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BASIC IGNEOUS ROCKS AND METAMORPHIC EQUIVALENTS

FROM COMMONWEALTH BAY.

BY
J. O. G. GLASTONBURY, B.A., M.Sc.

WITH TWO PLATES.

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PART 5.

BASIC IGNEOUS ROCKS

AND

METAMORPHIC EQUIVALENTS

FROM

COMMONWEALTH BAY.

BY

J. O. G. GLASTONBURY, B.A., M.Sc.

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Plates VI and VII.]

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BASIC IGNEOUS AND METAMORPHIC EQUIVALENTS FROM COMMONWEALTH BAY.

BY

J. O. G. GLASTONBURY, B.A., M.Sc.

SECTION I. PREFATORY REMARKS.

A GREAT variety of metamorphic rocks and basic igneous rocks was collected from the moraines at Cape Denison, Antarctica. Dr. Stillwell has described some of the leading types of amphibolites and associated basic rocks of this collection. The present contribution* deals with a further section of such rocks.

Herein are given to the igneous rocks the ordinary descriptive names ; stating as well, wherever it seemed useful, the position of the rock in Johannsen's modal classification. The present work closely follows Harker's treatment of the metamorphic rocks ; the extent to which the author is indebted to Harker's excellent work, " Metamorphism " (1932), will be obvious to anyone acquainted with that classical treatment of the subject. In the case of the metamorphic rocks, quantitative modal analyses have frequently been made and the results recorded. With some coarsely crystalline gneissic rocks it was obviously futile to make a micrometric analysis across a section wherein major peculiarities of composition were almost certain to occur. Indeed, with the size of the ordinary rock section and the width of the bands in the gneissic rocks even three sections cut in mutually perpendicular directions would frequently fail to give anything like an adequate indication of the quantitative modal mineralogical constitution of the rock.

The terminology used in connection with the igneous rocks calls for no further discussion. In connection with the metamorphic rocks, the terminology is that used by Harker except in connection with some hornblende rocks which are clearly examples of complete amphibolitization even to the exclusion of plagioclase. Here the term, amphibolite, has been used whereas hornblende-fels has been employed previously. It seems more logical to proceed in the manner suggested here than to do as others have done. A rock which contains both plagioclase and hornblende (and of course, of the type treated here) is called a plagioclase-amphibolite, the logical procedure is to call an amphibole rock an amphibolite. In at least one instance, viz., No. 462, there seems to be no equivalent mentioned in Harker's work and consequently a new name had to be devised.

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* This and other manuscripts contributed by Glastonbury were finally completed in 1934.

SECTION II. BASIC IGNEOUS ROCKS.

(1) General Discussion.

The occurrence of these rocks in the moraines renders it impossible to determine with certainty either their origin, the relations between the parent masses and magmas, or the ages of the intrusions or extrusions of which they were a part. For this reason the main petrographic descriptions will be given with each individual specimen described. Nevertheless, a short, more or less comprehensive, general description will serve as a summary of the more detailed matter which follows.

The igneous rocks represented are of four main types, viz., diorite, basalt, dolerite, gabbro. Of these the least represented is diorite and the most dolerite.

(2) The Diorite.

The rock which represents this group is specimen No. 433A. The diorite, in virtue of its quartz content, is a member of the quartz-diorite group.

The saussuritization of the felspar, the presence of epidote and zoisite and certain of the textural qualities show that this rock is by no means unaltered, and it could quite easily have been classified as an early stage metamorphic derivative of an intermediate rock. The preservation to a large extent of its original igneous textures has been the determinative factor in the retention of the term diorite.

No. 433A.—*Quartz-Biotite-Hornblende Diorite.*

This fine-grained rock is observed in the hand specimen to consist of leucocratic and melanocratic bands. The dark bands carry a large quantity of mica as well as amphibole.

As seen under the microscope the essential minerals of this quartz-biotite-hornblende diorite are quartz, labradorite, biotite and green-blue hornblende. The primary accessory minerals include sphene and apatite, and possibly magnetite, but this last mineral seems, in part at least, to be derivative. The secondary accessories are magnetite (already referred to) epidote and zoisite, with some fibrous saussuritic matter which has developed in the felspar.

The presence of a considerable amount of quartz in the rock mass throws it into the quartz diorite division. Some of the quartz seems to be secondary in nature ; the sutured edges, the mosaic of variously oriented crystal and undulose extinction give this part of the rock a crystalloblastic appearance. Here, too, those crystals which give an interference cross usually show the mineral to be slightly biaxial, the optic axial angle being small, about 10°. Other parts of the quartz suggest that here this mineral is primary.

The most characteristic features of the felspar are the very complete development of two cleavages, the low interference colours and the presence of three kinds of twinning, carlsbad, albite and pericline. These last two twin forms result in the felspar having a cross-hatched appearance, not unlike that shown by microcline, but from which it is distinguished by the absence of " peg-structure " and the abrupt termination of one kind of twin at the junction with another.

The felspar has begun to suffer the saussuritic change so common in this mineral. The change has not developed much—a little cloudiness indicating it when the mineral is seen by ordinary light, and the characteristic fibrous, highly-coloured polarized masses of it when seen under crossed nicols establish its nature.

The biotite developed in the rock is of the ordinary kind. It is pleochroic in brown, dark and light, it gives high polarization colours and straight extinction ; it is developed in prismatic forms which tend to be linearly arranged.

The chief characteristics of the hornblende are its bluish-green colour and its pleochroic nature. There is some little suggestion of a linear arrangement of the individuals of this mineral.

The sphene exhibits those properties which render it so easily determinable, brown colour, high relief, high double refraction and wedge-shaped forms. The apatite is found in colourless, highly refringent grains which have very low birefringence. Epidote and zoisite occur as colourless (or nearly so) masses in the rock. They occur on the edges of hornblende crystals, sphene crystals, and occasionally, on the borders of the felspar crystals. The higher double refraction of the epidote serves as a means of discrimination between it and the zoisite.

The rock is holocrystalline. Its texture is granulitic. There is, however, an imperfect grouping into light and dark portions of mineral matter ; that is, there is a suggestion of incipient, or partly developed, gneissosity.

(3) The Basalts.

There are four basalts treated in this work, Nos. 909, 934, 875, 224. Three of them are somewhat akin to one another, but the fourth is of an entirely different nature. The last-mentioned rock, No. 224, is definitely extrusive. The conditions under which its magma consolidated being patent from its vesicular nature.

Except for the grain-size the other three rocks could well be called dolerites. But as Hatch,* points out it is difficult, even by reference to textures and mode of occurrence, frequently to differentiate between basalts and dolerites. He refers to the oligoclase basalts which Harker describes as "fine-grained, though definitely intrusive

* " Petrology," p. 336. (8th Edition.)

rocks forming sills in Skye," and to "lavas almost similar in appearance and composition being described from the Midland Valley of Scotland, while a coarse-grained oligoclase dolerite occurs in a sill at New Abbot, Derbyshire." Seeing that one of the three rocks, No. 875, here being described is an oligoclase basalt and another, No. 934, andesine basalt, it will be apparent that the occurrence of these rocks in the moraines renders it impossible to say whether they are intrusive or extrusive. One of the rocks, No. 909, shows a variation in texture which is evidence of alteration in the conditions under which the magma consolidated.

No. 909.—*Basalt.*

This rock in the hand specimen appears black, fine-grained and dense.

Under the microscope there are revealed four main mineral components. Two are considerably in excess of the other two. They both occur in two generations. The phenocrysts are in the typical ophitic intergrowth of dolerites while the groundmass has an intergranular texture. Except for a variation in size and an associated increase in the ratio of the length of the lath to its width the laths of felspar in the groundmass are much like those of the phenocrysts and have the same relative orientation.

The phenocrysts of augite are ophitic to the large felspar laths and ophitic to subophitic to the second generation of the felspar. The second pyroxene generation occurs as small grains of somewhat darker hue than the earlier augite among the large and smaller felspar laths. We have, then, good evidence for postulating that during the depth-history of the magma the felspar and pyroxene began to crystallize. This resulted in the formation of the large ophitic phenocrysts. Due to some tectonic movement the magma was forced to a region where crystallization was more rapid, possibly a surface flow—and now both felspar and augite crystallized in small masses which produced the groundmass between the pre-existing intergrowths. The augite phenocrysts nearly invariably show salite striae. They are of a pale brown colour and under crossed nicols give moderate interference colours. Simple twins and hour-glass structure are by no means infrequent.

The other two minerals are both derivative. They are magnetite and serpentine. Some of the magnetite may possibly be primary, but so frequent is the skeletal variety that this seems unlikely. It, with the serpentine, seems to have been derived from the alteration of the augite. There is a remote possibility that the serpentine is the only evidence of pre-existing olivine—but its dense structure and its intimate association with altering augite crystals point to its derivation from the pyroxene. There is an abundance of apatite needles in the mesostasis. There are also present a few grains of pyrites.

Rosiwal Analysis:

Felspar	40·0%
Augite	43·2%
Magnetite	12·2%
Serpentine	4·6%

Thus the rock is 3312 E. Mela Basalt (Johannsen).

No. 934.—*Andesine Basalt.*

Viewed in the hand specimen this is another dark, dense, aphanitic rock in which a dark mineral component is occasionally betrayed by a flash from a cleavage face.

Viewed under the microscope the main characteristics of this rock are its holocrystalline nature and dark coloration. The crystalline constituents are essentially pale-coloured augite and felspar. There is a marked tendency towards the development of uniform grain-size ; the augite is more or less equidimensional, whereas the felspar occurs in laths which are more considerably elongated. The mineralogical characteristics of these minerals may be summarized as follows:

The augite is very light-coloured, non-pleochroic. It is frequently simply twinned, its extinction is undulose, its double refraction is not very high (about ·022). The extinction angle, when the undulose nature of the extinction does not prevent measurements, is high (about 45°). The felspar is found in laths, poorly cleaved, showing poly-synthetic twins, undulose extinction ; where this does not prevent measurement the extinction on 010 is found to be about 22°. The polarization colours are low ; the plagioclase is basic andesine.

The dark nature of the rock is due to alteration products present. The chief of these minerals are serpentine, epidote, zoisite, sphene, ilmenite, leucoxene, and other opaque, platy iron (or titaniferous) minerals. Pyrites grains and apatite needles are also present. The serpentine is found in yellow-green infilling masses. They are slightly pleochroic, but have very low double refraction. The epidote and zoisite seem to be derived from the felspar as it suffered metamorphism.

There are a few grains of calcite which show a most interesting property. This mineral is biaxial with 2V about 20°. This is one of the features which Walker and Parsons* say characterize primary calcite. The other characteristics of this variety of calcite quoted by these authors are a pearly lustre (this, of course, cannot be observed in the microscopic grains of this rock), cleavage on e $(01\bar{1}2)$, incomplete extinction (a marked feature of the grains of this rock) and the trace of the cleavage on e $(01\bar{1}2)$ is marked by narrow bands which do not appear to be twin lamellae, but rather to represent a confused aggregation of carbonate. The twin lamellae shown in this specimen are markedly different from those which characterize ordinary calcite. They are here very poorly defined and of a most indefinite nature. The authors quoted record that Boeke,† determined that at a temperature of 970° + 5°C a reversible transition from $CaCO_3$ to $\alpha-CaCO_3$ occurs. These facts, together with the presence of augite, epidote and titanite, point to the interesting conclusion that the calcite found in this rock was formed at a temperature above 970°C and is most likely of primary origin.

