Petrographical Notes on the Rock-specimens collected in Antarctic Regions during the voyage of H.M.S. Erebus and Terror under Sir James Clark Ross, in 1839-43.

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Introduction.

THE rock-specimens collected during the Antarctic Expedition of 1839-43 were deposited in the British Museum. A few years ago, in the course of a re-arrangement and registration of the rock-specimens n the Museum, this collection amongst others was examined, and microscopic sections of some of the specimens were prepared. Nothing, however, was published at that time, since it was found that the greater part of the collection had been practically duplicated by the rocks of the *Challenger* Expedition, which had a year or two previously been deposited in the Museum, and it was felt that mere petrographical descriptions of specimens have but little to recommend them in the absence of geological data as to the mode of occurrence and mutual relations of the rocks in the field.

During the recent revival of interest in Antarctic exploration, however, inquiries were made regarding the rock-specimens collected by the Ross Expedition, and it was suggested by Sir John Murray that some petrographical description of them would at the present time be highly desirable. The following notes on the specimens collected in Antarctic regions have accordingly been prepared.

By far the greater part of the Ross collection consists of specimens from Kerguelen Land similar to those brought back by the *Challenger* Expedition. The latter have been fully investigated by Renard: the present paper is therefore confined to the description of the rocks collected in Antarctic regions during the three voyages southward made by the Expedition, starting from Tasmania, New Zealand, and the Falkland Islands respectively.

The Antarctic Expedition of 1839-43 was undertaken by the Government at the instigation originally of a Committee appointed by the British Association for the Advancement of Science at its eighth meeting, held at Newcastle in 1838. Its main object was to advance the Science of Terrestrial Magnetism by an extensive series of observations made in high southern latitudes. An account of the Expedition is given in *A Voyage of Discovery and Research in the Southern and Antarctic Regions during the years* 1839-43, by Sir James Clark Ross (London, John Murray, 1849); and also in *Voyages of Discovery in the Arctic and Antarctic Seas, &c.*, by Robert McCormick (London, Sampson, Low, 1884). McCormick was chief surgeon on board the *Erebus*, and was mainly responsible for the collection of the rock-specimens. In appendices to Ross's book he gives brief geological accounts of the various regions visited by the expedition; but unfortunately these so-called geological accounts in most cases resolve themselves into exasperating (from a petrological point of view) descriptions of birds, for the doctor appears to have been a more enthusiastic ornithologist than geologist.

The Expedition started from Chatham in September 1839, and after visiting Madeira, the Cape Verde Islands, St. Paul's Rocks, the little island of Trinidad off Brazil, and St. Helena, at all of which places magnetic observations were made and a few rock-specimens collected, arrived at the Cape of Good Hope in March 1840. Thence it proceeded to Kerguelen Land, and after spending two months on that desolate island, reached Tasmania in August. Here the Expedition remained until November, when a start was made on a voyage into Antarctic regions.

I. First Voyage Southward.

In the first voyage southward, the first land visited by the Expedition after leaving Hobart Town was the Auckland Islands.

(1.) *Auckland Islands.*

These islands, discovered in 1806 by Captain Bristow, are situated about 300 miles south of New Zealand, in about lat. 50° 32′ S. and long. 166° 12′ E.

According to McCormick they are volcanic, being constituted chiefly of basalt, which at Dea's Head, a promontory of Auckland Island, forms fine columns. These islands were used in 1874 by the German astronomers as the station for the observation of the transit of Venus. According to Hermann Krone, a member of this Expedition, the largest of the islands has an area of seven square miles; all of them are volcanic, and

consist of an older trachyte[1] formation succeeded by basalt; the highest hill, Mount Eden, is 404 metres high, and is crowned with a mass of basalt. A few rolled pebbles of basalt collected by Dr. Seeliger, another member of this expedition, have been described[2] by Max Hartmann. They were all felspar-basalts, mostly of coarse-grained doleritic structure; in one of the specimens the presence of nepheline is doubtfully recorded.

All the specimens from the Auckland Islands collected by the Ross Expedition are also of *felspar-basalt*, but of a fine-grained porphyritic rather than of doleritic type. Most of them consist of flat slabs (with brown weathered surfaces) of a bluish-grey fine-grained rock, showing large (up to 1 cm. in length) porphyritic crystals of black augite, and of perfectly fresh and transparent yellow olivine. Under the microscope, phenocrysts of pale purplish titaniferous augite and, in less amount, of olivine with a few labradorites are seen distributed in a fine-grained groundmass of felspar laths showing flow structure, magnetite, and pale green to purple granular augite. In one specimen the groundmass also contained small olivines.

The augite phenocrysts in some specimens have definite crystal outlines, and show octagonal sections bounded by prism and pinacoid faces, but in others they have been corroded and penetrated by the magma, and have rounded contours with a margin of alteration crowded with grains of magnetite. The pleochroism in basal sections was from purplish brown to yellowish brown; the extinction on cleavage flakes was nearly 40°; polysynthetic twinning on $a(100)$ was noted in several sections, and also hour-glass structure. Inclusions of magnetite and of groundmass were common; in one section very minute black needles arranged in two parallel sets inclined at an angle of about 60° were observed.

The olivine phenocrysts have slightly rounded outlines, and are very clear and fresh. Between crossed nicols inclusions can be seen in some sections of very minute star-like radiating groups of a strongly doubly refracting mineral. They remind one of the gypsum crystals obtained in microchemical reactions, and are thus very similar to the sahlite needles in the altered olivine of the Medenbach picrite recently described and figured by R. Brauns.[3] In the present case, however, from their small angle of extinction, I am inclined to refer them to tremolite. I have

[1] No specimens of this trachyte appear to have been collected by this German expedition, nor was one found in the Ross collection. Some uncertainty must therefore exist as to the nature of this older formation.

[2] *Neues Jahrb. f. Min. u. Petr.* 1878, pp. 825–30.

[3] *Neues Jahrb. f. Min. u. Petr.* 1898 (2), 179.

noted similar minute inclusions in the olivine of nepheline-basalts from Fernando Noronha.

