those obtained by polishing a more compact mass. Magnetite, presenting no noteworthy peculiarity, is also an essential constituent of this andesite.

Some other specimens, which must also be classed with the andesites, resemble that just described very closely in their microscopic characters, only the ground-mass is darker, more iridescent, and less vesicular. There are some minor differences also which must be referred to in detail. Fig. 29 shows a section of plagioclase with hemitropic lamellæ, following the albite law. These belong to two principal individuals, which mutually penetrate each other, and present, each in its turn, a larger development in the different parts of the section. The two principal individual crystals, which sometimes form the groundwork and sometimes the lamellæ, are twinned in the following manner:—

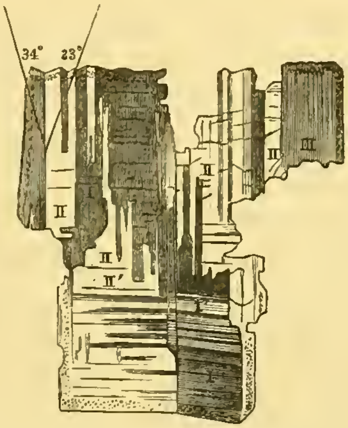

Fig. 29.—Andesite of Ternate. Section of plagioclases, albite, pericline, and Carlsbad twin.

I. II. . . .	Albite twin.
I. I.′ . . .	Pericline do.
II. II′. . . .	do. do.
III. (I. II.) .	Carlsbad do.

Cleavage parallel to the face *P* is noticeable in both individuals. This is shown in the figure by lines sensibly perpendicular to the albitic lamellæ. Extinction takes place at 33° to 34° from on the trace of *M*. The polysynthetic lamellæ following the pericline law (I′. II′), extinguishing at 27°, meet at an angle corresponding exactly to the trace of *PP′*, which is clearly indicated at the lower part of the figure. The third individual (III), joined to the preceding group in the plane *M*, must be considered as forming a Carlsbad twin with (I. II); in fact, this individual gives an asymmetric extinction at 20°.

The augitic sections in this rock show strong pleochroism, recalling hypersthene by the tints observed. We have:—

α β	$> \gamma$
reddish yellow.	greenish.

The form of the augite crystals is not that usually found in andesites, the sections being terminated by an obtuse summit very like those of bronzite. This mineral is sometimes twinned, and the value of its extinction never allows any doubt regarding its correct description as monoclinic pyroxene. The rock we describe has the general characters of an augite-andesite; it contains, however, small hexagonal or rhombic sections of olivine. The ground-mass is a base, enclosing a great number of felspathic microliths, appearing like belonites, and magnetite, which also occurs as inclusions in the constituent minerals.

Another specimen of augite-andesite contains zonary sections of felspar, parallel to *M*, which allow the extinction to be measured accurately. They show that the plagioclase is labradorite (extinction 23°) at the centre, and bytownite (extinction 29°) on the edges. The rock is altered on the surface, and covered with a whitish layer, to which we shall return presently; the undecomposed portion contains 55 per cent. of silica.

A specimen, which must be classed as basalt, presents just the same kind of surface alteration into whitish material; it has been so much decomposed by the action of fumaroles that only felspar and a few grains of olivine can be distinguished. Microscopical examination shows a number of large and sharply defined crystals of olivine with the angles of this mineral and cleavages $\infty\breve{P}\infty$, OP. Augite has a reddish tint, more common for this mineral in basalt than in augite-andesites, where the colour is usually green. It occurs in large microporphyritic crystals, and is often found as microliths in the ground-mass, frequently in small prisms forming a zone round larger crystals of the same kind. The plagioclase crystals are twinned according to the albite law, and sometimes according to that of pericline. Sections showing both systems of lamellæ very clearly, and almost parallel to *k*, give extinctions from 30° to 35°, measured from the trace of *M*. This extinction angle classes this felspar near labradorite. The ground-mass is that of an ordinary felspathic basalt.

The action of fumaroles has so penetrated the specimen we are about to describe, that, were it not for its density and structure, one might take it at first sight for a fragment of pumice. Microscopically the alteration appears in the following manner: the ground-mass is composed almost entirely of a quartzose aggregate, in which no well-formed crystals are to be seen, but only grains of plagioclase and augite traversed in every direction by cracks, the augite especially. Some remains of olivine crystals may sometimes be seen. The rock is sprinkled with little brownish patches of a substance occurring also crystallised in small prisms, the appearance and arrangement of which strongly resemble sagenite; but they are so small, so opaque, and so entirely surrounded by the ground-mass, that it is impossible to determine their nature with certainty.

XIV.—ROCKS OF THE PHILIPPINE ISLANDS.

A. *Rocks from the Volcano of Camiguin.*

The island of Camiguin, on which the volcano about to be described is situated, belongs to the Philippine archipelago, one of the most remarkable centres of eruption on the globe. These islands form a link in the great volcanic chain, which, embracing the Kuriles, Japan and Formosa, passes through Mindanao and Sangir, and runs out towards the Moluccas, dividing there into two branches, one of which trends towards Java while the other stretches eastward to meet New Zealand.[1]

Several of the Philippine Islands have lately been the subject of important geological observations, and to these we shall have occasion to recur. Professor Roth has given an account of the geology of the archipelago in an Appendix to the narrative of the explorer Jagor.[2] This work exemplifies the great erudition and precise knowledge which distinguish this geologist. I wish to mention very specially the results obtained by Von Drasche during his scientific voyage among the Philippines;[3] and, finally, the excellent monograph, published by Professor Oebbeke, on the rock specimens collected on these islands by Professor Semper.[4] In spite of the peculiar interest which ought

New Volcano, Camiguin Island.

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[1] In considering in more detail the relations of the Philippine archipelago to the neighbouring lands, it can be connected with a chain of islands which commences at Formosa, passes through the somewhat scattered groups of the Batan and Babuyan Islands, and runs on to Luzon. At this point the great chain breaks up into a series of secondary chains, which lead to the Sunda Islands. The group of Busuanga and the island of Palawan trend towards the north point of Borneo; the western portion of the peninsula of Mindanao and the Sulu Islands seem to link themselves to the north-east end of Borneo; Luzon, Samar, and Mindanao lie on a curve, the convexity of which is towards the Pacific Ocean. To the south of Mindanao comes the chain of the Sangir Islands, which advances towards the Celebes and the Talant Islands. These latter stretch towards Halmahera. See F. S. Hahn, Insel Studien, p. 49, Leipzig 1883.

[2] Fr. Jagor, Reisen in den Philippinen, Berlin 1873; appendix, p. 333: Ueber die geologische Beschaffenheit der Philippinen. In this notice by Professor Roth are condensed all the observations on the geology of this archipelago which had appeared before the publication of Jagor's book; it contains, besides, a large number of personal observations on the lithology and mineralogy of these islands.

[3] R. von Drasche, Fragmente zu einer Geologie der Insel Luzon, Wien, 1878.

[4] K. Oebekke, Beiträge zur Petrographie der Philippinen und der Palau-Inseln, Stuttgart, 1881.

to attach to the volcanoes of this archipelago, and the somewhat advanced state of our knowledge concerning the geology of the great islands constituting it, scarcely any precise details were known of the lithological nature of the island and volcano of Camiguin. The specimens collected by the Challenger naturalists make it possible in a certain measure to fill up this blank.

The study of the products of the volcano of Camiguin is, as will be seen, very closely related to the study of the substratum on which it has been formed, accordingly it will not be useless to give a short sketch of the geological constitution of the archipelago. As we have just said, some recent volcanic rocks of this group have been worked out by various able geologists, but the examination of the rocks of the subsoil and of the sedimentary formation have not been the object of such detailed researches.

It has nevertheless been established that the greater part of the underlying rocks of the Philippines belongs to the schisto-crystalline series; on these the sedimentary beds are deposited, and the latter, which are partly to be referred to the eocene period, are in their turn covered over by more recent deposits. There are, besides, to be observed some raised coral reefs, sometimes containing mollusca belonging to a species still living in the Pacific.

Finally, certain eruptive products, which are, according to von Richtofen,[1] later than the nummulitic limestone, are overlaid by deposits that must be referred to the present period. Some of the rocks found at Luzon and Zebu contain fossils of an older period.[2] When describing the rocks of Zebu, it will be shown that certain eruptive rocks of that island ought to be referred to the pre-tertiary series. The existence of granite in the archipelago is a fact of very great importance, and must be taken into account in explaining the origin of the material ejected by the volcano of Camiguin. Von Humboldt[3] points to the north of Luzon as containing masses of that rock. In the same region Jagor collected rocks of the granitic type, but he did not see them *in situ*, his specimens consisting of rounded pebbles. In other parts euphotide, serpentine, diorite, spilites, and epidotiferous rocks have been observed. Crystalline schists, gneiss, mica schists, amphibolites, and chloritic rocks, associated with the older eruptive series, play a more conspicuous part in the geological constitution of the island than do the recent volcanic formations. It is to these ancient schisto-crystalline rocks that certain well-known metalliferous deposits in the Philippines belong.[4]

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[1] In Roth, *loc. cit.*, p. 334.

[2] *Ibid.*, p. 333.