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* University of Toronto Studies: Geological Series, No. 20, 1925.

† "N. J. Min.," 1912, 1, pp. 91-121.

The other group of minerals shows an interesting chain of alteration. These are abundant grains of ilmenite (perhaps magnetite). These grains occur in two main sizes, there are very few of an intermediate size. There is an occasional considerably larger skeletal crystal. This mineral has been derived from the augite, and it, in its turn, gives rise to leucoxene, white and opaque, and this, on staining and further change, forms darker opaque masses. These masses and the veins of serpentine and chlorite, and the general alteration to greenish matter in the augite itself account for the dark nature of the rock.

No. 875.—*Oligoclase Basalt.*

This is a dense, fine-grained, melanocratic holocrystalline rock. The weathered surface has become somewhat gritty owing to a removal of material from the spaces between the grains which remain. Microscopic examination reveals the following minerals.

Felspar intergrown with quartz corresponds to oligoclase or acid andesine. Augite occurs in pale brown non-pleochroic laths. It is much altered to chlorite, which is a green, non-pleochroic variety ; but, in the neighbourhood of magnetite grains, the alteration of the pyroxene has gone to make biotite. This mica shows a highly developed cleavage and exhibits pleochroism in different tones of brown. The augite itself is frequently twinned. Magnetite grains are rather commonly spread throughout the rock. A few grains of pyrites occur in the rock. They are easily recognized by their brass yellow colour in reflected light. Quartz is very sparingly present.

The augite laths are frequently euhedral, but the felspar laths are, at the most, subhedral. The particles are more or less even in size. There is micrographic intergrowth of quartz and felspar.

Rock No. 224 : vesicular olivine basalt.* This is a black, very vesicular rock, the vesicles being drawn out in fluidal fashion.

Microscopically the rock is very fine-grained and hyalopilitic (Plate VII., fig. 3). The predominant mineral is labradorite (about $Ab_{42}An_{58}$) in laths averaging about ·2 mm. in length, and with fluxion arrangement. The interstitial material is brown glass, thickly studded with minute octahedra and rod-like skeletons of magnetite. Colourless olivine in tiny prisms and granules is sprinkled through the rock, generally stained brown round the margin, suggesting an iron-rich variety ; it is much corroded. No pyroxene was observed in the rock. The vesicles are sometimes empty, at other times lined with a crust of botryoidal calcite with fibrous radial structure, and their centres may be filled with calcite or with a colourless isotropic substance of low refractive index which may be analcite.

The rock, which is evidently a fairly recent lava, may be termed an olivine basalt.

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* Description supplied by Dr. W. R. Browne on examination of the rock in the year 1920.

(4) The Dolerites.

The members of this group are Nos. 579, 647, 868, 871, 876, 879, 906, 922, 923, 938, 1219, 1225.

The dolerites are somewhat alike in general appearance.

Mineralogically, they are seen essentially to consist of labradorite and augite, usually with a proportion of secondary magnetite.

No olivine has been detected in the rocks although there are some regions occupied by serpentine which possibly represent earlier olivine. Even so, the amount of olivine must have been extremely small. Apatite occurs mainly in needles in what Browne calls "mesostasis."

No. 579.—*Dolerite.*

In the hand specimen this is seen to be a holo-crystalline, medium-grained, granular rock in which the melanocratic and leucocratic minerals occur in approximately equal quantities. The recognizable minerals are felspar and a ferro-magnesian.

Viewed under the microscope the average grain-size is seen to be 0·5 mm. The most obvious mineral is a pale violet, faintly pleochroic, titan-augite. Two cleavages are prominently developed, the extinction angle is large, about 46°. There is another pyroxene which has similar properties to the titan-augite under parallel light but which under crossed nicols is seen to have a much lower double refraction and straight extinction. This is taken to be enstatite.

Felspar occurs sometimes in micrographic intergrowth with quartz when it, no doubt, is orthoclase.

The main felspar mass is highly saussuritized, exhibits albite twin lamellae very abundantly, not so frequently pericline twin lamellae and less frequently an occasional carlsbad twin. Where the extinction angle was not too much obscured by the undulose extinction the felspar was found to be labradorite. There is some tendency to zonal structure, the peripheral regions being very albitic. There are very numerous apatite rods penetrating the felspar mass. The felspar is occasionally clear but there are more frequent regions of alteration to turbid masses, some of which are granular—showing cataclastic effects—but most are prismatic where whole laths are often completely saussuritized.

There is present quite an amount of magnetite. This mineral usually occurs in largish grains, it contains occasionally a centrally unchanged augite crystal.

The augite seems to change in the usual way. First to magnetite and chlorite (sometimes to chlorite only). Where magnetite grains are found in contact with chlorite the two usually suffer a further modification with the resulting production of pleochroic biotite. There is occasionally some zoisite to be seen in the neighbourhood of the pyroxene. It has been derived, most probably, by the alteration of this mineral.

The mineral composition by the Rosiwal method is as follows:—

Augite	36·3%
Felspar	58·7%
Biotite	4·5%
Magnetite	0·5%

In Johannsen's classification this rock would be called 3312 H.

No. 647.—*Dolerite* (*altered*).

This is a heavy, holo-crystalline, dark coloured rock.

The rock when viewed under the microscope is very dark. This is due to the absorption of light which has been brought about by the large quantity of iron oxides which permeate the rock. The average grain size is 4·3 mm. The constituent minerals have suffered alteration; particularly is this true of the felspar and pyroxene, the two main mineral constituents. The rock is holo-crystalline, the texture is sub-ophitic.

The felspar exhibits a few albite twin lamellae. Its double refraction is low, but many of its optical properties are obscured by haematite which penetrates the plagioclase to a very large extent. From extinction angle measurements, it is found to be oligoclase. It is very greatly saussuritized, the localised patches of saussurite extinguish straight and provide the felspar with a typical poikiloblastic appearance.

The pyroxene is very pale in colour; it has the ordinary prismatic cleavage, but in addition, a definite diallagic parting has developed. There is a concentric structure in the large crystals, and in these more than in the ordinary crystals the extinction is undulose. The double refraction is low; the mineral shows simple twinning on 100, bent hour-glass structure, and optic axial angle (2V) of approximately 50°—all characteristics of hedenbergite. In addition to this variety of pyroxene there is another which shows schiller structure, salite parting and higher double refraction. It is the more common pyroxene, salite. This variety of pyroxene shows even more strikingly a poikiloblastic texture than does the hedenbergite. The idioblasts are of chlorite.

There are comparatively large areas occupied by chlorite. This mineral has been stained a lemon yellow colour by hydrated iron oxides. It occurs in peculiar fibrous masses. Its extinction is straight, its elongation is positive and its double refraction is about 0·018. Occasional veins of this more highly birefringent chlorite interpenetrate a mass of less birefringent material whose orientation is typically felty, it is another variety of chlorite. All the chlorite has been derived from augite, it is pseudomorphous after augite. In some parts the derived mineral is in such a relation with the felspar laths that were it pyroxene the texture would be called ophitic.

Other more accidental minerals are calcite, which is found in a few largish grains, epidote which occurs mostly in the vicinity of the last mineral of this group, magnetite. The magnetite is mostly skeletal. The embayments and hollows are usually occupied by felspar but occasionally the infilling is pyroxene.

A Rosiwal examination showed the following percentage composition :—

Felspar	47·9%
Pyroxene	32·1%
Chlorite	14·4%
Magnetite (and pyrites)	5·6%

This puts the rock into 3212 P of Johannsen's classification. The name according to this nomenclature is meladiorite.

No. 868.—*Metamorphosed Augite Dolerite.*

Macroscopically examined this is seen to be a dark, fine-grained igneous rock. Some felspar crystals and dark ferro-magnesian minerals are visible to the naked eye. The rock seems to have undergone alteration to some extent.

A microscopic investigation reveals the following minerals present: andesitic labradorite having a composition very nearly $Ab_{50}An_{50}$; green hornblende with pleochroism very pronounced in greens and greenish brown ; augite, light brown in colour, showing alteration to hornblende ; magnetite, black, opaque ; epidote, colourless, high D.R., alteration product of felspar.

The rock has undergone pronounced alteration. This is best shown by the appearance of hornblende as a result of the alteration of the augite. There are patches of turbid material in the felspar which under high power and crossed nicols reveals a calcitic mass. Other parts of the felspar have changed to epidote.

A Delesse-Rosiwal linear measurement of the rock slide determines the mineral composition by volume to be as follows :—

Plagioclase ($Ab_{50}An_{50}$)	46·75%
Green Hornblende	30·16%
Pale brown Augite	20·87%
Magnetite	1·69%
Epidote	0·53%

From these figures the approximate chemical composition of the rock (by weight) has been calculated as follows :—

SiO_2	47·85%	MgO	7·48%	H_2O (+)	0·26%
Al_2O_3	16·22%	CaO	9·08%	TiO_2	0·45%
Fe_2O_3	7·72%	Na_2O	4·60%	MnO	0·17%
FeO	6·27%	K_2O	0·08%		
				Total	100·18%

Based on these figures the rock is found to appear in the C.I.P.W. classification as class III, order 5, rang 4, subrang 5 (Auvergnose).

No. 871.—*Augite Dolerite.*

This is a dark, very fine-grained, holo-crystalline, basic igneous rock. A few white crystalline specks and some dark minerals are visible.

Viewed microscopically the minerals present are seen to be a light coloured augite, numbers of laths of felspar, and some accessories including biotite, apatite, quartz, magnetite and chlorite. The felspar has the characters of bytownite. The existence of the quartz is of considerable interest. It occurs in two ways. One as a graphic intergrowth with the felspar, and the other as small crystalline grains exhibiting higher polarization colours than the plagioclase. The former of these occurrences proves the quartz to be primary. Apatite is present as small euhedral grains and also in great numbers of attenuated, highly refringent, needles interpenetrating the whole rock but especially the felspar. The biotite is found in a few isolated dark coloured prisms which are pleochroic and well cleaved. The borders are much altered, often to chlorite. Scattered through the whole are grains of opaque magnetite which mineral is rather prominent.

The rock is holo-crystalline and even-grained. The ssential minerals are augite and plagioclase. There is hardly any evidence of ophitic texture, but presence of bytownite (the rarest plagioclase) and micrographic intergrowth of quartz and felspar are interesting features. The whole rock is much discoloured, due to the presence of chlorite which resulted from the alteration of both biotite and augite.

No. 876.—*Porphyritic Augite Dolerite.*

This is a dense, fine-grained, holo-crystalline, melanocratic igneous rock in which the individual crystals are too small to be determined by the naked eye.

The microscope section reveals that the most abundant mineral present is augite. Its colour ranges from a very pale grey to moderately dark brown. All colours are non-pleochroic. It is frequently seen to be in ophitic intergrowth with felspar laths. Twins are common: usually simple, but occasionally polysynthetic. Hour-glass structure is very poorly exhibited in some crystals.

Felspar laths are next in abundance to the augite. This mineral is seen in crystals which are considerably smaller than the average augite crystal and which are very rarely clear; the more usual occurrence is that of turbid laths whose turbidity is due to alteration to saussurite. The cleavages are not as clearly defined as is usual in felspar in such rocks.