The porphyritic felspars are small prismatic, and often occur in patches of several individuals. They show broad albite twin-lamination with symmetrical extinction of about 30°, so that they may be referred to labradorite; a few crystals, however, with zonal extinction appear to be of a more acid type.

The specific gravity of this rock was 2·85.

In general character the basalt approximates closely to some of the Bohemian felspar-basalts described by Boricky.

Another specimen less distinctly porphyritic, and apparently of more basic type than the preceding, was of a dark grey colour, and showed to the naked eye only small porphyritic olivines. Under the microscope it presents somewhat similar characters to those of the last rock, but the olivine phenocrysts are in far larger amount, and show along cracks and round the margin a green alteration product. The pale purple augite occurs generally in groups of several individuals, often in association with the olivine; in one case a large olivine crystal is completely surrounded by a border of augite grains. The felspar phenocrysts are in subordinate amount, and show all stages of absorption by the base. They are rounded and corroded, often into the most fantastic shapes; in some cases the groundmass has penetrated into them along definite channels, in other cases its constituents, magnetite and augite microliths, pervade them in such a way that they lose all definite outline.

Of a somewhat different type is a rock labelled "Oceanic Point." It is a dark grey basalt, not markedly porphyritic, but showing to the lens on the rough weathered surface small yellow olivines. Under the microscope the only phenocrysts are seen to be of olivine. These are small and clear, but are generally rounded, and are often penetrated by and include portions of the groundmass. This groundmass consists of lath-shaped crystals of labradorite (symmetrical extinction of about 25°), with much pale green to colourless granular augite and iron ores. The latter (in part probably ilmenite) is in rod-like skeleton crystals, generally wedged between the felspar-laths and obviously one of the last minerals to consolidate; in the neighbourhood of the olivine phenocrysts in some cases the rods (or plates) are arranged at right angles to the axis of the olivine, as observed by Reusch in basalts from Jan Mayen[1] and by Streng

[1] *Neues Jahrb. f. Min. u. Petr.* 1883 (2), 224.

in the Londorf dolerite.[1] This directional character is particularly marked in the case of patches of groundmass included in the olivines.

A specimen labelled "Pig Island" is a black compact basalt consisting of a very fine-grained felt of felspar laths, pale green augite microliths and much granular magnetite. Olivine occurs very sparingly in small grains, and a deep purple augite in minute prismatic crystals.

Finally, from Dea's Head is a basalt of a somewhat coarser-grained type than any of the preceding. It is a dark grey, slightly vesicular rock, showing to the lens small yellow olivines. These, under the microscope, are seen to occur in small idiomorphic crystals, some giving the usual hexagonal outlines, but others long prismatic and rod-shaped. All have a deep orange-red alteration product round the margin. Purple augite in prismatic crystals of varying size and often forming radiating groups is present in large amount, and is idiomorphic with respect to the small lath-shaped felspars which in subordinate amount form as it were the paste for the other constituents. Magnetite occurs in fairly large grains. One large irregular plate of ilmenite (?) enclosed crystals of felspar and purple augite.

(2.) *Campbell Island.*

Campbell Island, the next land touched by the Expedition, is about 120 miles S.W. of the Auckland Islands, in lat. 52° 33′ S. and long. 169° 8′ E. Hazelburgh, who discovered the island in 1810, states that it is 30 miles in circumference, and is mountainous. The hills, of which the highest has an elevation of 1,500 ft., were less wooded than those of the Auckland Islands.

According to McCormick, the geology of the island is very similar to that of the Aucklands. Pebbles of quartz and agate, however, and traces of limestone were found amongst the shingle on the beach, "the only indication of the sedimentary class of rocks which we met with after our departure from the Australian lands."

The specimens from Campbell Island consist of *basalt, silicified foraminiferal limestone*, and *chert*.

One large specimen of compact dark bluish gray porphyritic basalt presents both macroscopically and under the microscope almost precisely the same characters as those of the basalt from the Auckland Islands described on p. 71.

Another basalt specimen is very vesicular and of a coarser-grained type. Under the microscope crystals of purplish augite, altered olivines

[1] *Neues Jahrb. f. Min. u. Petr.* 1888 (2), 181.

with hexagonal sections and prismatic felspars, are seen in a medium-grained base of granular purple augite, felspar laths and skeleton growths of magnetite. The olivine and felspar are almost wholly converted into a green alteration product, while the purple augite remains perfectly fresh.

Of the sedimentary rocks referred to by McCormick there are three specimens. One of them is a small fragment of hard compact siliceous limestone labelled "Lime from a vein in basalt, South Harbour, Campbell's Island." A thin section shows that it consists largely of the remains of foraminifera (globigerina) in fairly good preservation. Treated with acid it effervesces strongly, but leaves a large siliceous residue. A partial quantitative analysis made on 0·7640 gram of this rock gave the following result:—

SiO_2	=57·46
$CaCO_3$ ...	=39·26
$MgCO_3$ ...	= 0·36
$Al_2O_3(+Fe_2O_3)$	= 1·48
H_2O, &c. ...	=(1·44)
	100·00

The specific gravity of the fragment was as low as 2·15.

To the kindness of Messrs. H. W. Burrows and R. Holland I am indebted for the following note, in which are enumerated the species of foraminifera identified by them in sections cut from this specimen:—

"This is a compacted *Globigerina* ooze of essentially modern character, certainly, in our opinion, not older than Post Pliocene.

"It is closely matched by the deposits now accumulating at other parts of the S. Pacific, and is very like some of the soundings in our own collection, notably those off Molyneux, and off Otago, New Zealand.[1]

"The *Foraminifera* are in a very fresh condition, and in this respect resemble those in a palagonite-tuff in Mr. C. W. Andrews' collection from Christmas Island.

"We have determined the following species in the two slides—

"v.r. *Pulvinulina Micheliniana*, d'Orb.

"v.c. *Globigerina bulloides*, d'Orb., spinose.

"v.c. *Globigerina bulloides*, var. *triloba*, Rss., spinose.

[1] The precise localities referred to are—Off E. of Otago, 953 faths. lat. 45°55′ S.; long. 172°46′8″ E. Off Molyneux, 614 faths. lat. 46°37′ S.; long. 171°2′7″ E.