[3] See Humboldt, Kosmos, vol. vi. p. 405.

[4] Roth, *loc. cit.*, p. 334. The existence of ancient crystalline rocks in the Philippine Islands is pointed out in several passages in Professor Roth's memoir. R. von Drasche in his geology of Luzon admits that the gneissose rocks, the diabases, and the gabbros form to some extent the framework of the southern part of the island.

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These general remarks on the geological nature of this archipelago will suffice as an introduction to the description of the volcano of Camiguin.

This small island is situated between Siquijor and Mindanao, to the north of the latter island, and 80 miles east of Zebu. The volcano of Camiguin, which stands hard by the village of Catarman, was still in an active state when the Challenger Expedition explored it in 1875. It was then re-entering upon a period of repose, after the terrible eruption of 1871. According to the account of that catastrophe, which we borrow from Professor Roth,[1] the islands of Bagol, Zebu, and Camiguin had for some months been suffering severely from earthquakes, until, on the 1st of May 1871, about five o'clock, a mountain near Catarman was rent open; a central cavity appeared, from which ashes and stones were projected amid explosions and clouds of smoke. An elliptical crater was formed, which measured 1500 feet along the major axis, 150 along the minor, and attained a depth of 27 feet. At seven o'clock a second eruption occurred; but, like the first, it sent out no lava streams. After this catastrophe almost all the inhabitants, to the number of 11,000, deserted the island. According to the details furnished by J. G. Gray of the Royal Navy,[2] eruptions took place only in July, and the phenomena of internal activity continued for nearly two months. The hill was entirely formed during this eruption, and according to Mr. Gray it was about two-thirds of a mile in diameter, and 450 feet high. When, in 1875, the naturalists of the Challenger touched at Camiguin with the intention of studying this volcano, its summit rose to a height of 1950 feet. The volcano is situated close to the shore. Its form is that of a dome, resembling, according to Mr. Buchanan, some of the small volcanoes in the Auvergne. When it was explored all traces of a crater had disappeared, neither pumice nor scoriæ were found; the rocks were still incandescent at a dull red heat, and, by night, the mountain was seen crowned with glimmering light. Hot springs gushed from all the crevices at the foot of the volcano,[3] and fumaroles were to be seen everywhere. The vapours which escaped from these had effected profound changes in the neighbouring rocks. According to the observations of Buchanan and Moseley, who collected the specimens we are about to describe, the volcano is situated

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[1] Roth, *loc. cit.*, p. 335. This note on the eruption of the volcano of Camiguin appeared in the *Spenersche Zeitung*, No. 167, 1871.

[2] Hydrographic Notices, No. 8, London, 1872.

[3] It is not within the scope of this description to report the very interesting observations which were made at the volcano of Camiguin on the temperature conditions under which certain low plants live. For this point we refer the reader to Narr. Chall. Exp., vol. i. p. 654; but the interest which, from a geological point of view, arises from these questions induces us here to recapitulate the results. At places where the temperature of the hot springs reaches 65° C., the presence of algæ was not observed, but on some blocks that were bathed by the hot water, and rose above the level of the current, greenish spots were noticed. A little below the source algæ were found abundantly in a small pool into which the water fell, and still retained a temperature as high as 38° C. Still lower they were seen growing in the middle of a brook, whose waters reached 45°·3 C., the highest temperature at which these plants were observed to exist at Camiguin. The resistance which these organisms offer to high temperature is the more interesting, since thermal waters are almost saturated with the various salts that result from the decomposition of the rocks they traverse.

on slightly undulating and greatly denuded strata, formed, as can be seen on the shore, of beds resembling trachyte. We shall now describe the lithological nature of the eruptive products that constitute the volcano.

The rocks collected at Camiguin belong to the andesite type; sometimes, as we shall show, augite predominates in them; in other instances hornblende seems to play the leading part, but, in all cases, these two bisilicates are present, and the transition between the amphibolic and pyroxenic andesites is gradual. We shall therefore describe both types together. In general, these rocks are very close grained; the constituent minerals are readily detached from the mass; the colour is greyish passing into reddish on alteration; when the rock is more massive, it is a little darker. With the naked eye or the lens it is possible to distinguish only some whitish glassy grains, which are plagioclases; blunted crystals of black hornblende, or patches of augite approaching a greenish tint, are sometimes seen.

Microscopical examination shows that these rocks belong to two types of andesites, the amphibolic and the pyroxenic, passing from the one to the other through all stages; in some instances, by the presence of olivine, they are allied to the basalts. In all, however, the microtexture and mineralogical composition remain much the same. In a ground-mass, composed chiefly of small prismatic crystals of plagioclase and augite, united nearly always with a colourless glassy base, are embedded large fragments of plagioclase, augite, generally in greenish grains, hornblende without any crystallographic outlines and of a yellowish brown hue; and, lastly, biotite, bronzite, and especially magnetite, which is scattered in small sections everywhere, both in what we call the paste and in the sections of the above-named minerals.

Having now indicated the microscopical texture and the constituent minerals, we shall describe the characters which each of them presents under the microscope. Plagioclase is incontestably the most important and interesting mineral in the andesites of Camiguin. The adjoining figures represent some of the sections of these felspars.

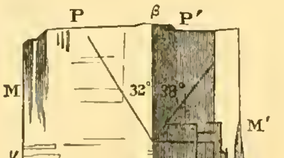

Fig. 30.—Andesite of Camiguin. Section of plagioclase, albite and pericline twins. $\frac{1}{20}$ crossed nicols.

The group represented in fig. 30 shows two individuals twinned according to the albite law. The principal individuals are joined following M; one observes the repetition of I and II reciprocally intercalated in each of the two individuals. In the lower part of the figure, the reëntrant angle α is formed by the traces of P of I and II. In the upper part the obtuse angle is 7° 50′. The double angle of extinction is 70° (32°–38°); γ indicates intercalation of lamellæ following the pericline law. The intercalation of these lamellæ shows that the section is very nearly perpendicular to the edge P/k.

Another mode of grouping is seen in fig. 31; the face *M* of II is superposed on the face *P* of I. This section is nearly perpendicular to the edge *P*/*M* of I; other forms of twinning and different groupings can be seen, such as are represented in fig. 32.

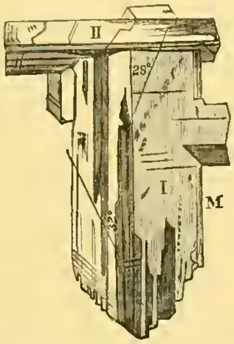

FIG. 31.—Andesite of Camiguin.
Section of plagioclase, nearly perpendicular to *P*/*M*.
$\frac{1}{30}$ crossed nicols.

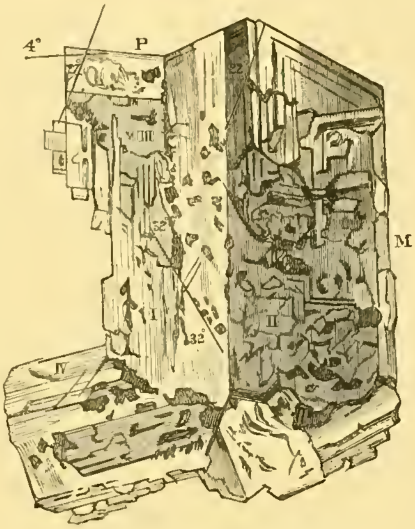

FIG. 32.—Andesite of Camiguin.
Section of plagioclase, Baveno, albite, and pericline twins.
$\frac{1}{20}$ crossed nicols.

This (fig. 32) shows I, Baveno twin; II, twin crystals of albite; I and III, twin crystals of pericline; I, IV, Baveno twin.

Fig. 33 shows I and II Carlsbad twin and one of albite; the extinctions for I are 35° on the average (32° to 38° for *a*, and 32° for *b*). The section then approaches the face *x* for this individual. The individual II extinguishes at 10° for *a* and 6° for *b*; therefore the section for II approaches the face *P*.

FIG. 33.—Andesite of Camiguin.
Section of plagioclase, albite and Carlsbad twin.
$\frac{1}{50}$ crossed nicols.

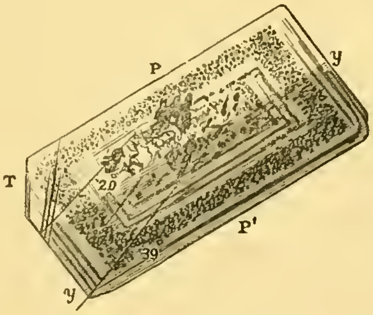

FIG. 34.—Andesite of Camiguin.
Section of plagioclase following *M*, pericline twin.
$\frac{1}{60}$ crossed nicols.

The section shown in fig. 34 is parallel to *M*, and shows a pericline twin. The two individuals are joined in the plane of the rhombic section; as the figure shows, this plane is visibly inclined towards the face *P′* in the same direction as the extinction, which is negative and of 39° for one individual, for the other 20°.