The laths are polysynthetically twinned, and from the extinction of albite lamellae on 010 the variety of plagioclase is found to be labradorite (extinction angle 25°). The labradorite laths occur as an infilling between the augite crystals.

Considerable alteration has taken place in the rock. The pyroxene has altered to uralitic hornblende whose pleochroism is readily perceptible. The felspar, as already mentioned, has altered to saussurite. Grains of magnetite (rather common) and pyrites (rare) are easily detected by reflected light. The texture developed is intergranular.

No. 879.—*Augite Dolerite.*

This is a dark, fine-grained, holo-crystalline igneous rock in which crystals of felspar and augite can be detected with difficulty by the naked eye.

The commonest mineral present in the microscope slide is augite which occurs in well crystallized forms. The crystals developed are often almost completely euhedral, the faces being well-defined, the edges of the faces being sometimes bordered by a multitude of minute magnetite grains. The augite crystals are usually pale greyish brown, but sometimes a green colour is observed. This is due to alteration: the alteration product being plainly pleochroic, and tending to a fibrous form ; it is apparently, uralitic hornblende. In the vicinity of magnetite grains, biotite is the more usual alteration product. Simple twinning is evident in the crystals of this mineral.

The felspar crystals which occur as laths are altered in patches to show a turbidity not evident in those parts where such alteration has not taken place.

The laths commonly exhibit albite twin lamellae and, very rarely, pericline polysynthetic twin lamellae. Extinction angles on 010 from these lamellae are respectively 30° and 20°, showing the plagioclase to be labradorite. The laths of plagioclase fill the spaces between the larger augite crystals. The laths of felspar often include highly refringent rods of apatite which, quite frequently, are arranged in parallel alignment. Another feature occasionally exhibited by the felspar laths is an undulose extinction. The texture developed in the rock is intergranular.

No. 906.—*Dolerite.*

This is a dense, fine-grained, melanocratic rock. The crystals are too small to be identified with the naked eye, yet they are of sufficient size for the hand-specimen to be identified as holo-crystalline. The exposed surface shows glacial striae.

The rock is seen to be a true dolerite when viewed under the microscope. It has the ophitic texture of dolerites developed to a high degree. There are two main mineral constituents, felspar (labradorite) and augite. The felspar occurs as multiple twinned laths. It is little altered, usually being quite clear, but occasionally some saussurite is seen. The augite is very pale brown in colour. The salite texture, so frequent in these dolerites, is almost entirely absent. It is occasionally simply twinned. The double refraction is suggestive of pigeonite, but inability to measure the optic axial angle rendered impossible a conclusive determination. Where the augite is smaller grained and where salite textures are seen the slide is frequently much darker due to the alteration minerals present. These are mainly magnetite and biotite which, in places, is giving way to chlorite.

Grain size 0·07 mm.

Mineralogical Composition :—

Percentage Mineral Composition by volume :—

Augite	51·7%
Felspar	42·6%
Magnetite	5·5%

It is 3312 H, *Mela Gabbro* (Johannsen).

No. 922.—*Augite-Magnetite Dolerite.*

The surface of this, though very fine-grained, differs from that of 934 and 938 in that it is much lighter in general appearance—the rock is, however, melanocratic.

A microscopic examination shows that this augite-magnetite dolerite has undergone considerable change. The rock consists of a mass of augite and felspar laths arranged in the typical dolerite manner. Some of the augite crystals tend to be more equi-dimensional than prismatic. The augite and felspar are sub-ophitically intergrown. There are several clearly defined phases in the alteration of the augite. Some crystals are almost entirely unchanged. There are others with a border zone of green where alteration to chlorite is perceptible. The next phase is characterized by the development of magnetite (or ilmenite). The early stages of this development are shown by skeletal crystals of these new minerals. Further change has produced massive crystals of magnetite except in the central region where there is an occasional residue of unchanged augite : more usual, however, is the presence of alteration chlorite and accompanying biotite with a little residual augite in this central region. Sometimes felspar laths seem to be ophitically intergrown with magnetite.

The felspar present in this rock is usually marginally clear, but centrally cloudy ; sometimes it is completely homogeneous-looking (quite clear) when viewed by polarized light. Cleavage is only moderately well developed. Micrographic intergrowth with quartz is common ; occasionally such intergrowth is shown combined with similar arrangement with both apatite and rutile needles. Apatite needles, also, are common throughout the felspar mass.

No. 923.—*Porphyritic Augite Dolerite.*

This is a heavy aphanitic rock. The typical ophitic texture is developed to a limited extent. A variation from the ordinary nature of dolerites is seen in the development of phenocrysts of augite. These phenocrysts are usually simply twinned. From observations of colour, relief, cleavage, double refraction, extinction angle and configural relationship with the felspar the phenocrysts are seen to be essentially the same in nature as the grains of pyroxene which, with felspar laths, form the groundmass of the rock. Double refraction and extinction angle measurements indicate that the pyroxene is a member of the pigeonite-hedenbergite series, near the pigeonite end. Some of the phenocrysts enclose felspar laths in true ophitic manner, others are sub-ophitic to felspar, and some do not include felspar at all. The undulose extinction of the pyroxene and the occasional pittings in the mineral indicate that it is beginning to suffer alteration.

The felspar is like the pyroxene in two main respects. It is present in two generations and it is remarkably fresh. The unaltered nature of the two chief mineral components of the rock results in the rock as a whole having a clear appearance and the original igneous textures have been preserved remarkably well. In the larger laths both carlsbad and albite twins occur; in the smaller laths of the groundmass only albite twins are seen. The large laths are andesine with $Ab_{60}An_{40}$; the smaller ones are slightly more basic, being labradorite with $Ab_{45}An_{55}$.

Of the other minerals present magnetite is the most abundant ; it occurs as numerous octahedra scattered through the rock and also as a fine dust-like matter rendering cloudy some areas in the pyroxene.

No. 938.—*Dolerite.*

This is a dark, aphanitic, dense rock.

A microscopic examination reveals that this rock has a definitely ophitic texture, but it is much more fine-grained than 579. The average grain-size is 0·16 mm. It resembles 579 very much in its mineral content ; its mineralogical composition being augite, labradorite, magnetite, chlorite, epidote, and rarely calcite.

The augite is pleochroic in pale purple brown. It is occasionally simply twinned. It has an undulose extinction but none-the-less its extinction angle is easily seen to be large. It is centrally altered (as is the augite of rock 1219) to chlorite which is pale green and very slightly pleochroic. The rare grains of highly birefringent epidote seem to be derived from the alteration of the augite.

There is an ophitic intergrowth of labradorite with the augite. The felspar is much saussuritized. An interesting feature is the presence of a Baveno twin.

There are magnetite grains present. They, too, are derivative products of the alteration of the augite and chlorite.

Occasionally apatite needles are found in the rock.

The modal nature of the rock is shown in the following mineral composition :
Augite 36·1% ; felspar 54·0% ; magnetite 9·8%.

This places the rock in 2312 H (gabbro, hypabyssal equivalent).

No. 1219.—*Dolerite.*

This is a dense, fine-grained, melanocratic, holocrystalline rock in which some of the pyroxene crystals have suffered a change which has rendered them lustreless and these dull regions form local zones whose nature differentiates them from the rest of the rock.

Under the microscope the rock is resolved into an ophitically intergrown mass of labradorite and nearly colourless augite ; because of its relatively large development magnetite must be ranked as an important mineral, although the presence of considerable quantities of the mineral in the skeletal form as well as idiomorphic octahedra suggests that some of it, at least, is secondary (Plate VI, fig. 1.).

Original olivine is represented by pseudomorphs of green serpentine ; the central part of one of the original crystals being occupied by a carbonate mineral which is biaxial. It is probably calcite which has been observed in a similar rock of this series, No. 934.

The felspar, in addition to being ophitically intergrown with the augite, exhibits the three more common types of twinning, albite, pericline, carlsbad. Then, again, some laths are so large as to warrant being called phenocrysts.

Apatite needles occur in great abundance in the mesostasis. Some biotite of dusty appearance has developed to a very small extent.

No. 1225.—*Dolerite.*

This is another melanocratic, dense, heavy, fine-grained basic rock. It is holocrystalline and definitely doleritic.

Seen in microscope section this rock has an intersertal texture. There are two generations of both felspar and pyroxene. A considerable development of magnetite is also noticeable. The larger felspars and pyroxenes are ophitically intergrown. The felspar laths are hypidiomorphic and the augite granules allotriomorphic.

The pyroxene has a purplish-brown colour. It is non-pleochroic. The extinction angle, though high, is frequently undulose. Hour-glass structure is developed. Occasionally the augite mass completely enwraps a felspar lath. The pyroxene is the variety known as pigeonite—the optic axial angle is 38° and the extinction on the 100 cleavage is 36°. The birefringence is 0·028. Simple twins on 100 are not uncommon. There is a more or less concentric bending of the augite cleavages. Where this is more characteristically developed the extinction is more pronouncedly undulose. The double refraction is comparatively low.

Rarely, small patches of serpentine are to be found. These probably represent rare grains of olivine which have been entirely replaced by this mineral. There are one or two patches where the serpentine is contained within augite.

In the mesostasis are numerous apatite rods arranged linearly. The felspar occurs in laths which are, for the most part, clear and unaltered. Cracks have developed within it to some extent. These are filled by a green serpentinous mineral. The cracks have usually developed along cleavage lines. Their curved nature indicates that the felspar has been subjected to considerable stress. It is labradorite of $Ab_{65}An_{35}$ composition.

There are considerable quantities of magnetite often bordered by chlorite or chloritic biotite. These minerals seem almost entirely to be derived from the metamorphism of the augite.

Rosiwal Analysis—

Augite	35·6
Felspar	43·3
Mesostasis	9·9
Magnetite	1·2

(5) THE GABBROS.

This group of rocks is represented by Nos. 423, 1220. In general characteristics they approximate very closely to the gabbro group but in some details they do not strictly do so. For instance, 1220 is texturally allied to the dolerites.

In mineral content No. 423 is somewhat different from No. 1220. This latter rock consists essentially of augite and plagioclase. The plagioclase of No. 1220 is a basic labradorite.

No. 423 contains considerably more plagioclase than the sum of all the other mineral components. In 1220 these mineral subdivisions are roughly equal. In spite of this, the basic nature of No. 423 is rendered apparent by the presence (in the mode) of some 10% of olivine, and less conclusively by the presence of titan-augite. The metamorphic nature of some of the minerals is discussed more fully in the detailed description of the rock. It will suffice here to mention the very ready change (under suitable conditions) of biotite to chlorite, and the interesting occurrence of a little lawsonite in this rock. This mineral is seen to be one of the derivatives of the plagioclase of the rock.

No. 423.—*Gabbro.*

This is a holo-crystalline rock in which there is a preponderance of leucocratic mineral matter over melanocratic. Under the microscope this rock is seen to be composed of plagioclase, a peculiar titan-augite, olivine, magnetite, biotite-chlorite, apatite and lawsonite.

The labradorite is $Ab_{45}An_{55}$. It exhibits pericline, albite and carlsbad twin forms. It occurs in masses and laths. Some parts are pellucidly clear while others are much altered to a turbid highly birefringent mass. Among the metamorphic products of the plagioclase is lawsonite, a white mineral of moderate relief and medium birefringence.