"v.c. *Orbulina universa*, d'Orb.
"r. *Bulimina affinis*, d'Orb.
"r. *Bolivina* sp.

"The species are, doubtless, more numerous, as we notice fragments which are not referable to the above-named species, but they are not sufficiently distinct to be determinable."

The other two specimens are of chert, probably representing the final stages of the silicification of the limestone. One of them, of flinty hornstone-like appearance, shows under the microscope remains of globigerina, but in a far less perfect state of preservation than in the preceding specimen.

The third specimen has a more felsitic appearance, and is covered with small quartz crystals. No organisms can be definitely distinguished under the microscope.

(3.) *Possession Island.*

After leaving Campbell Island, the Expedition crossed the Antarctic Circle, and soon after became beset in the pack ice. Having passed through the pack, it emerged into an open sea, and, proceeding further southward, on January 11th, 1841, in about lat. 71° S. and long. 171° E., discovered Victoria Land, "rising steeply from the ocean," as described by McCormick, "in a stupendous mountain range, peak above peak, enveloped in perpetual snow." Some of these peaks attain an altitude of from 10,000 to 15,000 feet. From the dark colour of the rocks, where they broke through their icy covering, and from several black pebbles dredged up off the northern promontory, Cape Adare, Ross formed the opinion that the newly-discovered land was of volcanic origin.[1] The mainland could not be approached, but a landing was effected on a small island (Possession Island) lying off it in about lat. 71° 56′ S. and long. 171° 7′ E.

According to McCormick this island is composed of "volcanic conglomerate, vesicular lava, and basalt," rising to a height of about 300 feet. It showed not the smallest vestige of vegetation. McCormick describes the fantastic shapes assumed by the basaltic rocks, and mentions a cave showing fine columns, "a Fingal's cave in miniature."

The specimens labelled as from Possession Island include *basalts palagonite-tuff*, *phonolite* and fragments of *muscovite-granite*.

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[1] According to Sir John Murray (*Proc. Roy. Soc.* 1898, LXII. p. 424) Borchgrevink and Bull have recently brought back fragments of mica-schist from Cape Adare. A nepheline-tephrite from the same locality has been described by Teall.

Basalts.

A scoriaceous black basalt, in which no porphyritic crystals could be distinguished with the naked eye, was seen under the microscope to consist of a very fine-grained dense almost opaque felt of magnetite grains, felspar laths, and minute colourless augite microliths, with here and there, very sparingly, rhombic sections of olivine showing generally a central inclusion of glass. The larger felspar laths, on one of which a symmetrical extinction angle about the twin lamellæ of 25° was measured (labradorite), marked the flow-structure of the rock. Small phenocrysts of a pale purple augite, showing inclusions of magnetite and olivine, occur sparingly.

An interesting feature is the presence of a few small phenocrysts of a deep brown basaltic hornblende. Some of these, in process of absorption by the base, are lenticular in shape, and are surrounded by a zone of magnetite grains. In one case this hornblende forms a zone round an irregular fragment of augite, as though of later date.[1]

In the hand-specimen a fragment of this hornblende, about 2 mm. cube, occurs loosely attached in a cavity, as if it had been caught up in the lava flow. Cleavage flakes from this fragment are only transparent when very thin, give almost straight extinction, and in convergent light show signs of both axial brushes, so that an optic axis is not very near the centre of the field as it is in the case of ordinary hornblende. The pleochroism was, in a cleavage flake, light yellow-brown to deep brown (almost black); in a section showing both cleavages, light yellow-brown for a and deep reddish-brown for b. The cleavage angle measured on the reflecting goniometer was 124° 34′.

A rolled pebble of compact black basalt, showing to the lens only a few minute phenocrysts of augite, presents under the microscope somewhat similar characters to those of the preceding rock, but is of coarser grain. The only phenocrysts are of a pale purple augite (generally with a green centre). Most of the sections have well-defined rectangular or octagonal crystal outlines, but some are corroded and surrounded by a zone of magnetite grains, and some show hour-glass structure. They generally enclose magnetite, and in some cases grains of olivine. In this specimen the hornblende has been wholly absorbed; many pseudomorphs, however, of the crystals are left as patches of densely crowded magnetite

[1] Since writing the above description, I find that Mr. Teall has recently examined and described some specimens of basalt from Possession Island brought back by Captain Jenssen. Sections kindly shown to me by Mr. Teall present precisely the same characters as those described above.

grains, sometimes lenticular in shape, but occasionally presenting crystal outlines. Some of these patches are surrounded by a narrow border of purplish augite; others have clearer spaces in the centre filled with an aggregate of magnetite, purple augite, and felspar, more coarsely crystallised than the groundmass. Consideration of this specimen and of the preceding suggests that it was only in the quickly cooled surface of the lava that the hornblende crystals have been preserved. In the more slowly cooled material they have been almost wholly absorbed by the groundmass.

The groundmass consists of magnetite and felspar laths, with olivine, a little augite, and traces of glass. The felspar and olivine have the same characters as in the preceding rock: the granular augite is in very small amount. The magnetite occurs in two generations, in grains and octahedra (in which form it is enclosed in the augite phenocrysts), and in minute rod-like skeleton growths fringing and often set at right angles to the sides of the felspar laths, and certainly one of the last minerals to separate. The specific gravity of this rock was 2·82.

These basalts are very similar to the hornblende-basalts in the Rhöngebirge, *e.g.* to the rock from Kirschberg, near Rasdorf, a specimen of which is in the Museum collection.

Another rolled pebble of black compact basalt is similar to the preceding, but is finer grained, and contains no porphyritic crystals. It consists of a fine grained felt of felspar laths, a little granular augite and olivine, with much magnetite in grains and some purplish-brown glass. It is worthy of note that in this specimen containing glass there are no magnetite skeletons.

In the section are a few grains of quartz; these have probably been derived from the granite to be later described; they are surrounded by zones of pale greenish radiating needles, from their high angle of extinction (about 30°) referred to augite.

Adhering to this specimen was a piece of brown tuff containing, besides fragments of glassy basalt, also broken crystals of basaltic hornblende similar to that described above, and rounded grains of quartz.