The principal characters of the plagioclase in the rocks of Camiguin may be summarised as follows. The optical properties of this mineral, its structure, groupings, and twinnings, indicate that it represents a plagioclastic mixture intermediate between oligoclase and labradorite. One of the most interesting features of this felspar is, that this mineral has crystallised in these rocks with numerous and very well-developed faces; the traces of *M P T l x y* can be seen in the sections. This abundance of faces is a somewhat rare occurrence, and one to be noticed. The zonary structure is no less remarkable; it manifests itself in all the sections, one may say. For the external and internal zones there are found extinctions of very different values—which point to variations in the chemical composition of the magma at various stages in the growth of the mineral in question. Generally speaking, the extinctions for the internal zones occur at less angles than for the external. We have therefore to admit that the acidity of the magma has been decreasing in proportion as the felspar has gone on developing. In certain cases the various layers of which the crystal is formed have extinctions whose values gradually rise from the central zones to the periphery; in these cases the section presents undulating extinction. This zonary structure is, moreover, characteristic of the intermediate felspars—oligoclase, labradorite, and above all of andesine. No less conspicuous are the twins and groups of which our figures furnish some examples. These plagioclastic sections are almost always striated, following the albite law; often the hemitropic lamellæ are very thin, and appear as simple lines. Twins following the pericline and albite laws are often seen in the same section, sometimes that of albite only. In this latter case the plane of union between the two individuals often appears indistinct. The form of the sections is very variable; some are seen to be symmetrical, with two opposite angles blunted; they are more or less parallel to the face *P;* the more or less rounded lines are the traces of *l* and of *T.* The sections with asymmetrical contours are generally cut in a plane very nearly parallel to *M;* nevertheless, thanks to the crystalline faces of this plagioclase, we sometimes also notice sections that are parallel to *M*, and have a symmetrical appearance. They can always be distinguished from the first (sections parallel to *P*), because the cleavages are not equal, nor are they equally inclined to one another, as is the case with prismatic cleavage. Moreover, the trace of a face may be observed, which makes with one side, alternate or adjacent, an angle approaching a right angle. The face *h* not being known, one may say, in the felspar in question, the conclusion ought to be that we are here dealing with *y*, which again proves that the crystal has been cut in a direction coinciding with *M*, or approaching that plane. The felspathic microliths of the ground-mass yield extinctions that appear to refer the felspar to labradorite.

Augite is one of the most constant minerals in these rocks; it is found in the pyroxenic andesites, and it is also, although subordinate, always present in the amphibolic andesites. The description we are about to give applies to the augite of both types of andesite. This mineral occurs in microporphyritic sections and in microliths in the ground-mass. The augite of the first generation usually takes the shape of grains without definite crystallographic contours; often these crystalloids are found grouped at one point, where four or five may be seen together. They are traversed by fissures, which sometimes assume the direction of the cleavages; most frequently their direction is irregular. These fissures are marked out by a black coating, which might be considered as due to incipient decomposition; the outer outlines are themselves strongly marked in black, the cleavages being less pronounced; but the most striking feature is the pleochroism which gives $a = \gamma$, green; β, reddish or flesh coloured. The structure is zonary, and the sections often show twinnings of the ordinary type, or twinned groups of two individuals, referable to the type $+P2$. Magnetite may be mentioned as a pretty common inclusion in this mineral. In certain cases the augite shows also inclusions of plagioclase, but, on the whole, it is in the interspaces of the large crystals of pyroxene that we can observe these felspathic inclusions. Augite itself sometimes occurs as an inclusion within sections of olivine. We have just remarked that the decomposition of the augite betrays itself by a network of black lines, and by strongly marked outlines; when the mineral is more weathered a black nucleus is found at its centre. But another kind of decomposition occurs in the microliths of the paste, and in some large microporphyritic grains; they take on a reddish tint, due to hydroxide of iron, which sometimes makes them almost opaque.

The small crystals of augite in the ground-mass belong, without doubt, to a second generation. They are prismatic, much better formed, slightly rounded at the extremities, and, in ordinary light, almost colourless or with a greenish tinge. They are not easily distinguishable from the plagioclastic microliths, except that, when decomposed, they are charged with red ferric oxide. Augite and hornblende are frequently intimately associated in the augitic andesites of Camiguin, especially when the latter mineral shows decided indications of alteration. For instance, a prismatic section of hornblende may be seen terminated at both ends, and edged along the prismatic faces, by greenish microliths arranged parallel to the vertical axis of the crystal they surround. While the yellow amphibolic nucleus extinguishes between crossed nicols at an angle of about 15°, the small crystals of the outer zone sometimes extinguish at 40°, clearly establishing their nature as augite. In other cases no nucleus is found, only some outlines remaining to indicate the previous presence of a hornblende crystal, parallel to the vertical axis of which the small green augite prisms, by which it was replaced, are arranged. These facts, showing a phenomenon quite the reverse of an uralitisation, are more common and also more distinct as the hornblende is more altered. We may observe that small green crystals of augite also occur bordering sections of olivine, but even although this is the case the olivine is not appreciably decomposed.

Hornblende is represented in all the preparations of the volcanic rocks of Camiguin, and is at once distinguished by its yellow-brown colour, which is sometimes rather dark. Unlike augite, it is never found in the form of microliths, and it always belongs to the first phase of consolidation. The sections rarely present a sharp crystallographic outline; they are always rounded and bordered with a black aureole of magnetite interlaced with pale-green augite microliths. The crystals are often deeply indented and broken, some portions lying at a little distance. The sections show in some cases cleavages of about 124°, and hexagonal outlines corresponding to traces of the prism and of the face $\infty \bar{P} \infty$. Sections parallel to the vertical axis are frequently laminated and broken at the edges, thus acquiring a close resemblence to biotite. Pleochroism is clearly marked, $\gamma > \beta > \alpha$ being observed. This hornblende is often twinned according to the ordinary law. It is unnecessary to discuss the alteration into magnetite and the zone of augitic microliths, still the rock presents the finest examples of this decomposition. It may be followed from one section bordered with some grains of magnetite to another completely impregnated by this opaque oxide or little crystals of almost colourless pyroxene. The hornblende is sometimes zonary, and alteration has not taken place equally throughout the crystal. In such cases a sort of frame of perfectly fresh hornblende may be observed surrounding an opaque nucleus in which magnetite is accumulated. Sometimes large crystalloids of hornblende are joined, without the interposition of a matrix, to sections of plagioclase; this association, one might say this interpenetration, of the two minerals is common enough to be worth pointing out. Sometimes small prisms of hornblende are enclosed in felspathic sections, and the mineral also occurs associated with olivine. The last-named mineral does not always occur in the rock; when it appears it assumes the form of sporadic grains, sometimes grouped in threes or fours, and frequently of considerable size. Olivine does not exhibit crystallographic outlines, but it may be distinguished at a glance from augite, as it is almost colourless or of a pale pink tinge, and from felspar by the fissures which furrow its surface. Some lines of this network of fissures are clearly defined and parallel; examination in convergent light shows them to be arranged following the plane of the optical axes, the cleavage being thus parallel to the pinacoid OP. This mineral is quite undecomposed, being perfectly colourless, except at the edges of the sections, which assume a reddish tint, and it contains inclusions of magnetite and bubbles of gas.

Some comparatively rare but characteristic sections occurring in the rock should be classed with bronzite. Although very small, they are easily distinguished from augite and hornblende. They present a fibrous structure such as the two minerals just named do not possess in this rock; the colour also is rather greyish, with a scarcely perceptible red tinge. The sections are prismatic, with angular or rounded outlines, often very irregular; they give straight extinction, and some hexagonal sections remain dark during a complete rotation between crossed nicols. The basal sections show polar rings in convergent light. Pleochroism is not very pronounced, in fact one can hardly detect any difference in tint.

Magnetite is shown generally in octohedral crystals or in somewhat large grains, but when these grains are without crystalline form it becomes difficult to say whether the mineral is primary or whether the irregular sections were hornblende now replaced by magnetite.