There are incipient and micro-crystals of pale green hornblende. These crystals seem to be forming at the expense of the felspar and so apparently give further evidence in favour of Lacroix's contention that some metamorphic amphiboles contain potential felspar. The felspar is often zoned, the extinction frequently being undulose.

The ferro-magnesian minerals are interesting. There is a beautiful mauve titan-augite (Plate VI., fig. 4). It is faintly pleochroic. A zonal structure is frequently seen in ordinary light. Difference of structure and composition are rendered evident by a difference in colour. The zonal nature is made more evident under crossed nicols where different polarization colours differentiate between the two components. Another interesting alteration is seen in connection with this mineral. It had grown round euhedral apatite crystals. These crystals seem to have been centres of instability in the subsequent history of the augite. Alteration in the mineral structure of the pyroxene is apparent by reason of the difference in birefringence in these areas. The alteration areas are roughly lath-shaped and they have for nuclei perfect rectangles of unaltered apatite.

The other essential ferro-magnesian present is olivine. It occurs in fairly large granular masses. The felspar frequently seems to be more completely crystallized than the olivine—thus suggesting crystallization from the parent magma at an earlier stage. In one or two instances there are embayed olivine crystals which seem to have grown round earlier laths of felspar, that is, there is a poikilitic intergrowth of felspar and olivine. The ilmenite is frequently skeletal, sometimes mesh-like. The spaces of the meshes are not infrequently filled with biotite. The biotite in the rock seems to have been produced in two ways. The first is the mineralogical change which has set free ilmenite as well as mica from the pyroxene. Under these circumstances the biotite is a deep reddish brown, with particularly strong absorption and marked pleochroism. In the second mode of occurrence the biotite is a more or less chlorite variety. It is bleached and greenish. It here seems to be one of the final products of the olivine alteration. This alteration has given the olivine a peculiar appearance. Large cracks where metamorphic minerals have been produced, penetrate the grains in all directions. Sometimes the alteration has given rise to rod-like crystallites, perhaps rutile rods. These rods are arranged along the cracks and are so oriented that a multitude of minute crosses has been produced.

Rosiwal mineral analysis—

Plagioclase	71·8%
Titanaugite	8·9%
Olivine	10·8%
Magnetite	3·3%
Biotite-chlorite	4·3%
Apatite	0·9%
Lawsonite	p.

The rock is 3312, *Mela Gabbro*, in Johannsen's classification.

No. 1220.—*Gabbro Gneiss.*

This is a holocrystalline, medium-grained rock in which melanocratic and leucocratic minerals occur in nearly equal proportions. Average grain-size is 2·2 mm.

The rock represents the earliest phase of metamorphism. The original igneous-rock structures are preserved in their entirety. The metamorphic nature of the rock is made evident by the relationship between the pyroxene and amphibole. It is of interest to note that here is a rock which is commencing the alteration which if uninterrupted would result in the production of an amphibolite, yet neither of the initial phases mentioned by Harker as being typical of the early grade metamorphism of dolerite in the Highlands or the Lizard area is occurring. In the former the formation of chlorite is a sign of early metamorphism and in the latter epidote appears, to a greater or less degree, a characteristic mineral of all grades. In this rock neither chlorite nor epidote has developed. The nearly colourless pyroxene present has frequently given way to pseudomorphous bastite which in turn has coalesced into compact crystals of considerable size of ordinary green-yellow hornblende.

There is not nearly as much magnetite in this rock as there is in some of the less altered dolerites from these moraines. Apparently the separation of magnetite and the production of bastite-to-hornblende are variations of the early changes which pyroxene minerals can undergo.

The felspar of the rock is in a remarkably unaltered state. There are only occasional sporadic developments of saussurite, elsewhere the mineral is quite clear and fresh. The twinning and extinction are hardly affected ; these factors are ready indicators of stress effects and internal molecular rearrangement. From extinction angle measurements the plagioclase is found to be basic labradorite with $Ab_{45}An_{55}$. This shows that the differentiation of this mineral into more calcic and more sodic portions has not yet begun.

Among the adventitious minerals are apatite and magnetite.

Rosiwal Mineral Analysis—

Hornblende	32·1%
Felspar ($Ab_{45}An_{55}$)	45·1%
Augite	22·8%

SECTION III. METAMORPHOSED BASIC IGNEOUS ROCKS.

(1) General Discussion.

The general nature of this discussion is determined by Harker's conclusions of the basic igneous rocks. Others whose work is of particular importance in the guidance and suggestion of thought are the works on the epidiorites of the north western Highlands, but more especially Tilley and Wiseman.

To return to the classification set forth by Harker. He correlates the stages of the metamorphism of the dolerite sills of the Highlands with that of the numerous horizons of the Dalradian and Moine series into which they have been intruded. In this way he is led to recognize the following six zones of increasing metamorphism.

(a) calc-albite-chlorite-schist.
(b) albite-epidote-chlorite-schist.
(c) albite-epidote-hornblende-schist.
(d) plagioclase-amphibolite.
(e) epidote-(or zoisite-)amphibolite.
(f) garnet-plagioclase-amphibolite.

Although it is obviously impossible to make such a certain correlation with erratics from moraines, yet the similar arrangement of intrusive doleritic dykes into surrounding metamorphosed rocks renders it possible for one to diagnose with some confidence the conditions which obtained in the Cape Denison region during the metamorphism of the dykes themselves. The great similarity between these rocks and those of the Highlands has been mentioned by several investigators but when we find that members of all but the first of the above six series of rocks of Harker are represented in the moraines, we realize more certainly the similarity in original rock composition and structure and also in metamorphic history and final mineral composition.

As has been suggested above, the last five (b to f) of Harker's series of rocks are certainly represented in the specimens from the moraines. In the collection some series are more plentifully represented than others, (group (d) for instance, being represented by a single member and group (e) by some seven members). Modifications produced by retrograde metamorphism are noticeable, representatives of such processes being present in all groups.

For convenience of description in the sequel we shall call the series grades and treat them in the following manner :—

Grade A (Series a of Harker), absent.
Grade B (Series b of Harker), specimens Nos. 455, 574, and 965 (retrograde).
Grade C (Series c of Harker), specimens Nos. 468, 636, 1218, 1217, 1216.
Grade D (Series d of Harker), specimen No. 553.
Grade E (Series e of Harker), specimens Nos. 193, 548, 578, 887, 1215, 115 (retrograde).
Grade F (Series f of Harker), specimens Nos. 1259, 517.

The general characteristics of each of these grades will be dealt with immediately, the detailed descriptions of each of the rocks being given in a subsequent division.

GRADE B. THE ALBITE-EPIDOTE-CHLORITE-SCHISTS

AND

GRADE C. THE ALBITE-EPIDOTE-HORNBLENDE-SCHISTS.

These two grades are treated together because it seems that a single grade wherein both chlorite and hornblende develop simultaneously would represent the more usual type of mineralized change which has occurred in these rocks. There are rare instances where an earlier development of chlorite can be traced to a subsequent development of hornblende, but this is the exception not the rule.

Indeed, Wiseman (p. 371) urges that the simultaneous development of hornblende and chlorite from augite and felspar is to be expected. The members of the present discussion confirm his conclusions. There are specimens in this collection which show centres of unaltered augite within peripheral altered hornblende. There are also specimens which show needles of hornblende set in a mass of felspar, clear evidence of the assumption of a considerable portion of the composition of the felspar by the hornblende in its formation. Again, throughout all the members of the lower grades of this series there are intimate associations of hornblende and chlorite where it is impossible to say that one is derived from the other but where it seems almost obvious that they have developed contemporaneously. These three points are the arguments Wiseman has used in support of his contention, and the frequency of these features in the rocks of this collection give strong confirmation to his theory.

The small felspar content in some of the members of these groups might suggest that they belong to a higher grade, but in reality it shows that so much of the original felspar material has been assumed by the newer hornblende that very little is left (Plate VII., fig. 1). The acidic nature of the felspar shows that the lime of the plagioclase has been used most freely in this reaction and that the sodic part has proved less suitable. Again, the conclusions reached agree with those of Wiseman (p. 372), thus showing the very close relations which exist between these Antarctic rocks and the low grade epidiorites of the Highlands.

The presence of some calcite in Nos. 965 and 468 shows that they are either end members of Group I or that they are retrograde members of the present groups. In the case of No. 965 the scaly nature of the calcite and its scattered distribution are more suggestive of retrograde effects than progressive ones ; but the decision in the case of No. 468 is not so easy. The occurrence of the mineral suggests that it is a remnant of non-assimilated lime matter from the felspar, but the reason for not immediately accepting this is the peculiar optical nature of the mineral. It is definitely biaxial and so may possibly be aragonite, yet there are not many (if any) records of this mineral in calc-albite-chlorite-schists. If, on the other hand, it is biaxial calcite it must have crystallized at a temperature above 970°C. which seems to be unduly high for a low grade metamorphic rock. It seems equally high for a retrograde formation of calcite. No solution of the problem has been found as yet.

A series within Grade C consists of rocks 1218, 1217, 1216. They show peculiarities which are fully treated in their detailed descriptions. The end member of this little series is No. 1215 and, although not a member of Group C, its detailed description is given with those of the other three, no better place being found for it.

GRADE D.—THE PLAGIOCLASE AMPHIBOLITE.

Little need be said here of this specimen (No. 553) except that it is nearly a standard member of Harker's series (d). The variation is brought about by the presence of some little calcite showing that retrograde metamorphism played a part in the final nature of the rock.

GRADE E.—THE EPIDOTE (OR ZOISITE) AMPHIBOLITES.

The members of this group show the most important features of Harker's series (e). Generally, there is a marked increase in the amount of hornblende, a decrease in chlorite, sphene and felspar, and an added importance given to the minerals of the epidote suite. The felspar tends towards andesine.

GRADE F.—THE GARNET-PLAGIOCLASE AMPHIBOLITES.

Even though there are only two members of this group represented they show the marked variations in garnet content which Harker (p. 283) says typifies rocks of this kind. In No. 517 very little of this mineral occurs, whereas in No. 1259 it is one of the most prominent minerals present. They differ also in the kind of felspar they contain, that of No. 517 being andesinic but that of No. 1259 is an acid oligoclase. No. 517 contains a large amount of chlorite (delessite) which suggests that this rock is showing the mineralogical readjustments required by lowering of temperature and decrease of pressure subsequent to the relief of metamorphic conditions. No. 1259 is practically free from chlorite of any kind, but contains notable amounts of biotite and lawsonite, the last mineral probably representing, to some degree at any rate, calcic matter which is present in the other rock as epidote and chlorite.

An increase in coarseness of grain size in the higher grades of the members of this metamorphic suite is shown by these last two rocks. In No. 517 the grain-size is such that the rock is best described as a gneiss.

(2) Detailed Descriptions of Rocks.

GRADE B.

No. 495.—*Felspar-Chlorite-Biotite-Schist.*

This is a dense very fine grained rock which has a tendency towards schistosity. Occasional light coloured minerals can be seen but they are too small to be determined by the naked eye.

Under the microscope the rock is resolved into a schistose aggregate of highly saussuritized felspar—acidic, probably oligoclase—quartz, in very small grains, much chlorite giving rise to biotite, some hornblende and sphene and apatite.