Palagonite-Tuff.

A section of a pale brown palagonite-tuff, similar to that adhering to the basalt, showed fragments of highly vesicular basalt-glass, and of less glassy basalts similar to those described above, cemented by yellow palagonite and zeolites. Crystals of basaltic hornblende, quartz and felspar, and a fragment of the phonolite described below, also occurred.

The felspar was tabular, showing twin striations with symmetrical extinction of 6° (oligoclase). The quartz showed liquid inclusions with spontaneously moving bubbles, thus suggesting its deep-seated origin.

The very vesicular basalt-glass is light brown and fairly transparent. It contains comparatively large grains and crystals of magnetite, and lath-shaped felspars marking flow structure, with minute microliths of olivine, hornblende, and a little augite. Beside the lath-shaped crystals of felspar there are also extremely thin rhombic plates of a more acid felspar. The hornblende occurs in long prismatic microliths and also in perfectly rounded blebs. It is strongly pleochroic, and similar to that described above. The olivine occurs sparingly in minute rhombic sections, but mainly in forked skeleton crystals as figured in Rosenbusch's *Mikrosk. Physiog.* 2nd Ed. Vol. I. Plate II. Fig. 4. Often two of these skeleton crystals are crossed apparently in twin position. The augite in very minute long prismatic microliths, showing terminal faces and giving wide angles of extinction, is very sparingly present.

Some of the basalt fragments in the tuff were less glassy than the above. In these the magnetite had separated to a large extent in skeleton crystals: they also contained hornblende crystals and small rhombic sections of olivine.

Phonolite.

The specimen of phonolite from Possession Island is a compact brownish grey somewhat altered rock, showing to the naked eye only a few small porphyritic crystals of glassy felspar. Under the microscope it is seen to consist of a felt of felspar laths, a little magnetite, and ægyrine-augite uniformly distributed in small prismatic crystals and occasionally in granular aggregates. The maximum extinction in these prismatic crystals of ægyrine-augite was about 34°. An octagonal section showed a nearly rectangular cleavage, and in convergent light the emergence of an optic axis just off the field. The pleochroism in this section was from green to reddish-brown, while in a prismatic section it was green to brownish-green. These characters correspond to the ægyrine-augite of Rosenbusch, with axis a inclined 34° to c, and with pleochroism a=green, b=brownish-green, c=reddish-brown. The felspar laths give almost straight extinction; they show a general tendency to point in one direction, but sometimes form radiating groups. The structure is trachytic.

The presence of nepheline was only doubtfully indicated by a few rectangular sections with weak double refraction. A few minute grains of a strongly doubly refractive mineral are doubtfully referred to sphene.

Granite.

The fragments of muscovite-granite were probably derived from the tuff, since one of them had a little of the tuff adhering to one side of it. The granite consists of a medium-grained aggregate of quartz, microcline, orthoclase, oligoclase, and muscovite, with small black prismatic crystals of tourmaline. The quartz is the most plentiful constituent. It contains dusty inclusions, and also very minute liquid inclusions with spontaneously moving bubbles, as in the fragment included in the basalt. The felspars are quite fresh. The microcline is the most abundant. It appears to have been, as is generally the case in granites, the last mineral to consolidate, for it moulds the quartz which is generally rounded in contact with it, and it includes rounded grains both of quartz and oligoclase: a rounded quartz grain in contact with microcline appears to have been corroded and penetrated by the latter. The cross-hatching of the microcline is well shown between crossed nicols. The oligoclase shows very fine twin laminæ, and gives low angles of extinction. The muscovite occurs in large ragged plates. The tourmaline is in prismatic crystals enclosed in the quartz and microcline. In the quartz it occurs in all gradations of size down to the finest hairs. The pleochroism is from deep indigo-blue to pale lavender, but the larger crystals have a border with different pleochroism from brownish-yellow to pale lavender.

Some of the fragments of muscovite-granite contained, in addition to the tourmaline, small pink garnets.

(4.) *Franklin Island.*

After leaving Possession Island, the expedition proceeded along the coast of Victoria Land, with its "magnificent chain of mountains" stretching away to the southward, as described in Ross's account. A lofty peak named Mount Melbourne was, according to McCormick, evidently a volcanic cone, with a perfectly shaped crater.

When in about lat. 73° S. the dredge brought up a "block of grey granite, composed of large crystals of quartz, mica and felspar, with apparently a clean and recent fracture, as if lately broken off from the main rock." This specimen was not found in the collection.

Franklin Island, the most southerly land on which a landing was effected, is situated in lat. 76° 8′ S. and long. 168° 12′ E. and is about 12 miles long and 6 miles broad. According to Ross, it is composed wholly of igneous rocks. Not a trace of vegetation was found upon it.

The specimens collected are all of *basalt* of the same type.

It is a black compact rock, not markedly porphyritic. Under the microscope small idiomorphic olivines and magnetite are seen very

uniformly distributed in a base of purplish to colourless augite in minute prismatic microliths, and felspar in laths and in plates. In the base in subordinate amount were patches of a weakly doubly refractive mineral, which appeared to form a paste for the lath-shaped felspars. This is doubtfully referred to nepheline, since it gave straight extinction along straight edges, and in one section, which remained dark between crossed nicols, a faintly distinguishable uniaxial figure.

The olivine is in sharp hexagonal sections, generally bordered with a deep orange-red alteration product.

The augite of the groundmass is in minute prisms idiomorphic with respect to the felspar.

The felspar laths give nearly straight extinction, and are probably to be referred to andesine.

The specific gravity of the rock was 2·87.

The result of a quantitative chemical analysis is as follows :—

SiO_2	...	=	45·61
TiO_2	...	=	3·48
SnO_2	...	=	trace
Al_2O_3	...	=	15·70
Fe_2O_3	...	=	6·17
FeO	...	=	7·29
MnO	...	=	trace
CaO	...	=	6·34
MgO	...	=	4·84
K_2O	...	=	2·67
Na_2O	...	=	5·06
Loss on ignition		=	2·34
			99·50

In this analysis 1·4817 gram was used for the determination of silica, &c., by fusion with sodium and potassium carbonate; 0·6968 gram for the determination of ferrous oxide by decomposing with hydrofluoric and sulphuric acids in an atmosphere of carbonic acid, and titrating with permanganate of potash; and 0·6401 gram for the determination of alkalies by Lawrence Smith's method.