Amongst the most interesting specimens collected at Camiguin we may mention, in the first place, some fragments the mineralogical composition and texture of which are altogether different from the andesitic volcanic products just described. The rocks now under consideration are undoubtedly granitic, and they must be viewed as portions of the underlying masses torn up and thrown out by the volcano. These inclusions are instructive, because they show the deep modifications produced by the intense caustic action of the volcanic magma in which they were embedded. To the naked eye the specimens appear milky white, speckled with brilliant scales of black mica. The white minerals have a vitreous aspect; the constituent quartz and felspar which compose this granular mass are not easily made out even with the lens. The rock looks as if it were fritted, and crumbles readily into a powder of irregular grains like those of pulverised glass or quartz. Microscopical examination reveals such decided differences of composition and structure, between this rock and those of the volcano, that it must be viewed as not belonging to the same formation as the andesites of the Camiguin volcano, but should be classed with the rocks of granitic type. Thin slices show a distinct granitoid structure in which monoclinic and triclinic felspars, quartz, biotite, titaniferous iron, and minute augitic microliths take part. At the first glance it is seen that some of the principal elements have not the microscopic appearance of the minerals of a normal granite. They are corroded, cracked, full of gaseous inclusions, and, what is in accordance with the principal features, a colourless amorphous material is found infiltrated between the constituent minerals. This substance is perfectly isotropic at the points where it is isolated, and it contains the characteristic crystals which occur in the glassy cement of sandstones vitrified by contact with eruptive rocks. In certain cases this glass appears to be cracked, and to be derived probably from the fusion of the felspar. As the elements are almost never outlined by crystallographic contours, and as they are deeply altered, specific determination is very difficult, especially in the case of the plagioclases. Sections of these felspars are widely distributed in the rock; they are zonary, and almost always show numerous fine lamellæ twinned according to the albite law; periclinic lamellæ are also sometimes seen. Other sections of triclinic felspar appear to belong to microcline or microperthite; they are slightly milky plates, in which some more or less lenticular intercalations of another felspar appear, resembling the inclusions of albite in microcline. Orthoclase appears in nearly opaque milky sections, rarely twinned according to the Carlsbad law, but, on the contrary, almost always forming a single crystalloid without interpositions of hemitropic lamellæ. The two cleavages at right angles, which characterise this species, are apparent in some cases. This felspar, which seems more altered than the plagioclase, shows yet no trace of decomposition into micaceous matter, nor of saussuritisation. The sections extinguish uniformly. It appears probable that this mode of decomposition is due to an action of a special nature. The orthoclase is often seen bordered with a vitreous zone due to the fusion of the felspathic matter. Although no vitreous inclusions are to be seen, the sections of felspar are riddled with air-bubbles. Quartz in irregular grains is recognised by its brilliant colours in polarised light, and the arms of the cross of monaxial crystals appear in convergent light. This mineral is remarkably fissured and split, being also filled with gaseous inclusions such as are observed when quartz is fused in fulgurites for instance. No liquid inclusions are to be seen, but some fine vitreous ones have been observed; these are in all probability of secondary origin. This mineral is represented in the microscopic preparations by numerous sections showing clearly all the characters of the species. Biotite appears in the form of dark-brown strongly pleochroic sections. The outlines are irregular and black, but not opaque at the edges, as is common to the hornblende of the andesites and of the basaltic lavas. This mica presents no noteworthy peculiarities, except that a number of excessively minute microliths of a very pale greenish colour are attached to the broken edges. Some of these little prisms extinguish at angles which may rise to as much as 40°; they should be classed as augite. It is also to be remarked that their long axes are arranged in directions more or less parallel to the pinacoid of the mica they surround. Augite has also crystallised as inclusions in the interior of the biotite. Here we have facts which bear a close analogy to what has been observed in the case of the hornblende of the andesites. Everything leads to the conclusion that, in the embedded as well as in the eruptive rock, the formation of the little crystals around mica or hornblende must be due to the same caustic action. Irregular granules of titaniferous iron, sometimes surrounded by a zone of rutile, are found in the altered granitic rock.

Finally, we may mention amongst the ejected rocks fragments of quartzose rocks which were embedded in the eruptive mass. These are milk-white in colour, and extremely fine grained in texture; they have a fritted appearance like the granite just described, and they are furrowed by fissures of contraction. This appearance of the specimens plainly shows that they have been submitted to intense heat. A zone of fusion marks the place where they are united to the eruptive rock; the quartzite, assuming a darker colour, passes insensibly into andesite. The alkalies present in the andesite doubtless acted upon the silica of the quartzite to produce this zone of fusion. The embedded fragments measure 4 or 5 centimetres; some smaller specimens were seen, but they have almost entirely fused, assuming an opaline appearance. Microscopic examination shows that, except in the zone of fusion, these quartzites are made up of irregular grains of quartz, without any amorphous matter. Very small greenish crystallites grouped in gerbs or fans, and imbricated scales of tridymite, are observed in the quartzites.

B. *Rocks of Zebu and Malanipa Islands.*

The few specimens from these two islands of the Philippine group which we will describe were collected by Mr. Buchanan in the course of a hurried exploration, and they represent some only of the lithological types which are characteristic of these islands. The specimens deserve attention, because these localities are rarely visited by geologists, and because the rocks allow us to extend to these islands, with great probability, the interpretation admitted for the larger islands of the group, regarding the schisto-crystalline nature of the archipelago, and the presence of ancient eruptive rocks.[1] These researches also allow us to generalise another order of phenomena, which has been observed in other islands of the group, viz. the alteration of volcanic rocks by the action of sulphurous emanations. It is well known that no fumaroles containing hydrochloric acid have been observed in the larger of the Philippine Islands, while sulphurous fumaroles play a considerable part in the decomposition of rocks in that locality. We shall see that the massive eruptive rocks of Zebu have undergone the action of sulphurous vapours like those of all other parts of the archipelago.

The island of Zebu, famous for the death of Magellan, has been long known to naturalists, since it is almost the only locality where the beautiful siliceous sponge *Euplectella aspergillum* was formerly dredged. Zebu is 120 miles long, from 10 to 17 miles in breadth, and has an area of about 1200 square miles. It is traversed from north to south by a chain of mountains, and contains deposits of lignite which are being worked.[2]

The rocks to be described were collected in the neighbourhood of the town of Zebu, where they are exposed in the bed of a river. One of them is a greenish black fine-grained specimen; little lamellæ of plagioclase are seen sparkling, with the naked

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[1] Mr. T. E. Tenison-Woods has published a resume of his researches on the geology of Malaysia, the south of China, &c. (see *Nature*, vol. xxxiii. p. 231, 1886). His conclusions with regard to the nature of the geology of Malaysia and the Philippines agree closely with those put forward by Professor Roth in the appendix to Jagor's work, and with those derived from researches on some rocks from the island of Camiguin. The vast region examined by Mr. Tenison-Woods presents a remarkable uniformity in geological structure. Granites and intrusive rocks form the lower masses, and are covered by palæozoic schists and slates. In some places beds of limestone, probably carboniferous, appear, and finally deposits of coal belonging to different formations. Marine deposits of miocene and pliocene age were also observed.

[2] For the age of the coal and lignite beds of the Philippine Islands, see Tenison-Woods, *loc. cit.*

eye, in the ground-mass, and with the lens some grains of olivine may be detected. These minerals are enclosed in a dark-coloured matrix. The rock has a plane fracture. The microscopic texture is microporphyritic, and felspar and augite are present as large crystals or as microliths. The latter, grouped in the ground-mass, belong to a second generation. Olivine often appears in rather well-formed crystals. The felspathic sections exhibit the interesting peculiarity of being sometimes twinned according to the Baveno law; two individuals with plagioclastic striæ are joined at right angles, and extinguish simultaneously. These hemitropic lamellæ give symmetrical extinction at 17°. Hence the felspar may be classed as labradorite or bytownite. The twin of pericline is rarely seen, and the crystals of plagioclase are generally broken and corroded by the action of the magma. They preserve their freshness only in certain parts of the section. They are usually covered with a network of viridite, which also penetrates the larger constituents of the rock. Augite appears as a rule in patches without regular outlines, and this mineral is even more corroded and broken up than the felspar. Crystals of augite are often seen broken into a number of fragments which are piled up one on the other, yet they may readily be reconstructed, for the corresponding pieces bear the form of the primitive octagon of sections perpendicular to the vertical axis. The cleavage and optical properties leave no doubt as to the determination of this mineral. It is sometimes twinned according to the ordinary law, and its pleochroism is very slight. One can hardly see any difference in the absorption of rays vibrating parallel to $\mathfrak{a}$ and to γ; both are green. The augitic sections are penetrated by the same greenish substance which forms veins in the felspars, and they are also surrounded by a zone of pyroxenic microliths similar to those of the ground-mass.

The olivine is entirely altered, and only pseudomorphs of it by serpentine are to be found, but these furnish exact models of the primitive crystals. The pseudomorph polarises in blue tones; this homogeneous tint is not that usual in this alteration product of olivine. Its sections are traversed by threads of opaque black granules arranged parallel to the cleavage. These dotted lines trace out blunt-angled squares. In the interspaces of the crystal, which sometimes correspond to the cleavages, calcite has crystallised, and from these it extends in somewhat thick veinules, which subdivide into fine ramifications, penetrating the serpentinous matter. Minute patches of calcite are also seen in the ground-mass. Magnetite occurs in rather large sections, but in this case it is never bounded by crystallographic outlines, and like most of the minerals composing this rock it shows traces of corrosion.

The ground-mass, in which fluidal structure is distinctly marked, is made up, with the exception of olivine, of the minerals which have just been described. Felspar and augite assume the form of microliths, and viridite penetrates all the interstices between them.

Another rock from the same locality showed on examination a composition and structure identical with that just described. The one detail to note is that epidote was found in yellowish grains included in the felspar. Although this mineral plays a purely accessory part, its presence has a certain significance, in relation to the determination of the age of the rock in question.

At first sight one is tempted to refer these rocks to basalt, for they have the same composition and structure, but on taking their mode of decomposition and the presence of epidote into account, it seems more natural to class them with the melaphyres and peridotic diabases. It is known besides, as pointed out in speaking of the rocks of Camiguin, that palæo-volcanic masses are represented in the Philippines. There is nothing surprising, therefore, in finding rocks of the diabase family on this island. We must, however, add that this determination as palæo-volcanic rock cannot be established with certainty in the case under consideration so long as there are no stratigraphical data to found upon.