The quartz and felspar occur in poorly defined bands which more or less alternate with those of biotite-chlorite. Frequently, however, the streak of green mineral encloses a patch of leucocratic matter with the resulting production of lenticle or eye-shaped mass. The chlorite appears to have developed from both olivine and pyroxene. In the latter case it presents a peculiarly pitted appearance when viewed under crossed nicols. The actual chlorite gives ultra-blue interference colours, but the pittings resemble calcite in that their double refraction is extremely high. A possible explanation of the phenomenon is that the chlorite represents the magnesian content of the original pyroxene and the pittings the calcic.

The quartz and the acidic felspar are both metamorphic derivatives. The felspar is sometimes twinned, the lamellae frequently being cuneiform and very ill-defined. A few grains of epidote give an indication of the change which the lime of the original plagioclase has undergone.

The sphene is much more pleochroic than usual ; there are not only marked variations in absorption intensity but also an associated selective colour occurs. The colours of pleochroism are pale yellow brown and dark reddish brown. The sphene exhibits lamellar twinning, most probably on 221 ; a different variety—simple, on 100—also occurs.

No. 574.—*Albite-Epidote-Chlorite-Schist.*

Two differently coloured mineral complexes are seen to compose the essential components of this rock. One is dark, hornblende, and occurs to great excess, the other is light and consists of quartz and felspar. The amphibole crystals are large, often being up to 1 cm. in length.

This is a rock of the kind known as albite-epidote-chlorite-schists to Harker (p. 279) where he is describing the " epidiorites " of the Highlands. Here we have delessite as the variety of chlorite developed.

The rock contains a considerable number of important minerals which have a composite composition more or less equivalent to that of hornblende. These minerals are albite (with possibly some quartz), epidote, sphene and zoisite.

The most striking feature of the hornblende is its poikiloblastic nature ; the number and size of the contained minerals frequently increases towards the end of a crystal of hornblende where a definite reaction area of hornblende, epidote and felspar is to be seen.

Suggestions of the original nature of the felspar arrangement are given by the porphyroblasts of this mineral ; although it is streaked out and only faintly twinned yet definite boundaries are revealed by virtue of optical discontinuity. There are other regions, however where the felspar is not at all turbid, where saussuritic products are almost entirely absent and where all trace of the parent rock has disappeared. In the large turbid porphyroblasts occur numerous small crystals of sphene and epidote. These minerals suggest that a differentiation of the felspar into divisions has occurred and that the more calcic portion has gone towards the production of these minerals. Very frequently there is a belt of crystals. These may fulfil the function of carrying by molecular diffusion the part of the felspar which passes into a " potential state as part of the molecular composition of a complex amphibole." (Harker, p. 281).

The rock differs from the suite Nos. 1215 to 1218 in its complete absence of biotite. Whereas the last of that series has gone through all the stages of metamorphism typical of the " epidiorites " from a calc-albite-chlorite-schist to an amphibolite, this rock (574) seems to have followed the course of the green schists of the " Old Lizard Head Series."

No. 965.—*Calc-Albite-Zoisite-Hornblende-Schist.*

This is a coarse-grained (grain-size about 8 mm.), holo-crystalline, melanocratic rock. It is almost entirely composed of hornblende whose crystals are present in a granular aggregate. A little pyrites is also present.

Microscopically examined, the texture is seen to be porphyroblastic ; large porphyroblasts of hornblende occur almost exclusively. There is a quasi-groundmass in which bent laths of apatite, long leads of magnetite and occasional smaller porphyroblasts and granoblasts of albite occur. The hornblende occurs to such a large extent that, except for the few minerals mentioned, the rock is hornblendic.

The hornblende is strongly pleochroic with Z light olive green, Y deep olive green, and X yellow green. The absorption formula is $Z < Y < X$. The hornblende poikiloblastically contains small idioblasts of clear, low refringent acid plagioclase. The hornblende has been derived from pennine which is found in definite parallel arrangement and in combination with the amphibole prisms. There are associated with the main hornblende long, bladed, fibrous crystals of another amphibole, actinolite. This mineral is pleochroic, with X pale yellow Y green yellow and Z green. There is occasionally a plumose arrangement of the actinolite fibres.

The felspar content of the rock is mostly to be found in the porphyroblasts of that mineral where it is seen poikiloblastically to contain irregularly oriented hornblende crystals—it is as if the hornblende has taken up some of the potential felspar matter during its development. The felspar here is much clouded by reddish-iron mineral matter. There are, too, occasional traces of much saussuritized felspar. In addition to this kind of occurrence of felspar there is some felspar granulated by cataclastic effects in the veins between the main amphibole masses. The felspar grains are here found in a mosaic formation.

Epidote is not found to a very large extent save in the vicinity of calcite crystals. Zoisite is somewhat more common.

Apatite is found on a larger scale than is usually the case. It is found in long bent veins penetrating the main hornblende mass.

GRADE C.

No. 468.—*Chlorite-Felspar-Hornblende-Schist.*

In the hand specimen this rock is melanocratic, dense, heavy and fine-grained.

Viewed microscopically the texture noted is in part porphyroblastic but mainly crystalloblastic. The porphyroblasts consist of chloritic areas of prochlorite which seems to have been derived from pre-existing olivine. The prochlorite is not very abundant, but where it is found it occurs in fairly large masses. It is of a light green colour, faintly pleochroic. Under crossed nicols it assumes a peculiar brown colour (due to strong dispersion) and resolves itself into a mass of radiating fibres which take on a definite rosette appearance.

The main mass of the rock consists of a more or less granoblastic aggregate of hornblende, felspar, epidote, sphene, magnetite and calcite.

The hornblende has a tendency towards a nematoblastic arrangement. It is pleochroic, with Z dark green, Y green-brown and X pale brown-green. The absorption formula is $Z > Y > X$. The hornblende is occasionally twinned on 100. Quite frequently it is seen poikiloblastically including other minerals. Of these there are clear felspar, probably albite or andesine, magnetite as very small skeletal crystals, calcite occurring as a fairly common infilling, chlorite, and sphene in small particles of definite crystal form.

The felspar is found, not only included in the hornblende, but also to a much greater extent in the spaces between the hornblende crystals. Sometimes the felspar is seen to be cloudy in ordinary light and between crossed nicols it is thrown into a highly saussuritized mass. There is no suggestion of twinning ; the felspar seems greatly altered from the original variety of the parent igneous rock. Occasional laths of turbid felspar are indicative of the original rock being doleritic or gabbroic. At other places the felspar has been resolved into clear patches of irregular outline ; they are in part albitic and in part quartzose. The difference is made manifest by the uniaxial interference figure of the latter.

Epidote occurs in pale grains of high relief. Usually it is idioblastic to felspar and chlorite. It is xenoblastic to sphene. The epidote has been derived from the alteration of both hornblende and felspar. There are a few grains of clinozoisite which exhibit the usual ultra-blue interference colours.

Calcite is found as small crystals scattered throughout the rock. It is most closely associated with felspar and amphibole. It seems to have been formed at the expense of the former and to be providing material for the production of the latter. As Harker suggests (op. cit. p. 279) the chlorite and calcite of a calc-albite-chlorite-schist give place first to epidote to form an albite-epidote-chlorite-schist and then to hornblende with the accompanying production of an albite-epidote-hornblende-schist. We have in this rock sufficient remnants of the earlier chlorite, calcite and epidote to see that the mode of formation of amphibolites suggested by Harker is the correct one. Some of the calcite is biaxial. The optic axial angle is small, about 10°. This means that either the calcium carbonate has crystallized as aragonite or as calcite at a temperature above 970°C. (Winchell, 2nd Edition, Part II, p. 74).

Magnetite usually occurs as octahedra in the chlorite. Sometimes, however, it is found as a nucleus around which sphene has grown.

The crystalloblastic order is sphene and magnetite, epidote, hornblende, calcite and felspar and quartz.

Rosiwal mineral analysis: percentage by volume—

Epidote	3·1%
Hornblende	43·9%
Felspar	26·9%
Sphene	0·8%
Chlorite	25·0%
Magnetite	0·5%

No. 636.—*Albite-Epidote-Hornblende-Schist.*

This is a fine-grained schistose rock, essentially composed of black, dense hornblende ; there are, however, veins of quartz and felspar which traverse it.

The part of the rock which has been sectioned consists of hornblende-felspar matter traversed by a band of quartz-felspar material which is about 0·5 cm. wide.

The former part consists of a granoblastic aggregate of green hornblende and plagioclase. The hornblende is pleochroic with Z blue green, Y dark olive green and X yellow brown. The absorption formula is $Z > Y > X$. The hornblende is usually compact, but some crystals exhibit poikiloblastic structure. It, for the most part, is higher in the crystalloblastic series than the plagioclase although some prisms wich embayed sides show that this is not always the case. There is a certain minor proportion of biotite, pleochroic in dark brown and straw colour which is giving place to chlorite, some of which gives ultra-blue interference figures and other parts show the rosette structure and peculiar brown colour under crossed nicols typical of prochlorite. The biotite is sometimes less fibrous, under which circumstances it is poikiloblastic having as inclusions small grains of quartz. Definite reaction bands are seen between these two minerals. Octahedra of magnetite and lozenges of pleochroic sphene with an occasional hexagon of apatite are also present. The felspar is acid andesine ($Ab_{65}An_{35}$). It is usually quite turbid—being altered to a highly polarizing mass of saussurite. Epidote is a conspicuous alteration mineral. Some is practically colourless and non-pleochroic, while other is a bright yellow and shows marked absorption.

The vein of quartz and felspar is a granoblastic mass of undulose-extinguishing material. Here the felspar is much more acidic, being very albitic indeed. It is much less cloudy than in the other bands, although some regions are here quite highly saussuritized. A grain or two of epidote is found with it.

No. 1218.—*Albite-Epidote-Hornblende-Schist.*

The four specimens, Nos. 1215-1218, form an interesting series of hornblende schists which have many of the characters of intermediate and late grades of metamorphism as exhibited by the epidiorites of the Highlands—the type rocks of this kind of change. There are certain idiosyncracies peculiar to the suite now being described which will be pointed out as the discussion proceeds.

As an introduction a few general remarks will be made. A more detailed discussion will be found when individual rock descriptions are made below.

None of the rocks has calcite present, they have clearly proceeded beyond the stage known as calc-albite-chlorite-schists. Not all contain chlorite, hence there is a progression to be seen here ; some do not contain epidote, a further stage in the development is here noticeable, but all contain biotite, a mineral which is absent from the highest grade of the Highland epidiorites, the amphibolites. This is a departure from the general course of metamorphism as set forth by the Scottish geologists. Suggestions will be made below which will possibly serve as an explanation of the variation, and also as an explanation for the appearance of sphene and the disappearance of chlorite and epidote and the diminution (and possible disappearance) of biotite (Plate VI., fig. 2).

The rocks will now be treated in turn in the manner characteristic of this work.

FIRST STAGE :—*No.* 1218 : *Albite-Epidote-Chlorite-Schist.*

This is a coarse-grained gneissic rock in which large black crystals of hornblende predominate. Felspar crystals occupy the interstices between the grains of amphibole.