Proceeding southward from Franklin Island, the Expedition discovered in about lat. 77° 31′ S. and long. 167° 1′ E. the active volcano discharging "flame and smoke," Mount Erebus, 12,367 feet in height, with the neighbouring extinct crater, Mount Terror, 10,884 feet high.

From the cape at the foot of these mountains extended to the eastward

that vast barrier of ice forming a continuous perpendicular wall, varying in height from 100 to 200 feet, which prevented all further progress southward. Along the face of this great wall of ice the Expedition sailed for about 300 miles without finding any inlet. According to Sir John Murray (*Proc. Roy. Soc.* LXII. No. 387, pp. 424-51) this great ice barrier "was evidently the sea-front of a great creeping glacier or ice-cap, just then in the condition to give birth to the table-shaped icebergs, miles in length, which have been described by every Antarctic voyager." The proximity of this ice-barrier to extended land surfaces thus suggested receives some sort of confirmation from the fact mentioned by Ross, that in soundings made off the barrier in 410 fathoms in about lat. 77° 47′ S. and long. 176° 43′ E. the leads sank fully two feet into a soft green mud; for during the voyage of the *Challenger* the dredging up of blue and green muds, derived from the degradation of crystalline rocks, was always a sure indication of the approach to land. Unfortunately no specimen of this green mud appears to have been preserved.

II. Second Voyage Southward.

On the second journey southward the expedition was beset for long periods in the pack ice, and no landing was effected anywhere.

The only rock specimens collected were in the form of pebbles found in the stomachs of seals and penguins.

These specimens are of interest as throwing some light upon the question as to the existence and character of that great Antarctic continent which is supposed to encircle the South Pole, for in all probability they were obtained by the seals and penguins from floating ice which at one time helped to form the glaciers of that southern land. The fact that blocks of gneiss and granite,[1] which must have been deposited from icebergs, were dredged up by the *Challenger* Expedition in southern latitudes, is brought forward as evidence of the existence of this continent. The evidence afforded by these pebbles is of a similar character, as will be seen from the following descriptions. The effects of dynamic metamorphism observed in many of them also indicate that the region from which they came has been the seat of great mechanical disturbances. Amongst the pebbles are examples of the following kinds of rock :—

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[1] In the Museum is exhibited a large block of gneiss dredged from diatom-ooze, in lat. 53° 55′ S. and long. 108° 35′ E., about 600 miles N.E. of Wilkes Termination Land. According to Sir John Murray (*Proc. Roy. Soc.* 1898, LXII. pp. 424—51), the dredgings of the *Challenger* brought up, besides gneiss and granite, also mica-schists, diorites, quartzites, sandstones, limestones and shales.

From a seal caught Dec. 1841, in about lat. 63° 4′ S. and long. 151° 2′ W.: *granite* and *epidiorite*.

From a large penguin caught Dec. 22, 1841, in lat. 65° S. and long. 154° W.: *granite*, *basalt* and *rhyolitic breccia*.

From a seal caught Jan. 1842, in about lat. 66° S. and long. 156° W.: *granite*, *epidiorite*, *dolerite*, *basalt* and *rhyolite*.

From a penguin caught Jan. 28th, 1842, in about lat. 67° S. and long. 156° W.: *micaceous quartz-grit* (*micaceous schists*).

Granites.

The granites are pink and grey rocks, consisting of quartz, orthoclase, oligoclase, and a little biotite and hornblende. Most of them show to a greater or less extent the effects attributed to dynamic metamorphism. The quartz almost invariably shows marked undulose extinction, and each grain between crossed nicols resolves itself into an aggregate of irregular differently orientated smaller grains. It contains strings of dusty inclusions and fluid-pores with spontaneously moving bubbles.

The oligoclase shows thin twin laminæ which are often bent. In some specimens it is altered with development of much clear yellow epidote.

The biotite is generally only present in small amount: in some specimens it has been converted into pleochroic chlorite.

The orthoclase in some of the pebbles appears to have been largely replaced by microcline. The cross-hatching, however, is not well marked, and it is possible that we have here an example of microcline structure developed in orthoclase as the result of mechanical strain.

In some of the granites the effects of earth stresses are even more marked, and advanced stages of cataclastic structure precisely similar to those figured in Rosenbusch's *Mikros. Physiog.* Vol. II. Plate I. Figs. 3 and 4, are exhibited.

One pebble showed the contact of such a cataclastic granite with an epidiorite which is probably a dolerite metamorphosed by the same dynamic effects which have affected the granite.

Epidiorites.

The epidiorites are dark green rocks, presenting generally very similar characters to those of the well-known rock of the Scourie dyke described by Teall.[1] They are probably metamorphosed dykes of dolerite in granite, for several of the pebbles show the contact of epidiorite and granite. Under the microscope one specimen shows green hornblende in small

[1] *British Petrography*, Pl. XIX, XX, pp. 197–200.

ragged grains, often aggregated into groups, but generally fairly uniformly distributed in a paste of water-clear felspar, which is partly in laths with indistinct outline and partly in plates.

The felspar has the characters attributed to secondary felspar. It is water-clear, and for the most part shows no twin striations, so that it is often only to be distinguished from quartz by observation in convergent light. The lath-shaped crystals have nearly straight extinction, and are probably andesine. One or two larger sections showing twin striations are more basic, and are probably some of the original labradorite of the dolerite. One section, giving symmetrical extinction of about 28°, had a border of water-clear felspar, giving straight extinction. The hornblende is similar to that of the Scourie dyke, but does not occur in such large plates. The pleochroism was a=pale yellow, b=dull yellowish-green, c=dull bluish-green.

Magnetite is present in comparatively large grains, but in small amount. Calcite and epidote occur in minute veins.