We shall now describe the altered specimens and the secondary products formed by the action of fumaroles. One of these decomposed rocks is formed of a mass of whitish grey clay with a greenish tinge; it is friable, and may be scratched by the nail. The naked eye distinguishes small bright crystals of pyrites, and sometimes milky grains of felspar. The specimen is covered in some places with a coating of limonite, and gives out a strong argillaceous smell. Microscopic examination shows that the alteration has principally affected the ground-mass and the bisilicate, which must formerly have been a constituent, and has now entirely disappeared, giving rise to chlorite surrounding all the elements. The felspar is sometimes transformed into saussurite, granules and characteristic needles of which are found in the plagioclastic sections. The plagioclase is still fresh enough in some cases to show hemitropic lamellæ according to the albite law, and the primitive outline of this mineral may sometimes be traced out. In a section parallel to *M* traces of the faces *PyT* are seen, and the cleavage parallel to *P*, and also those of the prisms less marked. It is thus possible to estimate the angle of extinction accurately enough, and the mean of observations gave + 20° for the plagioclase. This felspar thus approximates a mixture of oligoclase and albite. The rock may be classed with diorites rich in felspar, if we admit, as is probable, that the bisilicate was formerly represented by hornblende. It is well known that the presence of oligoclase has often been proved in rocks of this type, and even albite has been observed in diorites. Epidote, of which some grains are occasionally found, also leads to this determination.[1] Numerous sections of pyrites, also a secondary mineral, are frequently observed.

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[1] We must note that epidote is found in recent eruptive rocks, for example, in amphibolic andesite (compare J. Roth, Chem. Geol., p. 351), but it is no less true that this mineral is comparatively rare in the crystalline masses of that age, whilst it abounds in the older amphibolic plagioclastic rocks.

We ascribe the decomposition of this rock chiefly to the action of fumaroles. The same explanation must also be given for the presence of gypsum associated with pyrites at Zebu. Specimens of this mineral collected in that island show a compact and whitish mass, sometimes laminated, and enclosed by a crystalline coating of pyrites; some of these crystals have the form of cubes, others of pentagonal dodecahedra. Under the microscope the mass of gypsum appears as an aggregate of entangled crystalline lamellæ, which assume brilliant colours in polarised light. Some of the sections show rectangular cleavages, and ought perhaps to be classed as anhydrite. Colourless hexagonal sections with one optical axis, and presenting all the characters of quartz, are to be seen in the microscopic preparations. These little crystals of quartz, which are often associated with gypsum, are microscopic, perfectly colourless, and contain liquid inclusions.

We have attributed the alteration of these rocks and the formation of the secondary products described above to the action of fumaroles. The effects of these emanations are generally observed in volcanic regions, and in the Philippines they occur on a large scale, for although, as stated above, there are no fumaroles of hydrochloric acid, those charged with sulphuric acid are very numerous, and perfectly explain the products of alteration we have described at Zebu.

The action of sulphuric acid fumaroles on eruptive siliceous rocks should produce gypsum, alum, hydrated aluminium, sulphate, and bianchetto, and according to the intensity and duration of the action, the alumina is eliminated or converted into sulphate. The deposits of gypsum are here explained by the decomposition of minerals of which lime is the base—hornblende, augite, and felspar, the presence of which in the rocks of the island we have pointed out. The formation of pyrites is similarly explained by the alteration of the iron-bearing minerals of the crystalline rocks. Analogous phenomena are common in many other parts of the Philippine archipelago. It suffices to recall that Mr. Semper has observed them at the sulphurous spring near Maquilin, and Professor Roth cites a great number of localities where Dr. Jagor has observed facts similar to those we have mentioned.

The little island of Malanipa, where the few rocks about to be described were collected by the naturalists of the Challenger, like Zebu, belongs to the Philippine archipelago. It lies near Samboagan, bearing N. 66° W. from that island, and has an altitude of 360 feet above sea-level.[1] The specimens examined are serpentinous rocks derived from the decomposition of peridotites.

One fragment of serpentine is traversed by veins of chrysolite; the rock itself is black and shining, spotted with green. Dark particles 3 to 4 millimetres in diameter,

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[1] Narr. Chall. Exp., vol. i. p. 605.

and presenting a metallic lustre like bastite, stand out from the ground-mass. Microscopic examination shows that this serpentine is an alteration product of pyroxenic peridotite, with granitoid texture. The olivine sections are often found altered, the mineral being almost always invaded by pale yellow or colourless serpentinous matter. The alteration has not affected enstatite so seriously; some fibrous sections of this mineral are to be seen, and the optical properties, although already somewhat uncertain, indicate a non-pleochroic rhombic pyroxene.

The serpentine in another specimen is clothed with a coating of chalcedony; the yellowish green serpentinous matter is brecciated, and the fragments cemented together by filaments of chalcedony. Under the microscope sharp angular splinters of serpentine are seen presenting the usual characteristics of this substance. There is no trace of a primary mineral remaining. The chalcedony appears either as a fibro-radial aggregate, showing the black cross of spherulites, or as a fibrous structure, composed of extremely fine needles. The association of these veins of chalcedony with serpentine may be explained by the silica eliminated, when the latter mineral was formed from the original rock.

Serpentine is not the only substance formed by the decomposition of magnesium silicates; another mineral produced in a similar way appears at Malanipa in a state of remarkable purity. The fragments in question are white and close grained, hardly to be scratched by steel, and breaking with a sub-conchoidal fracture. The surface is covered with irregular mammillations showing its concretionary nature. Chemical analysis shows that this substance is almost exclusively carbonate of magnesia, and the specimens represent a type, which is remarkable for its purity, and which possesses the mineralogical characters of magnesite. This mineral is frequently associated with altered rocks containing silicate of magnesia. Thin slices of magnesite when examined by the microscope are found to be made up of an aggregate of very small crystalline grains melting into each other, and not defined by crystallographic outlines. This greyish basis is grooved by microscopic fissures, along which larger grains of magnesite appear, with more distinct contours, and even surrounded by a slight irisation like the calcite grains in limestone. The fissures are lined by a yellowish brown fibrous coating of serpentine.

Finally, one of the specimens from Malanipa is a piece of calcareous tufa, similar to that found on many other islands, and described particularly when speaking of Fernando Noronha. The naked eye only distinguishes greenish black rounded grains of serpentine amongst the constituents of this pale yellow tufa, but the microscope shows the rock to consist almost entirely of fragments of the shells of calcareous organisms, the interiors being often lined with fibro-radial calcite. Little crystals of calcite, formed *in situ* and of indefinite outline, may be seen sparkling on the edges of fragments of shell.

XV.—ROCKS OF THE ISLAND OF JUAN FERNANDEZ.

The coasts of Chili, like all those of Western South America, have relatively very few large and profound indentations, and there are few islands in the adjoining ocean. With the exception of the Galapagos Islands, well known from Darwin's description, and those of Juan Fernandez, the only islets to be found along this coast are those of the Fjords, situated southward of the continent, and which belong to the older formations of Patagonia. The group of Juan Fernandez[1] is composed of several islands, the most important of which, bearing the name of Juan Fernandez or Mas-a-tierra, is famous from the sojourn of Alexander Selkirk, hero of Defoe's "Robinson Crusoe." With regard to natural history, Juan Fernandez has most interesting characteristics, which have long ago attracted the notice of zoologists and botanists. This islet, only a few miles in extent, is inhabited by birds and terrestrial molluscs, and covered by trees and ferns, which are not to be found on any other part of the globe, except perhaps at Mas-a-fuera, a little neighbouring islet. As just remarked, the fauna and flora of this group of islands have been already closely studied, but such is not the case with its geology, which is as yet but vaguely known.

The group is composed of Juan Fernandez, Mas-a-fuera, Santa Clara, and the little Goat Island; they are surrounded by numerous rocks, which rise to the surface at a short distance from the shore. Juan Fernandez, where the rocks that we shall presently describe were collected, is situated in lat. 33° 37′ 45″ S., long. 78° 53′ W. (Fort Juan Baptista); it measures 13 English miles by 4, with an area of 28 square miles. From the monument erected to Selkirk's memory by Commodore Powell and the officers of the "Topaze," the whole island may be seen; it is crescent-shaped, curved from E. to W.; a channel, 1 mile in width and 19 fathoms deep, divides Juan Fernandez from the islet of Santa Clara. The island rises into a peak, and is surrounded by high black cliffs intersected by deep gullies, where the most splendid vegetation is to be found. A mountain, called the Anvil (El Yunque) from its remarkable shape, surmounts the cliffs.