This rock is one of the less altered of the albite-epidote-hornblende-schists. The felspar, as stated by Harker is not necessarily albite, here being oligoclase, but, nevertheless, still highly sodic. There are definite porphyroblasts of felspar which are apparently maintaining the positions they had in the earlier igneous rock. In places the felspar is highly saussuritized, but in others it is quite clear, showing well albite twin lamellae. Yet again, it is much crushed, with the consequent production of a mosaic of clear undulose particles. These particles are very suggestive of quartz which they may well be. If this is the case, they represent a very intense concentration of the silica from the original basic plagioclase. The lime has been concentrated in the epidote and possibly some of the felspar content has also gone towards the production of the amphibole.

The chlorite and biotite where they occur give a schistosity to the rock.

The chlorite is frequently found in contact with epidote making veins through large amphibole crystals. The amphiboles are then terminated by definite reaction borders whose presence is made manifest by the lower D. R. of the region concerned. It seems as if the chlorite-epidote zone is a real or, at least, a potential reaction zone itself. These minerals are combining by molecular diffusion and in consequence their bulk as actual entities decreases. The amphibole is increasing in extent at their expense.

From the arrangement of the crystals it looks as if a similar—but more complicated—reaction occurs between the biotite and epidote. For the production of hornblende from these minerals it seems as if a third mineral, viz., felspar, has to take part in the reaction. But yet in other places another reaction seems to be taking place :—the biotite is becoming more chloritic, with a consequent separation of sphene, and, so, in this way, some of the mica, too, is rendered capable of finally entering into the amphibole as part of its composition.

Rosiwal percentage mineral composition by volume—

Chlorite	1·9%
Biotite	10·2%
Sphene	1·7%
Epidote	4·9%
Hornblende	42·1%
Felspar (+Qu.)	39·3%

SECOND STAGE :—*No.* 1217 : *Biotite-Felspar-Hornblende-Schist.*

In the hand specimen this rock is seen to have developed a certain schistosity. This mineral content is almost entirely melanocratic, but small quantities of felspar serve to accentuate the schistose development.

There are several variations exhibited in this rock from the characteristics of No. 1218. The volume composition from a Rosiwal measurement is—

Chlorite	Nil
Biotite	12·6
Sphene	0·4
Magnetite	3·2
Epidote	Nil
Hornblende	61·1
Felspar	22·6

From this we note the absence of both chlorite and epidote, the introduction of magnetite, the increase in hornblende and the decrease in felspar.

A further difference is evident in the texture of the rock. For, whereas in No. 1218, the felspar was largely porphyroblastic, it is here much more compact but present to a smaller degree showing that the hornbendic areas coalesced as the assumption of felspathic matter proceeded.

SECOND STAGE (MORE ADVANCED) :—*No.* 1216 : *Albite-Biotite-Hornblende-Schist.*

This specimen is a medium-grained, vaguely-schistose rock in which a considerable development of biotite and green-black hornblende is noticeable. Grains of felspar are visible, too, but although they reduce the intensity of the dark nature of the rock it is still very definitely melanocratic.

The rock consists essentially of hornblende, a reddish-brown biotite and felspar, there is some apatite and an occasional grain of magnetite.

The felspar is basic oligoclase. It has a tendency to be porphyroblastic. It exhibits both albite and pericline twinning. In places it has broken to a granulated mosaic of undulose-extinguishing matter. That it is still felspar and not quartz is made evident by the faint twinning which persists even after such severe strain.

Localized areas are given a schistose character where biotite and felspar are intimately associated.

The biotite is pleochroic in dark reddish brown to almost colourless. There are pleochroic haloes, probably of zircon, in the biotite and in the hornblende as well. The biotite does not ordinarily give rise to a schistose structure, there being a greater tendency to decussate structure than linear. The biotite laths are frequently bent, a mark of mechanical stress having been suffered by the rock.

The hornblende is pleochroic with X pale yellow-green, Y green, and Z bluish green. The absorption is $Z > Y > X$. There is frequently formed a decussate structure due to a combination of both biotite and hornblende crystals. The hornblende crystals are compact, not poikiloblastic like those of No. 1217 where the hornblende is honey-combed with felspar.

THIRD STAGE :—*No.* 1215 : *Hornblende-Plagioclase-Gneiss.*

This rock is coarser grained than Nos. 1216, 1217 ; it is granular in texture and dark black in colour except where it is crossed by two veins of felspathic matter and where there are one or two much elongated lenticles of this mineral.

The hornblende is by far the most common mineral in the rock. It is usually poikiloblastic ; the included mineral being any one of biotite, sphene, felspar. The biotite crystals, under these circumstances, have no definite directional arrangement, which is more or less in contrast to their behaviour when they are in contact with felspar, for they then exhibit a degree of parallelism and attenuation absent in other places. The felspar contained in the hornblende seems to be the residuum from a somewhat larger earlier mass. The hornblende has so increased at the expense of the remaining minerals that the latter have been materially reduced in quantity.

The complete absence of chlorite and epidote seems to suggest that their matter has combined to produce some of the hornblende present.

There is an almost entire absence of apatite from this rock.

Rosiwal determination of the mineral contents by volume—

Chlorite	Nil
Biotite	9·1%
Sphene	1·8%
Epidote	Nil
Hornblende	76·8%
Felspar	12·2%

GRADE D.

No. 553.—*Plagioclase-Hornblende-Schist.*

This is a dense, fine-grained, black rock. It is holo-crystalline and consists of a felted array of laths of ferro-magnesian and felspathic minerals.

The rock consists almost entirely of amphibole and felspar—there is some accessory epidote, zoisite, magnetite, calcite and quartz, the last in diablastic intergrowth with the felspar.

The amphibole consists of three varieties. There is ordinary green hornblende which is present in irregular masses with ill-defined outlines exhibiting either decussate texture when the mass is composed of small, well-defined crystals, or poikiloblastic texture including plagioclase and magnetite. Some of the amphibole is green fibrous actinolite and other colourless fibrous tremolite.

The felspar is an intermediate acid felspar, andesine with $Ab_{60}An_{40}$. Some is clear and shows albite, carlsbad and pericline twinning very well ; other is very turbid being almost entirely converted to saussurite. The plagioclase usually occurs in porphyroblasts with equidimensional outline, but sometimes it has preserved its earlier prismatic shape.

The epidote and zoisite are derived from the felspar. The calcite is found as small crystals associated with the hornblende. The magnetite occurs as isolated octahedra in the hornblende and as skeletal crystals, also usually confined to amphibole.

GRADE E.

No. 193.—*Hornblende-Plagioclase-Schist.*

This is a holo-crystalline rock in which the melanocratic content dominates the hand specimen to a very large extent. The dark material consists almost entirely of hornblende. The leucocratic portion of the rock is formed partly of clear granular felspar and partly of opaque, kaolinized felspar. Occasional rare grains of pyrites are seen. One surface of the specimen was previously a side of a vein which penetrated the rock. Here there are green epidote crystals whose size is something like 1 cm. × 0·5 cm. In this region the hornblende is much duller and the felspar very much more commonly opaque. A small area is occupied by some chalcopyrite.

Under the microscope the rock is seen to consist essentially of amphibole and felspar ; the latter is very much saussuritized into an aggregate which here consists of epidote, zoisite, orthorhombic amphibole and muscovite.

The amphibole of the main rock mass is not nearly so much altered as the felspar, but, nevertheless, it seems to have undergone considerable alteration. This is particularly noticeable at the junctions of felspar and amphibole where dactylitic texture is much in evidence. The hornblende seems, too, to be giving place to a more fibrous variety of amphibole, and the bluish green colour which is sometimes seen in the parts where this texture is developed suggests that there is a concentration of the glaucophane molecule in these regions. The hornblende crystals are often embayed, the in-filling material being felspar. There are, too, smaller idioblasts of felspar found in the larger xenoblasts of hornblende which give this part of the rock a poikiloblastic texture. This texture is developed to a very great degree in the main felspar crystals themselves where idioblasts of saussuritic minerals almost entirely fill the felspar mass. The development of fibrous mineral matter from the hornblende seems occasionally to be associated with a micaceous substance whose pleochroism and absorption are very suggestive of partially bleached biotite. The double refraction of this substance is by no means uniform, being a minimum at the periphery and reaching a maximum value in the central parts. There are regions where more fibrous amphibole (near to actinolite) is found in a meshwork arrangement. The fibres of the meshes are usually in two directions more or less perpendicular to one another. The double refraction shown by the amphibole in these parts is most irregular. Under ordinary light there is seen to be some lack of uniformity (in strength of absorption, for instance) but under crossed nicols this heterogeneity is accentuated very greatly. The difference in double refraction in a single crystal is evident and throughout the matted mass this difference becomes very evident indeed. Rarely the ordinary hornblende is simply twinned on 100. The pleochroism of the common hornblende is Z green, Y greenish-yellow, X very pale yellow, and the absorption formula is $Z > Y > X$.

The twinning of the felspar is of a striking character. Wedge shapes have developed in the albite twin lamellae. These wedges vary considerably in length, even in the same crystal. They are all attentuated in the same direction, their narrower extremities point to a part of the crystal where twinning is practically absent. This, with the saussuritized nature of the mineral, and the associated undulose extinction are all evidences of considerable metamorphism. Occasional carlsbad twins are seen, but again the alteration which the rock has undergone has resulted in the demarcation line between the parts of the twin being blurred and ill-defined, a marked contrast to the more usual clear-cut twin line seen in less altered felspar.

There is quite an amount of lawsonite present—7·5%. This is a colourless mineral, having high relief, a good cleavage and straight extinction. Its presence in similar rocks has been shown by Stillwell. Its occurrence in this rock is like those occurrences mentioned by Stillwell. It is found in grains and also in veins which frequently cut right through the amphibole crystals. There are local patches, of small extent, of calcitiferous matter in the neighbourhood of the lawsonite. This may be the result of the concentration of the lime molecule in these parts. The lime, no doubt, is derived from the alteration of the basic plagioclase, for in those parts where the felspar is least turbid over any considerable area the felspar is a basic labradorite, or, possibly, an acidic bytownite.

Thus, there is ample lime present to produce the zoisite, epidote (3·8%) and lawsonite present. It seems as if there are parts where the liberated lime from the basic plagioclase has been too great for the requirements of the zoisitic minerals and that the excess has recrystallised as calcite. These calcitic regions, however, are not entirely composed of calcite. There are " pitted " regions where pellucid felspar is seen. These crystals of felspar are very minute, but they are distinguished from quartz (which they very much resemble) by an occasional one of them exhibiting multiple twinning. From extinction measurements from these twins the felspar is found to be albitic.

A pale greenish mineral is seen. It is pleochroic with X pale bluish green and Z yellowish white. The absorption is $X > Z$. It has a straight extinction, low double refraction (0·002–0·004), exhibiting a peculiar brown colour and a rosette arrangement of the fibres when the nicols are crossed. It is one of the chlorites, prochlorite. This development of prochlorite seems to be equivalent to the antigorite development found in the lowest grades of the metamorphism of peridotites. This rock is, of course, by no means so basic, but the presence of this mineral and the abundance of hornblende point to the previous existence of considerable pyroxene.

Sphene crystals whose absorption is somewhat more than usual, a few apatite laths and rare grains of magnetite (usually in contiguity with the epidote) are also found.