Finally, there are one or two irregular patches of a yellow mineral, which from its very strong refraction and double refraction was referred to sphene. This was confirmed by observation of one section, which showed in convergent light a positive biaxial figure with a small optic axial angle and with strong dispersion $\rho > v$.

In the specimen showing the contact of epidiorite and cataclastic granite, this granular sphene with a little hornblende is seen to occur near the contact both in the granite and in the epidiorite. As in the case of the Scourie-dyke rock, the sphene has probably resulted from the alteration of the titaniferous iron-ore of the original dolerite.

Other specimens showed less advanced stages of alteration, and except for the change of augite to hornblende were nearer to ordinary dolerites. One example consisted of small lath-shaped felspars showing flow structure, with large irregular ragged patches of a fibrous hornblende showing pleochroism a=very pale yellow, b=pale dirty greenish-brown, c=dirty bluish-green. Biotite is present in small amount, and magnetite in comparatively large grains.

Another specimen was coarser-grained, and showed large prismatic felspars, a little quartz and large ragged patches of biotite and hornblende. The hornblende had obviously resulted from the alteration of augite, since the latter mineral occurs as the nucleus of one or two of the hornblende patches.

Dolerites.

The dolerites found among the pebbles were somewhat similar in

character to the unaltered dolerite of the Scourie dyke, and might well have been the original rocks from which some of the above epidiorites were derived.

One example consists of a coarse-grained aggregate of broad prismatic crystals of labradorite (symmetrical extinction of about 25°) and pale purple augite in irregular plates, penetrated by the felspar, and thus presenting a sub-ophitic structure. Iron-ore, probably titaniferous, occurs in irregular plates. Yellow fibrous hornblende is present in small amount, probably resulting from the alteration of the augite. In the section is a small patch of kaolinised felspar (in tabular crystals and of more acid type) which appears to be a foreign inclusion, probably from a granite.

Another specimen is of similar character to the preceding, but of much coarser grain. It consists of large interlacing prismatic crystals of labradorite with broad ophitic patches of greenish-brown fibrous hornblende, containing in many cases a nucleus of the original purple augite. Iron ore was present as in the preceding rock.

Basalts.

Amongst the basalts no specimen precisely similar to any of those described in the first section of this paper was found. This should not be surprising if the supposition is well grounded that the pebbles were mainly derived from a great Antarctic continent further southward. One specimen, however, bore some resemblance to basalts from Cockburn Island, off Louis Philippe Land, to be described in the next section.

In this rock the only porphyritic constituent is perfectly clear fresh olivine in large crystals, generally with fairly sharp hexagonal outlines, but sometimes invaded by the base. They contain a few inclusions of magnetite, picotite (?), and blebs of glass. The groundmass consists of very minute microliths and forked skeleton crystals of felspar in a deep brown glass crowded with minute skeleton growths of magnetite. Augite in small amount is only to be distinguished between the felspars and intergrown with magnetite by the polarisation colours. As in the Cockburn basalts (see p. 87), this mineral and the magnetite appear to have been the last to separate. In the groundmass were also a few small grains of olivine; sometimes two such grains would be attached on each side of a felspar lath, as though of later date. Scattered through the base were numerous minute round colourless isotropic patches, looking like microscopic vesicles filled with an isotropic zeolite.

Another basalt, medium-grained approaching to dolerite, shows microporphyritic lath-shaped felspars and altered olivine in a base of smaller

felspar laths, altered olivine and purple augite minutely ophitic with respect to the felspar. Magnetite is present in comparatively large crystals and rods. The larger felspars are of labradorite with a symmetrical extinction angle about twin laminæ of 29°, and are of the same general character as the smaller ones of the base. Symmetrical extinction angles, however, in the latter were generally lower (19°). The olivine is in large amount, but is all altered to a yellowish-brown fibrous strongly doubly refractive hornblendic (?) mineral.

Another basalt specimen is of more acid type. It consists of a few porphyritic labradorites (symmetrical extinction of about 21°) in prismatic crystals much corroded and partially re-absorbed by the base, with a few small purplish augites, in a dense base containing much granular magnetite, colourless augite in grains and minute prisms, and lath-shaped felspars giving straight extinction (probably andesine).

Rhyolites.

One specimen appears to be a rhyolitic breccia. It consists of much altered fragments of microfelsitic material, probably a devitrified glass, showing flow structure, and containing corroded quartz grains penetrated by the magma.

Another much altered specimen shows under the microscope alternating parts of clear and cloudy cryptocrystalline material. The cloudy material appears to consist of pseudo-spherulites. Between crossed nicols the section resolves itself into an aggregate of round patches of differently orientated material, but no definite black crosses are seen. One or two corroded quartz grains occur as the nuclei of some of the circular patches. Some of the Hungarian rhyolites present a similar structure, *e.g.* the rock from Abanj Szanto, Tokaj.

Micaceous Quartz-Grits (*micaceous schists*).

One specimen shows sub-angular quartz grains with brown interstitial matter containing smaller quartz grains and ill-defined biotite. The quartz contains liquid inclusions with spontaneously moving bubbles. In the arrangement of the quartz grains there is some approach to schistose structure.

Another specimen consists of clear quartz grains connected by a network of apparently more recent quartz, with lines of reddish-brown pleochroic biotite giving foliated structure.

The microscopic characters of these specimens suggest the idea that they may be quartz-grits metamorphosed by granite-contact into micaceous schists.

III. Third Voyage Southward.

In the course of the third voyage into Antarctic regions, the only landing effected was on Cockburn Island, in lat. 64° 12′ S. and long. 56° 49′ W., off Louis Philippe Land, south of the South Shetlands.

About this particular part of the Antarctic regions, according to Sir Archibald Geikie,[1] within recent years sealing vessels have brought home scraps of information. Thus from the islets of Graham Land to the south of the South Shetlands fragments of granite, volcanic rocks and fossiliferous limestone have been collected. From Dundee Island, close to Joinville Island which forms the north-eastern termination of Graham Land, come specimens of granite[2] and a piece of radiolarian chert very similar to cherts in the Lower Silurian formations of the United Kingdom. From Seymour Island, in the same district, Captain Larsen brought back pieces of fossil coniferous wood, and also fossil shells similar to species in lower Tertiary beds of Patagonia.