The rocks collected show (as already indicated by the shape of the island) that Juan Fernandez is composed of volcanic materials, but no crater nor recent flow of lava is to be seen. The shape of the island, the nature of its rocks, must cause Juan Fernandez to be classed, with regard to physiography, amongst the oceanic islands formed by the remains of ancient volcanoes, which do not any longer show the complete volcanic

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[1] For the physical and political geography of these islands, see Wappäus, Panama, New Grenada, Venezuela, Guyana, Ecuador, Bolivia, Chili, geographisch und statistisch dargestellt, p. 850, Leipzig. The natural history of Juan Fernandez, and the questions relating to the fauna and flora, are summed up in Narr. Chall. Exp., vol. i. pp. 818 *et seq.* A bibliography, almost complete, of the works on this group of islands is to be found there. See also Hahn, Insel Studien, p. 108.

superstructure, but from which the crater and accumulation of tufa have disappeared. It is therefore probable that Juan Fernandez, the other islands composing the group, and the reefs which surround them, belonged formerly to a volcano whose lighter products have been disaggregated and carried away by mechanical agencies. These islands being situated at a relatively short distance off an essentially volcanic region, it is quite possible that the former eruptions of Juan Fernandez were related to those of Chili. It has been ascertained that, when the latter country was devastated by great earthquakes, phenomena connected with those on the Chilian coast were observed in Juan Fernandez Islands. In the year 1855 thick columns of vapour, rising from the sea, were observed at the distance of an English mile from the western island, and the close proximity of a volcanic centre seems therefore to be implied.

Cumberland Bay, Juan Fernandez.

Amongst the rocks collected at Juan Fernandez by the Challenger Expedition in 1875, we have not, however, found any specimens which might belong to very recent eruptions; no tufas, no volcanic ashes are to be found, and everything seems to prove that they have been washed away by the waves and the atmospheric denuding agencies. The rocks which have been submitted to examination all belong to the basaltic type, and it seems probable that the whole island is made up of those that we are about to describe.

The rocks which form the central mass of the island appear in the specimens as dolerites or as common basalts. They have a tolerably fresh appearance, their colour is bluish grey, the fracture is even, the grain is compact, very few vesicles are seen.

With the lens some glassy white felspathic grains are to be seen; others are dark and ought to be ascribed to olivine, augite, or magnetite; the rock is slightly stained with little spots of limonite.

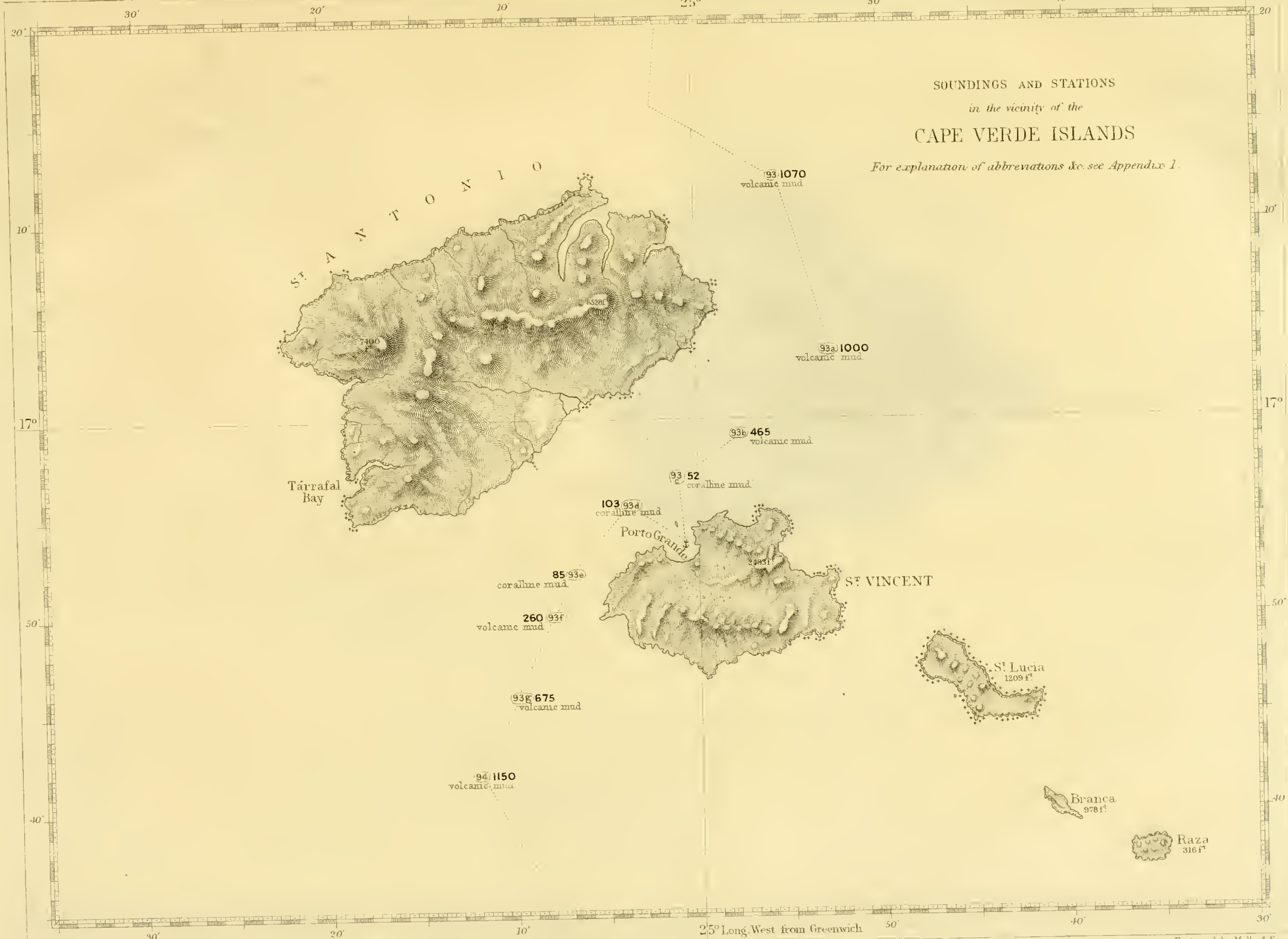
Under the microscope these rocks appear to be entirely composed of crystalline elements, the structure is that of dolerites; between the felspathic lamellæ the augite has crystallised; little sections of magnetite and some skeleton crystals of olivine are scattered amongst these minerals. The lengthened sections of plagioclase are twinned according to the albite law. It has been possible in one case to measure the extinction on a section almost parallel to the face *M*, clearly ended by the traces of the faces *x* and *P*; the value of the extinction was $-17°$. This plagioclase is consequently very closely related to labradorite. The olivine is to be seen, like the augite, in the shape of grains without distinct crystallographic outlines; it is rather difficult at first to distinguish these two minerals, but, besides the optical properties, it is observed that whilst olivine is colourless, the augite is slightly tinged with pink. The cleavages of the latter mineral are also more distinct, the olivine being more decomposed, and its grains often rounder than those of augite. The sections of olivine offer no noteworthy characteristics. We will only mention that the alteration undergone by the olivine is shown by a certain fibrosity, and that the grains of this mineral are often surrounded by a zone of small augitic microliths belonging, most probably, to a second generation. The pyroxenic element of this dolerite is, as we have just said, generally granular; more or less lengthened sections are sometimes visible, as also sections perpendicular to the vertical axis, showing the characteristic cleavage of augite. The colour of this mineral is here light pink, without perceptible pleochroism; sections parallel to $\infty \rlap{\,-}P \infty$ divided in four parts, showing the hour-glass structure, are to be observed. Some of the augite is twinned, the two individuals having for composition-plane the dome $-P\infty$. This mineral is also to be found in small granulations scattered between all the constituent elements. The magnetite occupies an important place in this dolerite; its sections are often lengthened, it frequently presents groups of small crystals, and it is found, as inclusions, in plagioclase and olivine.

Other specimens of the rocks which, together with those just described, form the central mass of the island, are not of doleritic structure; they are common felspathic basalts. They are not so dark in colour as the dolerite, their grain is finer, and the fracture is large and even; with the naked eye or with the lens, olivine alone is seen in large crystals 3 to 5 mm. in diameter. This mineral gives the rock a porphyritic structure, and is embedded in a fundamental mass of homogeneous appearance. The altered specimens show on the surface projecting peridotic crystals; the rock weathers into balls with concentric layers. The microscopic preparations show that this rock possesses the common basaltic texture; fine plagioclastic lamellæ with few polysynthetic twins are interwoven with grains of augite with indistinct outlines. Quantities of small sections of olivine are to be found in this fundamental mass, among which no glassy matter is seen. This mineral plays an important part as a porphyritic element; it is found in the microscopic preparations in large sections with usually rounded angles, bordered by a zone coloured yellow with hydroxide of iron; this zone follows exactly the outlines of the crystals, and lines all their crevices. Sometimes three or four crystals of olivine are grouped together, often several individuals are coupled with their vertical axes parallel. A striking characteristic of these sections is that they present two equal rectangular cleavages, which, at first sight, makes them look like sections of augite; the cleavage parallel to the face $\infty\bar{P}\infty$ is generally observed, but the cleavage parallel to $\infty\breve{P}\infty$ is here as clearly marked. Several sections of olivine, with hexagonal outlines, are ended by an obtuse dome of about 103°; these sections must be parallel to a face of the prism, for an optic is seen exactly in the centre of the field. The long sides of such a section are traces of the faces of the prismatic zone (prism or pinacoid). The angle of the summit does not correspond with the dome $\bar{P}\infty$ nor with $\breve{P}\infty$; it must be therefore ascribed to a pyramid. This face of a pyramid more lowered than the aforesaid domes forms the obtuse angle so often observed in the olivine of basaltic rocks.