A Rosiwal analysis showed—

Hornblende	50·9%
Felspar	35·9%
Lawsonite	7·5%
Epidote	3·8%
Prochlorite	1·9%

These percentages throw the parent rock into Johannsen's 3212 P group. This shows that the schist is the metamorphosed derivative of a previous gabbro.

No. 548*a.*—*Amphibolite.*

A specimen of this rock or a slight variant of it has been described by Stillwell (No. 548) in " Amphibolites and Related Rocks from the Moraines, Cape Denison, Adelie Land," p. 273. He, there, in accordance with his scheme (Vol. II, p. 262) called the rock a hornblende-fels, but it seems preferable to use the more systematic terminology of Grubenmann and other Continental writers and refer to it as a non-felspathic amphibolite. It would then seem likely that instead of being derived from an ultra-basic igneous rock as the term hornblende-fels would seem to imply, it would be obtained by the conversion of an original pyroxene-plagioclase rock without change of total composition (*vide* Lacroix, "Comptes Rendus," vol. CLXIV (1917), pp. 969–74, quoted by Harker (1932), p. 281).

For this reason and because of certain slight mineralogical differences it has been thought advisable to re-write the description of this rock.

In the hand specimen it is seen to be dense, dull black, faintly schistose rock. It consists almost entirely of medium sized crystals of black hornblende. A few grains of quartz are concentrated in one or two places.

In section it is found to be an almost monomineralic rock, composed of green compact hornblende crystals of about 0·5 mm., grain-size arranged in the decussate manner. Colourless tremolite is occasionally associated with it. One prismatic crystal of lawsonite was found in it—a very slight piece of evidence in favour of the theory suggested above to account for the formation of this rock, the lawsonite indicating that the original rock was basic, not ultra-basic, and that some of the traces of the order of metamorphic change still remain.

A vein of fine granoblastic quartz crosses one part of the rock. The vein is lined with small, dark brown, granules of sphene. Apatite prisms and hexagonal basal sections appear quite commonly. Occasional grains of magnetite and less frequent lozenges of sphene also appear in the body of the hornblende.

No. 578.—*Epidote-Andesine-Hornblende-Schist.*

This specimen differs so remarkably in the hand specimen that two slides were cut; one from the coarse end and the other from the fine-grained end. I shall call them 578A and 578B.

578A.—Here the rock consists almost entirely of hornblende. It has the usual cleavage and exhibits pleochroism where X is pale brown, Y green and Z is dark green. The absorption formula is $X > Y > Z$.

Mortar structure has developed where the peripheral parts of the large crystals have been granulated. Occasional veins of cataclastic albitic mosaic material are seen. Yellow epidote granules occur as an infilling between the large hornblende crystals where dactylitic textures are sometimes seen.

578B.—This section is much more interesting. The mineral content is more complex. Amphibole is represented by a green fibrous pleochroic actinolite; epidote occurs as veins through the rock; felspar, highly decomposed and giving place to saussurite, is seen poikiloblastically to contain green hornblende part of whose composition may be potential felspar; quartz is seen traversing the rock in veins.

Each of these minerals needs to be dealt with in greater detail as follows. The felspar is usually cloudy. Under high power objective it is seen to contain green masses which are more or less in parallel arrangement. The texture developed is typically poikiloblastic. The extinction is straight and double refraction low. In the saussurite there are masses which are occasionally grouped radially about a centre when their extinction takes place serially on rotation of the stage. These metamorphic products are seen occasionally to assume a plumose or a radiating form. Their double refraction is then very low, almost low enough for their being called isotropic. They seem to be an unusual kind of amphibole.

A dactylitic texture is developed at the junction of the hornblende porphyroblasts and the felspar. Here the hornblende becomes distinctly fibrous. The double refraction is considerably reduced. There also seems to be a variation in the optic orientation as is shown by the different extinction angles of the main mass of the porphyroblast and the fibrous mass at the end.

In addition to the production of zoisite, epidote, and amphibole the felspar shows alteration by the almost entire loss of its twin forms and by replacement of clearer felspathic matter. This more acid felspar gives the crystals a veined or honeycombed appearance; the new matter has a lower double refraction and its edges are not simply terminated but are more frequently indented and highly sutured; in other places the infilling (it looks like an infilling but, of course, it is made of metamorphic alteration material) occurs in irregularly directed lines, the extinction throughout these is not uniform but there is seen to be a graduation from one variety (acid) of felspar to another (basic) through a series of three or four components, these components becoming manifest by the zonal nature of the mineral. These regions of zonal felspathic material are sometimes in parallel alignment in a single large felspar crystal. They then give to the crystal a definitely banded appearance. The smaller saussuritic components cut across the direction of parallelism of these felspar zones. The zones are suggestive of the twin lamellae to be seen in much less altered felspar, but their mode of extinction, their vague and ill-defined extent, and the gradations in their polarization colours clearly differentiate them from twins. There are relics of old twin structure to be seen. These, however, have broadened considerably; they are seen poorly developed, but the parts on either side of a broad band are seen to extinguish together while the intermediate region extinguishes in a different position. The lamellae of these twins are not numerous. They have the same perthitic appearance which is so characteristic of some untwinned, unaltered crystals. The separate lamellae exhibit this phenomenon. Large felspar crystals rarely adjoin one another. Where they do their borders are not sutured but are comparatively simple.

More often, however, the large crystals of felspar are completely surrounded and separated from one another by a narrow band of dark matter. This matter is resolved under high power into a multitude of highly refractive, highly birefringent epidote crystals. They are frequently associated with a great number of low double refracting zoisite crystals. Imbedded in these veins are to be seen felspar crystals much smaller than those surrounded by the vein.

The large porphyroblasts of hornblende frequently include smaller felspar crystals. These felspar crystals are frequently seen in their typical lath shape, where they are elongated parallel to the c-axis. This development suggests that here the felspar is higher in the crystalloblastic order than hornblende.

This part of the rock is definitely gneissic, it is an epidote-andesine-hornblende gneiss.

No. 887.—*Plagioclase Amphibolite.*

A dark, fine-grained, aphanitic, igneous rock in which white crystals (apparently felspar) and indeterminable dark crystals can be seen by the naked eye.

Although in the hand specimen the rock appears to be aphanitic it is readily resolved into its proper category, phanero-crystalline, when viewed under the microscope.

The grains of the rock are of medium size, although the hornblende crystals seem greatly to have undergone shattering and crushing. They exhibit a crystalloblastic structure.

The minerals present are as follows. Hornblende crystals are seen as green, pleochroic (blue green, light and darker green, brown) allotriomorphic crystalline masses. The mineral occurs in crystalloblastic masses, and, a second generation, as inclusions in felspar. These inclusions are idiomorphic, prismatic, pleochroic, and more or less linearly arranged. They have altered to some extent forming iron compounds, chief of which is haematite which stains the neighbouring crystals brownish red.

Felspar is found in the rock in large white allotriomorphic masses. It is for the most part clear, but some patches are turbid. It contains inclusions of hornblende, it is well cleaved, exhibits albite multiple twinning and (very rarely) pericline polysynthetic twin lamellae. The extinction is undulose, but optical measurement shows the felspar to be labradorite.

Haematite, as red matter disseminated through the rock in flakes; magnetite as black octohedra and larger grains which have a metallic lustre in reflected light; pyrites, as yellow opaque disseminated grains, and epidote, an alteration product, also occur in the rock.

A Delesse-Rosiwal investigation of the modal character of the rock gives the mineral composition by volume as almost entirely acid labradorite (about 23%) and green hornblende (about 76·5%).

Adopting the most probable chemical composition for the felspar and for the hornblende, calculation shows that the percentage chemical composition of the whole rock is apparently as follows :—

SiO_2	48·58	MgO	11·26	$H_2O\,(+)$ ...	0·68
Al_2O_3	12·13	CaO	9·90	TiO_2	1·14
Fe_2O_3	4·26	Na_2O	2·65	MnO	0·46
FeO	8·98	K_2O	0·21		
				Total ...	100·25

From which follows that the C.I.P.W. classification is Class III, order 5, rang 3 (Camptonase), subrang 5 (Ornose).

No. 1215.—*Hornblende-Plagioclase-Gneiss.*

The description of this rock is included under Grade C.

No. 115.—*Biotite-Plagioclase-Hornblende-Schist.*

Macroscopic Characters.

The hand specimen is a heavy, dense, aschistose rock. The dark mass looks as if it is hornblende but a diagnosis of the hand specimen can proceed no further because of the very fine grained nature of the rock. Some pyrites grains and an iron oxide film can be seen on the exposed surface.

Microscopic Characters.

The rock consists of large porphyroblasts of hornblende and a granulitic mass of andesine. Magnetite and biotite also occur. The hornblende is pleochroic in blue, green and yellow-brown. Some of the blue amphibole is suggestive of a concentration of the glaucophane molecule. The absorption formula is $Z > Y > X$, where Z is blue-green, Y green-blue, and X yellow-brown. The amphibole poikiloblastically contains andesine and biotite. In parts of the slide this results in the sieve-structure being typically developed. In other places, however, the porphyroblasts do not show this structure so well. Here a more definite schistosity is developed. Polarity is obtained by the lineal arrangement of more elongated hornblende crystals. There is an alternation of melanocratic and leucocratic constituents; this colour difference is accentuated by part of the melanocratic constituents being magnetite and biotite. The linearity of the hornblende is achieved, in part, by flexures which are the result of stress effects. A similar bending is evident in the biotite crystals.

Quartz makes a part, at least, of the leucocratic portion. These light-coloured constituents show many cataclastic effects. They are granulated, they exhibit strain polarisation, they form the basis of a mortar texture together with crushed amphibole between the porphyroblasts of hornblende.

The biotite seems to have been derived at the expense of the hornblende. It shows very pronounced pleochroism, with Z dark brown and X nearly colourless, the absorption formula being $Z > Y > X$. These are characteristics of the phologopite-eastonite series.

Among the accessory minerals are numerous euhedral crystals of apatite and rare lozenges of sphene. Some epidote and allanite show the mode of transformation of the lime content of the altered felspar.

Grain size: Hornblende, 0·25 mm.; other minerals, 0·03 mm.

Mineralogical Composition.

Hornblende	47·3%
Plagioclase and Quartz	31·8%
Biotite	13·9%
Magnetite	7·3%

GRADE F.

No. 1259.—*Garnet-Amphibolite.*

This rock is seen in the hand specimen to give a suggestion of gneissose characters, there being a poorly defined division into dark green hornblende bands and opaque white bands of felspar.

Other minerals evident to the naked eye include clots (about 0·4 to 0·5 cm. diameter) of pink garnet and rare flakes of slightly bronzed mica.

Several interesting characteristics are seen under the microscope.

The first is the increase in the number of identifiable minerals. The suite is seen to include magnetite, lawsonite and apatite in addition to those macroscopically recognisable.

The relationships between the minerals of the rock are important. The rock is a member of one of the high grades of metamorphism as is seen from the absence of calcite, pyroxene and sphene, the minerals which characterize the lower grades. The felspar, where clear, is found by extinction in zones perpendicular to 010 to be an acid oligoclase $Ab_{85}An_{15}$, which is in accord with the nature of felspar in rocks of this kind (Harker, p. 284). This clear felspar shows both albite and pericline twin lamellae with a strong tendency towards the formation of wedge-shaped lamellae. The extinction is usually undulose. Granulation of the felspar is noticeable, particularly in the neighbourhood of hornblende masses. In the regions remote from hornblende the felspar is usually highly saussuritized and extremely cloudy. It seems that here little of the original calcic content of the felspar has been assumed by the hornblende, whereas in the clearer areas much of the lime has been so absorbed.