The specimens from Cockburn Island collected by the Ross Expedition include *basalt, palagonite-tuff, granite,* and *calcareous glauconitic sandstone.*

Basalts.

The basalt specimens are of a black compact, generally non-vesicular rock, showing to the naked eye porphyritic perfectly fresh yellow olivines, while with the lens small striated lath-shaped felspars can be detected. One large specimen shows the ropy surface of the lava consisting to the depth of more than half an inch of basalt-glass. All the specimens probably came from the same eruptive mass, but they show under the microscope interesting gradations of structure from a clear glass to a perfectly crystalline rock.

The most holocrystalline rock of this series consists of a medium-grained aggregate of olivine, felspar laths, deep purple augite and magnetite. The olivines occur in two generations, in large phenocrysts and in smaller crystals between the felspar laths. The augite is in small irregular ophitic patches penetrated by the felspars.

In other specimens the structure is more distinctly porphyritic: phenocrysts of clear unaltered olivine occur in a medium-grained base of lath-shaped felspars, the interstices between which are filled with augite intergrown with skeleton crystals of magnetite. The colour of the augite varies from deep purple to almost colourless.

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[1] *Proc. Roy. Soc.* 1898, LXII, pp. 424–51, and *Proc. Roy. Soc. Edinb.* 1898, XXII. p. 66.

[2] Described by Teall (*Proc. Roy. Soc. Edinb.* XXII. (1898), p. 58).

In other specimens the interstitial augite is more indistinct and more confusedly intergrown with magnetite, so that it can often only be recognised by the colours between crossed nicols.

In yet other specimens the magnetite skeletons are very minute and feathery, and no augite can be distinguished. In these specimens the same orientation as previously described of the magnetite rods at right angles to the olivine and to the length of the felspar laths was noted.

Then there are specimens in which the interstices between the felspar laths are filled with a deep brown glass, with only slight separation of magnetite.

Finally, on the surface of the lava-flow is a clear light-brown glass, with phenocrysts of olivine and felspar and no separation of magnetite whatever.

Such a concentration of iron in the mother-liquor of basic magmas as indicated by the above observations has been recently noted and emphasised by Teall in the case of basalts from Franz Josef Land.[1]

The olivine in all the above specimens is of the same character. It is generally perfectly clear and fresh. The large phenocrysts show mostly sharply-defined hexagonal sections, but sometimes occur in groups of broken fragments separated by the magma. Occasionally they are in elongated prismatic crystals, as described by Dana in the case of Hawaiian basalts.[2] In many cases they have been corroded and penetrated by the magma. They contain inclusions of brown sub-translucent octahedra of picotite (?) and of glass (showing sometimes separation of augite and magnetite).

The olivine of the groundmass is in large amount and shows rhombic sections with central inclusions of glass. It sometimes occurs included in the felspars, but is often in irregular patches interpenetrated by the felspar laths, as if of later consolidation.

The felspar in these specimens is mainly a basic labradorite with twin striations showing a maximum symmetrical extinction of about 32°. Besides these sharply defined lath-shaped felspars, in some specimens there are a few larger and broader felspars of a more acid type having zonal extinction. These are often cracked and bent, and show rounded indistinct outlines as if partially absorbed. One section, showing no twin laminæ, exhibited in convergent light a positive biaxial figure with a very small optic axial angle.

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[1] *Quart. Journ. Geol. Soc.* LIII, (1897), p. 487.

[2] *Am. Journ. Sci.* XXXVII. (1889). p. 441.

Magnetite occurs generally in skeleton growths as one of the last minerals to separate: only in the holocrystalline specimen, in which the augite is in ophitic patches, does it occur in large grains, and in this case these grains appear to be generally wedged in between the felspar laths.

Basalt Glass.

Sections from the large specimen with glassy surface showed that between the base of the specimen (about 7 in. from the surface) and about 1 in. from the surface the rock is fairly uniform in character, and consists of phenocrysts of olivine in a groundmass of smaller olivines and interlacing felspar laths with the interstices filled with glass so dense from separation of magnetite as to be opaque. As the surface is approached the amount of this dense glass increases. Then follows a zone in which the magnetite has separated in cloudy patches or cumulites, and also in thick seams round the olivine and felspar phenocrysts, leaving in the interspaces a clear yellow glass. To this succeeds a zone, in which there are no cumulites of magnetite, but the phenocrysts are still slightly coated, and the glass is darker and less transparent than in the preceding zone. Finally, on the surface is a clear light brown glass, in which occur olivines and felspars, but no magnetite whatever. The large porphyritic olivines in this glass are often corroded into fantastic shapes. Round one crystal the glass shows perlitic cracks. The smaller olivines are very sharply defined, and being so minute, show in the section actual faces of pinacoids and domes. Olivine also occurs in the form of forked skeleton crystals.

The felspar is mostly in sharply defined laths of labradorite, generally with ragged ends, but sometimes showing terminal c (001) and x ($\bar{1}01$) faces. It occurs also in extremely thin rhombic plates, showing zonal extinction and often enclosing olivine. These plates show traces of the faces c, x, and also of y ($\bar{2}01$). Supposing they are parallel to b (010) the extinction with respect to the trace of c varied from 4° in the centre to 16° on the edge. No augite microliths could be detected.

Some of the glassy basalts of the Rhöngebirge, *e.g.* the rocks from Schwarzenfels and Sterbfritz, present somewhat similar characters.

The specific gravity of the basalt about 7 in. from the glassy surface is 2·89: that of the glass on the surface 2·79.