The rocks near the monument erected to Selkirk's memory are of the same character as the dolerites and basalts just spoken of. These specimens have the same appearance as the basalts with large crystals of olivine, but this mineral is not visible with the naked eye, the rock is more vesicular; with the microscope it is seen that the texture of this rock is more like that of a dolerite. The lamellæ of plagioclase are very narrow as in the former case, symmetrical extinctions have given almost an angle of 30°. The augite is moulded on the other constituent minerals; sometimes it is to be observed with the clepshydron structure; it appears in the fundamental mass in the shape of grains. Sometimes the augite is macroscopic, and seems to take the place of olivine. The latter is again to be observed in sections with an obtuse top; this mineral is bordered by a zone of hydroxide of iron. A vein of limonite runs through the whole of the microscopic slides. Viridite has been deposited in some spots.

Among the specimens collected on the coast of Juan Fernandez it is necessary to mention a greyish very scoriaceous rock, from which stand out large crystals of plagioclase, of waxy and milky appearance, lengthened following the edge *P/M*. This rock is a dolerite with large vesicles, the only difference between it and the formerly described rocks being in its structure. Under the microscope the fundamental mass, in which the plagioclase crystals are embedded, has a doleritic structure. The felspathic crystals, with multiple polysynthetic twins according to the albite law, show large extinctions (38° to 41°), which may be compared with those of bytownite; often two large individuals cross each other. The sections of this mineral are cracked and pervaded with zeolitic matter, which forms an irregular network. This matter, which looks slightly grey when seen by ordinary light, remains obscured between crossed nicols. The augite is seen in roughly formed grains embedded between the felspathic sections. The olivine, of which large sections are seen, is uniformly changed into red hematite ; these sections, however, still show extinctions like those of unaltered olivine. In this rock, as in all the other rocks of Juan Fernandez, magnetite is often observed in elongated sections. In addition to the products of decomposition of plagioclase and olivine, small patches of olivine are to be seen. Some other specimens collected on the shore differ neither in structure nor in mineralogical composition from those just described. It is consequently to be inferred that Juan Fernandez is principally composed of basaltic rocks.

MAP I



SOUNDINGS AND STATIONS
in the vicinity of the
CAPE VERDE ISLANDS

For explanation of abbreviations &c. see Appendix 1.

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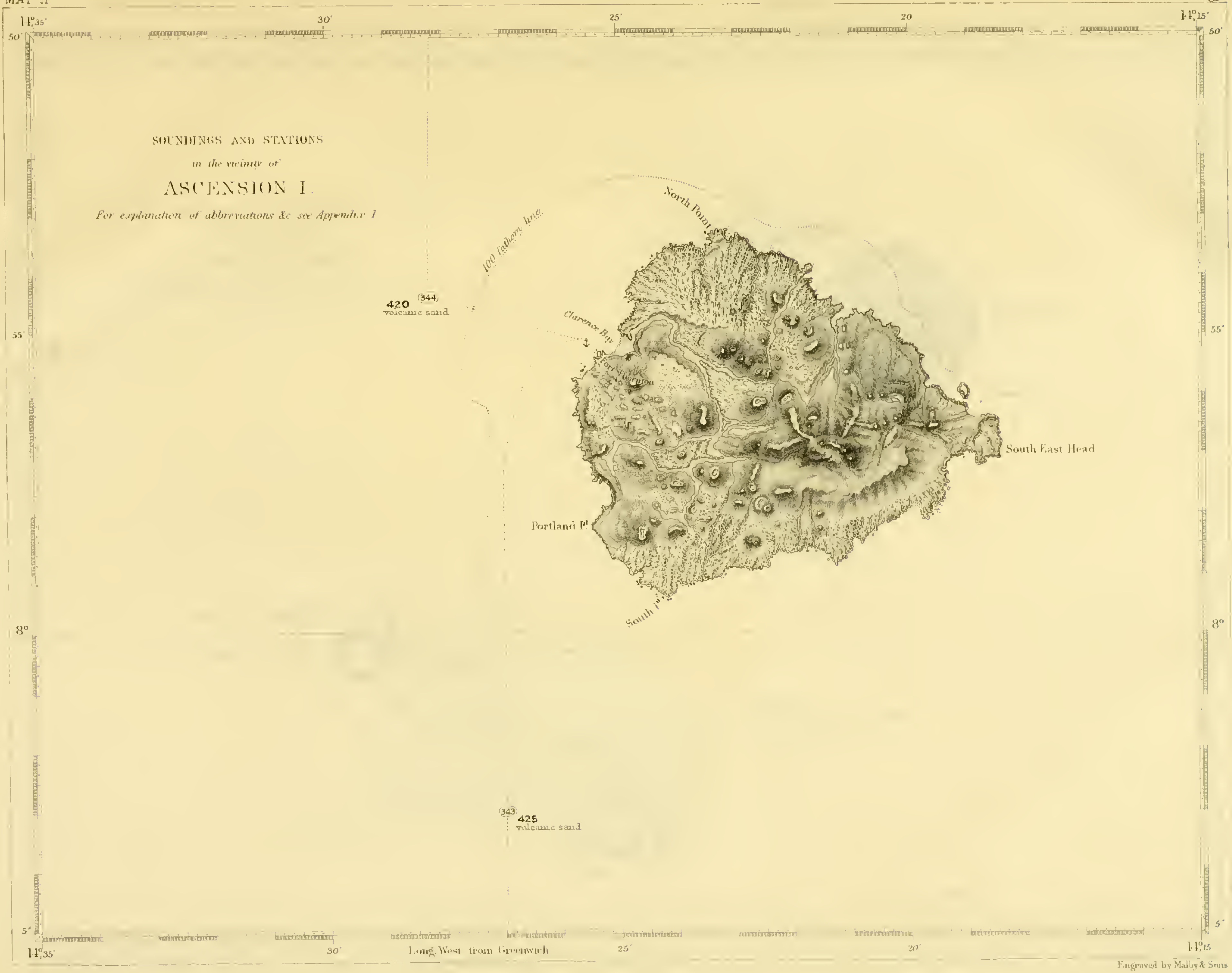
SOUNDINGS AND STATIONS

in the vicinity of

ASCENSION I.

For explanation of abbreviations &c see Appendix I



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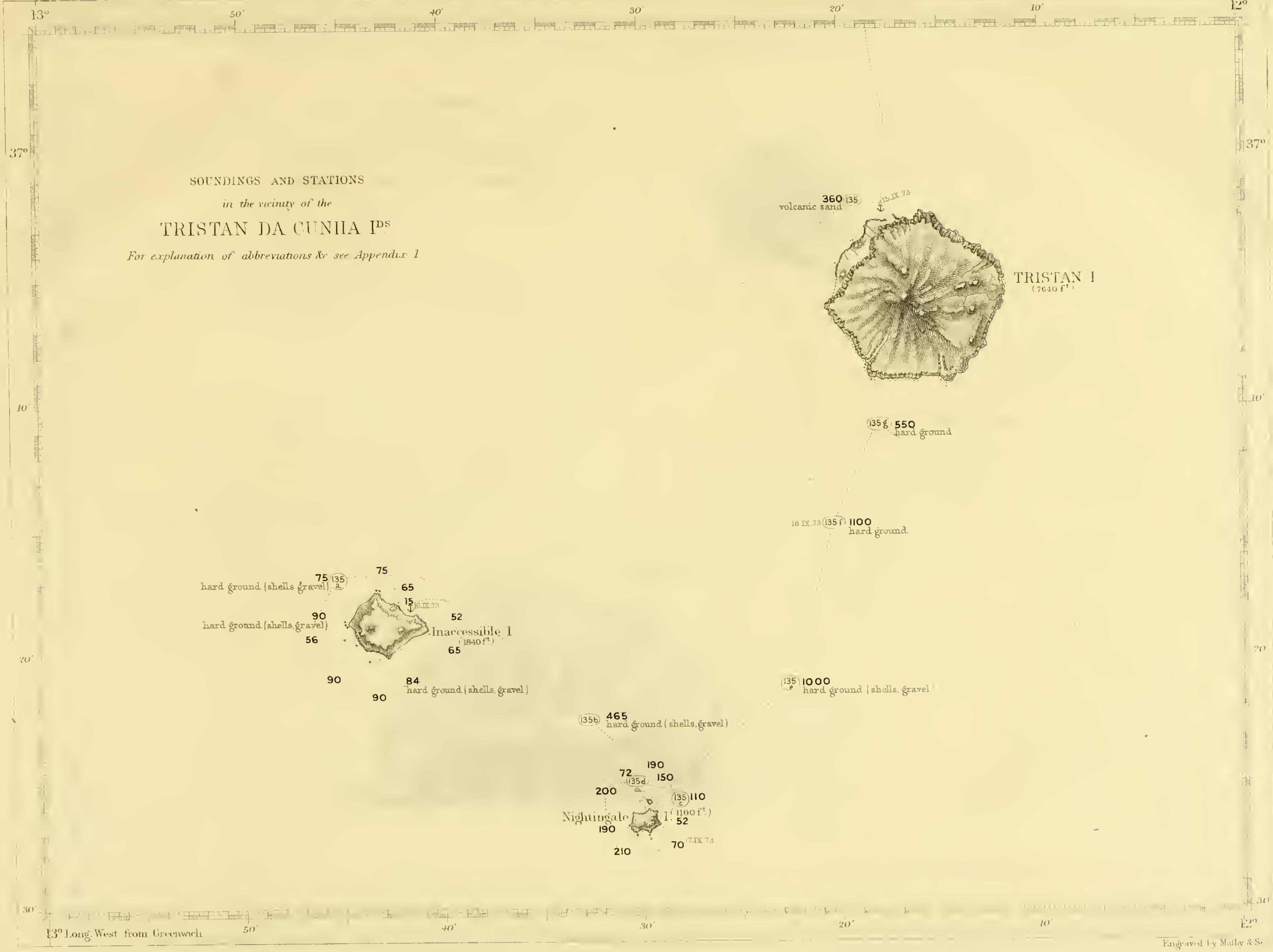
MAP III.