The results of quantitative chemical analyses of this basalt and of the glass are as follows:—

Basalt (7in. from surface).				Basalt-Glass.
SiO_2	= 48·97	...	...	50·22
TiO_2	= 1·62	...	...	1·95
Al_2O_3	= 16·12	...	...	16·20
Fe_2O_3	= 1·90	...	...	3·13
FeO	= 9·63	...	...	8·07
MnO	= trace	...	...	trace
CaO	= 8·73	...	...	8·57
MgO	= 7·64	...	...	7·54
K_2O	= 1·21	...	...	1·38
Na_2O	= 2·99	...	...	3·36
Loss on ignition (mainly CO_2)	1·39	...	...	0·22
	100·20			100·64

In these analyses the same methods were used as in the case of the basalt from Franklin Island (p. 80). The weights taken of basalt and glass were respectively—1·4479 gram and 1·4090 gram for the determination of silica, etc.; 0·8525 gram and 0·6968 gram for the ferrous oxide; and 0·6150 gram and 0·6401 gram for the alkalies. The fairly close agreement between the analyses precludes the idea that anything in the way of differentiation has taken place within a depth of 7 inches. The slight differences in the percentages of silica, loss on ignition (carbonic acid), and ferric oxide, may be accounted for by the fact that in the basalt, as noticed in many specimens, there has been some slight development of chalybite at the expense of olivine, and that the glass has suffered a little surface oxidation.

Palagonite-Tuff.

A palagonite-tuff from an iceberg off Cockburn Island consists of fragments of precisely similar glass to that described above altering to orange-yellow palagonite, and cemented by chalybite, calcite, and zeolites. In character it corresponds almost exactly to a palagonite-tuff from Kerguelen Land, described by Renard.[1]

Granites.

Of the two specimens of granitic rocks from Cockburn Island, one with pink felspars, described on the label as a boulder, shows under the microscope very beautiful micropegmatitic structure of quartz and orthoclase. Oligoclase is also present, and altered biotite with green hornblende. The felspars are altered with development of epidote.

[1] *Challenger Reports.* VII. Petrography of Oceanic Islands, p. 116.

The other specimen, a chip of grey granite with sharp edges, is fresher, and shows no granophyric structure. It consists of quartz, orthoclase, oligoclase and microcline, with biotite in large ragged plates, and hornblende. The quartz is idiomorphic (in parts of the section giving hexagonal outlines) with respect to the microcline. The hornblende in prismatic sections is pleochroic from dull green to yellowish-brown, and shows polysynthetic twinning on $a(100)$.

Calcareous glauconitic Sandstone.

This rock consists of sub-angular grains of quartz and a little orthoclase and oligoclase (symmetrical extinction of twin laminæ about 5°), with grains of iron ore, zircon, pink garnet and green glauconite, all cemented by calcite. The quartz shows liquid inclusions with bubbles, and also hair-like inclusions such as occur in the quartz of many granitic rocks. The grains of iron-ore, zircon and garnet generally occur in strings; with them are a few deep-red pleochroic needles of a doubly-refracting mineral, possibly rutile.

A specimen obtained from an iceberg off Cockburn Island is a very fine-grained grey loosely coherent *sandstone*, showing to the naked eye here and there minute scales of glittering white mica. Under the microscope it is seen to consist of minute sub-angular grains of quartz and felspar and a little glauconite, with brown dusty interstitial matter.

A light greenish-grey compact *quartzite* from a piece of ice off Cockburn Island showed under the microscope a minutely crystalline aggregate of sub-angular quartz grains with indistinct flecks of a pale green hornblendic mineral giving the colour to the rock, a few rounded granules of zircon and a little felspar and mica.

Pebbles from a young penguin caught off Louis Philippe Land on December 31st, 1842, include specimens of *basalt, perlitic and spherulitic rhyolite, quartz-grit, slate* and *gneiss*.

The *basalts* present characters very similar to those of Cockburn Island, one specimen corresponding to the holocrystalline anamesitic type with ophitic augite, and the others to the more glassy varieties.

Of the *rhyolites* one specimen of a pale green colour showed to the naked eye phenocrysts of quartz and milk-white felspar. Under the microscope the quartz is seen to be rounded and penetrated by the magma: the felspar in large prismatic crystals is kaolinised and nearly opaque; some sections without twin laminæ show the parallel parting characteristic of sanidine, while others with fine twin laminæ are probably of oligoclase. The microfelsitic base consists of alternating

bands of light brown cloudy material showing flow-structure, and of clearer material exhibiting perlitic structure made evident by means of a pale green chloritic mineral.

Another milk-white rhyolite showing phenocrysts of quartz and felspar is seen under the microscope to consist of a dense cloudy microfelsitic base, showing in parts spherulitic structure with black crosses, in which are distributed large prismatic crystals of sanidine and smaller and more fragmentary and corroded crystals of oligoclase and quartz.

These rhyolitic rocks, like those collected during the second voyage, in both their macroscopic and microscopic characters are very similar to some of the Hungarian rhyolites.

The specimen of *quartz-grit* consists of angular grains of quartz (containing liquid inclusions) and felspar, with a little altered ferro-magnesian mineral.

Pebbles of dark-grey banded *slate* showed schistose structure with wavy dark bands encircling minute lenticular eyes of quartz-mosaic and calcite.

The specimen of *gneiss* shows quartz and orthoclase with foliation well marked by bands of pleochroic biotite. Oligoclase occurs in small amount, and a few rounded grains of zircon. Pœcilitic rounded quartz grains are present in the felspars.

In conclusion is appended the following list of the various kinds of rocks from Antarctic regions found in the Ross collection: –

From Auckland Islands (lat. 50°32′ S.; long. 166°12′ E.): *basalt.*

From Campbell Island (lat. 52°33′ S.; long. 169°8′ E.): *basalt, silicified globigerinal limestone, chert.*

From Possession Island (lat. 71°56′ S.; long. 171°7′ E.): *basalt, palagonite-tuff, phonolite, muscovite-granite.*

From Franklin Island (lat. 76°8′ S.; long. 168°12′ E.): *basalt (nepheline-basanite?).*

From Cockburn Island (lat. 64°12′ S.; long. 56°49′ W.): *basalt, palagonite-tuff, granite, calcareous glauconitic sandstone.*

From seals and penguins caught between lat. 63° S.; long. 151° W. and lat. 67° S.; long. 156° W.: *granite, epidiorite, dolerite, basalt, rhyolite, micaceous quartz-grit.*

From penguin caught off Louis Philippe Land in about lat. 64° S. long. 54° W.: *basalt, perlitic and spherulitic rhyolite, quartz-grit, slate, and gneiss.*