SOUNDINGS AND STATIONS

in the vicinity of the

TRISTAN DA CUNHA I^DS

For explanation of abbreviations &c see Appendix 1

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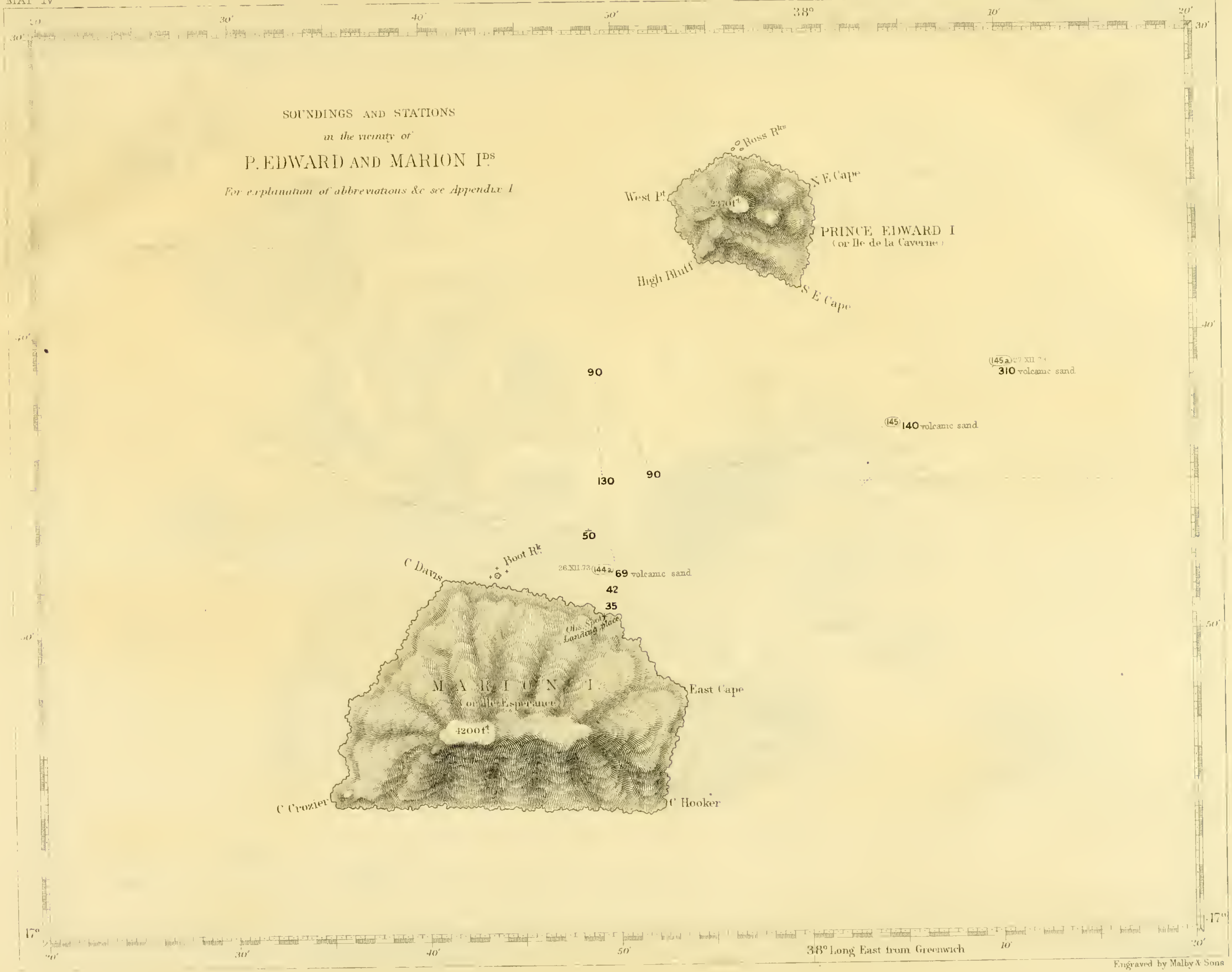

SOUNDINGS AND STATIONS
in the vicinity of
P. EDWARD AND MARION I^DS
For explanation of abbreviations &c see Appendix I

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MAP V.

SOUNDINGS AND STATIONS

in the vicinity of

KERGUELEN I.

For explanation of abbreviations &c see Appendix I

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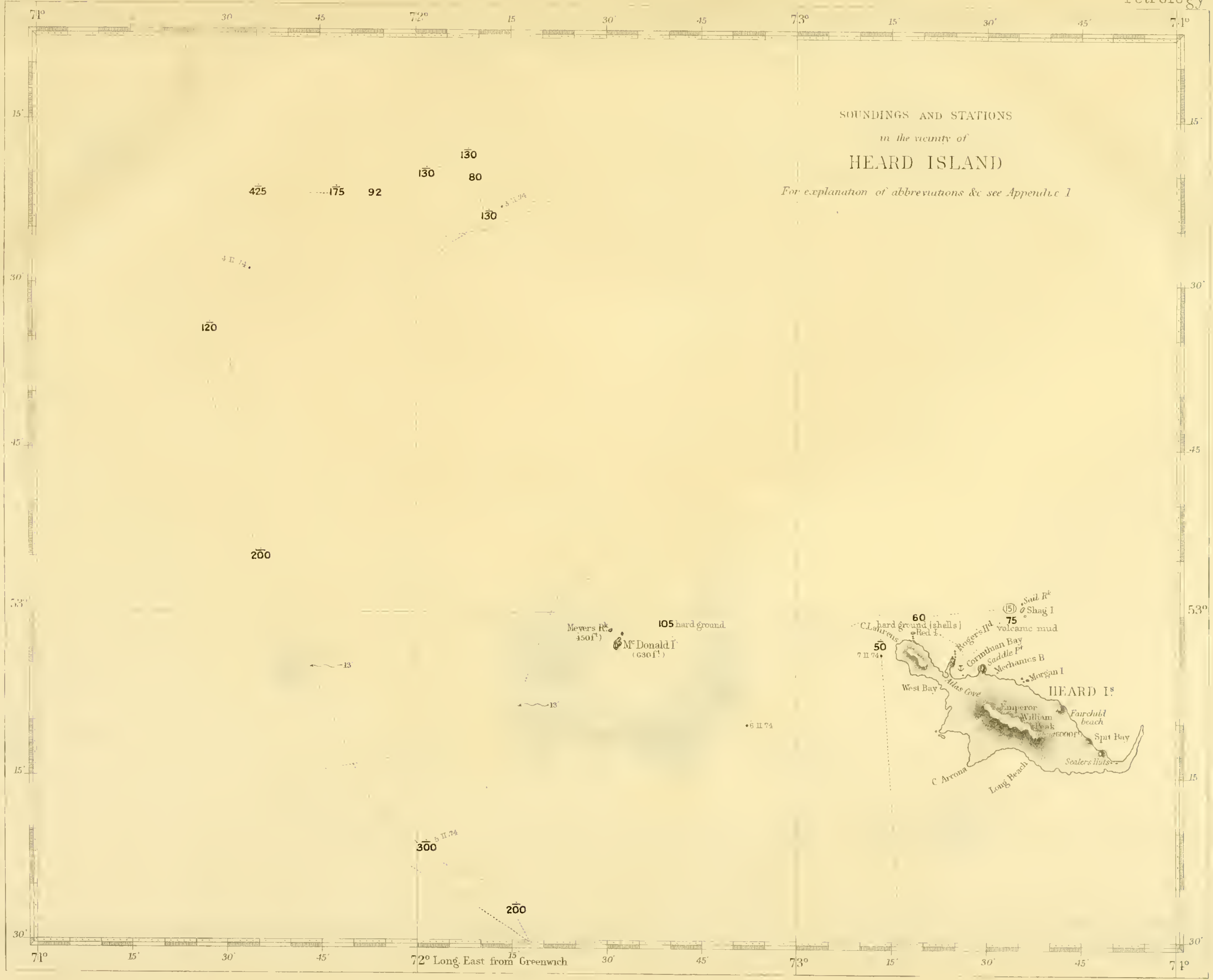
MAP VI



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SOUNDINGS AND STATIONS

in the vicinity of the

BANDA ISLANDS

For explanation of abbreviations &c. see Appendix I

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