Small sheaf-like patches of biotite are frequently present in the large massive hornblende crystals.

The relationship between the biotite and lawsonite is interesting. As in specimen No. 50 the lawsonite forms layers within the biotite which has a typically shredded appearance under these circumstances. This fibrous nature of the biotite is one of the characteristics which one notices even before seeing the small laths of lawsonite which in some rocks are so insignificant that they might otherwise be overlooked. In this particular rock there is no such danger, for the lawsonite is well-defined, of high-relief, fairly cleaved, moderate birefringence and negative elongation. That it is connected genetically with the biotite in some way is obvious.

Although this grouping of biotite and lawsonite is occasionally seen in the clusters within the large hornblende masses it is far more frequent in areas where connection with felspar is apparent. It then seems as if the lawsonite has drawn upon the felspar for some of its composition, which part of its content in the other areas must have been derived from the hornblende.

Garnet is present in large, clear, well-defined crystals. There is some magnetite, biotite and hornblende included in a few of the crystals.

No. 517.—*Delessite Hornblende Gneiss.*

This is a coarse-grained rock in which crystals of light and dark minerals are seen in approximately equal amounts. They are hornblende and felspar. There is a definite elongation tendency which aids in suggesting a somewhat gneissose appearance for the rock.

Viewed in microscope slide perhaps the most interesting mineral occurrence is that of delessite or negative pennine. This mineral exhibits pleochroism where Z = green and X = very pale yellow. The mineral is very common throughout the rock and is derived from the alteration of the hornblende. The connection between these two minerals is very evident, the delessite is seen clearly to be passing over from the hornblende (Plate VI, fig. 3). Another very interesting property of the delessite is its marked dispersion which not only produces ultramarine interference colours but which produces what may be called an " ultra-red " interference colour when the slide is rotated 90° from the position where the ultra-blue colour is seen. It seems that the dispersion is so large that not only is interference for reds reached thus producing the ultra-blue colour but when the mineral has been rotated through a definite angle there is interference for the blue, but not the red, and in consequence the so-called " ultra-red " colour is produced.

By far the greatest mass of the rock is made of hornblende. It is pleochroic in greens and pale yellow (Z = green, X = pale yellow) and the absorption formula is $Z > Y > X$.

The elongation of the prismatic sections is positive. It is mostly massive. The hornblende crystals are so large that one can hardly call them porphyroblasts, yet because of their relation to poikiloblastically intergrown plagioclase crystals one is inclined to use the term.

Three other minerals seem to be present in forms more or less related. They are epidote, zoisite and allanite. The epidote is very common, being found at the edges of the hornblende crystals and in the neighbourhood of the felspar crystals. The epidote is found highly refringent, highly birefringent grains whose polarisation colours vary considerably in one crystal mass. The zoisite is not very common. It has a very high refractive index but its double refraction is low. There are occasional prisms of this mineral which show straight extinction. The last of the three is the most interesting. It is the cerium epidote, allanite. It is orange-coloured and found associated with strong pleochroic haloes in hornblende. The mineral is practically isotropic, a condition which is indicative of a stage of metamorphism in the allanite. (Winchell, " Elements of Optical Mineralogy," Part II (1927), p. 358.)

There are some crystals of garnet present. It has the characteristic high refractive index, no cleavage, many cracks and isotropic nature. There is some magnetite which is usually associated with delessite. Sometimes, however, it has as a central core some hornblende; under these conditions it is, of course, skeletal. A little biotite is found in the rock.

There are a few crystals of zircon occurring in pleochroic haloes in the hornblende. The interference colours are very high. Some apatite is found as a colourless, highly refringent mineral. Its double refraction is so low that it is nearly isotropic. Hexagonal basal sections which occur are definitely isotropic.

In addition to these minerals there is quite an amount of plagioclase. The plagioclase exhibits many signs of metamorphism and stress. Some of these signs are its much strained appearance, its undulose extinction, the presence of tapering twins, and bent twin lamellae. There is an irregular distribution of the twins throughout the felspar and very frequently the twin lamellae end abruptly. When the felspar is clear it is found by referring its extinction to the 010 cleavage to be andesine. More usually, however, the felspar is highly saussuritized into a mass of sericite, epidote and much tremolite. There is some albite occurring as idioblasts in the hornblende. This albite is clear, untwinned, and lacking cleavage. It is determined by its low refractive index.

This rock seems to be very much like the "epidiorites" of the Highlands. There the chlorite of the albite-epidote-chlorite-schists passes over readily into hornblende; at the same time the amount of epidote present decreases. The same kind of thing is happening in this rock. The delessite is being reduced in amount. The epidote, too, is by no means as abundant as it is in some other of the basic rocks in these moraines. The small amount of felspar would be accounted for by Lacroix by suggesting that it has "passed in a potential state as part of the composition of a complex amphibole." The presence of the garnet in this rock points in the same direction. The rock has been derived most probably by the regional metamorphism of a dolerite.

The average grain-size of the hornblende crystals is 0·5 mm., and that of the felspar crystals is 0·75 mm. A Rosiwal micrometric analysis gave the following result :—

Felspar	60·9%
Hornblende	29·6%
Delessite	5·4%
Epidote	2·3%
Magnetite	2·0%

As andesine lies between $Ab_{70}An_{30}$ and $Ab_{50}An_{50}$ the Johannsen classification of the rock is 2212 M, i.e., the hypabyssal equivalent of a metamorphosed dolerite.

SECTION IV.—THE ULTRA-BASIC ROCK.

No. 462. *Anthophyllite-Hornblende-Phlogopite-Peridotite.*

This is the only representative of this group. It is a heavy, black, lustreless, holo-crystalline rock. Large crystals of dark amphibole are recognisable, a feature of these crystals being less lustrous black pittings (lustre-mottling) which mark their surfaces and which represent small olivine crystals.

The microscopic examination of the rock shows that it has close affinities to Judd's scyelite.* The dominant minerals in both rocks are hornblende which is colourless (or practically so) in thin section and poikilitically enclose serpentinized olivines. And here (No. 462), as in the rock described by Judd, is prominently present a pale magnesian mica (a phlogopite). The complete absence of felspar throws the rock into the peridotite-family, and the rock could be called a hornblende-mica-peridotite (after Hatch, p. 261) or a scyelite (after Judd).

There is an objection to this naming, however, for there are at least two other prominent minerals in the rock. They are anthophyllite and talc which both have a metamorphic origin and so throw light on the post-intrusion history of the rock. Magnetite in the body of the olivine also emphasizes this aspect of the nature of the rock.

A more detailed examination of the properties of these minerals leads to the following conclusions. Marked zones are present in the hornblende regions. These are sometimes arranged concentrically round an olivine centre. They are seen to pass from the centre to the outside in such a way as to show that the central areas are monoclinic and the outer orthorhombic. These properties are made evident when the nicols are crossed, for then the differences in extinction angles are very marked. Indeed, it is frequently found that a homogeneous amphibole mass under parallel light is resolved into zones when the analyser is inserted (Plate VII, fig. 4).

The olivine occurs in colourless globular masses of high R.I. and D.R. These masses are criss-crossed with serpentinized cracks, and frequently appear dark by virtue of the large quantity of discharged magnetite present. A different alteration of the olivine is indicated by the change in the nature of the hornblende in the zone immediately enclosing the olivine crystals. This zone has all the characteristics of a reaction centre and shows that a modification has occurred in the hornblende by reaction with the olivine.

Anthophyllite is one of the most interesting minerals present in the rock. It occurs in at least three different ways. First, as a peripheral border to the monoclinic hornblende (see above). Second, as large untwinned crystals of little colour, low D.R. and straight extinction. Third, as smaller laths, usually singly, but not uncommonly multiple-twinned, scattered throughout the rock. It also occurs associated with phlogopite.

* Judd, Q.J.G.S., XLI, 1865, p. 401.

The phlogopite of this rock is practically colourless, although occasionally a slight brown tinge is faintly visible and a more evident green colour is seen. The mineral laths are frequently bent and they are sometimes crushed between two olivine grains. Some of the phlogopite has undergone a peripheral alteration, strangely enough to an anthophyllite-like mineral. The changed nature of the mica is not apparent in ordinary light, but on throwing in the analyser the difference between the little-affected central mica and the altered exterior matter is readily discernible by the considerable variation in birefringence.

The talc seems to have been formed by hydration. A considerable number of spinel grains are present (probably chromite or picotite).

The rock is seen from the above description to be a medium grade member of the anthophyllite-talc-schist group, which finally give rise to anthophyllite-schists as are found in the Shetland Isles.*

That the rock has by no means reached this final stage is shown by its massive nature which gives no suggestion of schistosity.

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* Heddle, Min. Mag., iii, 1880, p. 21.

EXPLANATION OF PLATES.

Plate VI.

Fig. 1. *Dolerite.* Specimen 1219, erratic from moraines at Cape Denison.

The microphotograph shows skeletal ilmenite which has arisen from changes in some of the original augite. A considerable portion of the photo is occupied by a large plagioclase. Mag. 35 diams.

2. *Albite-epidote-hornblende-schist.* Specimen 1218, erratic from moraines, Cape Denison.

Illustrating the abundance of small sphene crystals in some members of the low-grade amphibolite series. Hornblende and biotite are also in the field of view. Mag. 35 diams.

3. *Amphibolite.* Specimen 517, erratic, Cape Denison.

Showing chlorite derived from garnet by retrograde metamorphism. A slight revival of the earliest conditions of metamorphism has produced a swarm of small sphene crystals in the biotite. Mag. 100 diams.

4. *Gabbro.* Specimen 423, erratic, Cape Denison.

A large crystal of titan-augite occupies the centre of the field. It includes small hexagons and rectangles of apatite. It is also sub-ophitically intergrown with felspar. A large crystal of olivine, distinguished in the photo by very heavy borders is seen in one corner of the picture. Mag. 27 diams.

Palte VII.

Fig. 1. *Amphibolite.* Specimen 965, erratic, Cape Denison.

The microphotograph shows a striking example of the poikiloblastic texture which is characteristic of the hornblende in some of the amphibolites from this area. Mag. 35 diams.

2. *Lawsonite-biotite-felspar injection gneiss.* Specimen 50, erratic, Cape Denison. This rock is described in Part VII of this volume.

The photograph is reproduced to show lenticular masses of colourless lawsonite occupying spaces between the laminae of the biotite. Mag. 80 diams.

3. *Vesicular basalt.* Specimen 224, erratic, Cape Denison.

The photograph shows a large vesicle lined with crystals of calcite. The hyalopilitic character of the rock is evident. The interstitial material is a brown glass thickly studded with minute octahedra and rod-like skeletons of magnetite. Mag. 27 diams.

4. *Anthophyllite-hornblende-phlogopite-peridotite.* Specimen 462, erratic, Cape Denison.

The central feature of the picture is anthophyllite; the patchy appearance being due to changes under way. Olivine and serpentine are also shown. The black areas are olivine in the extinction position. Photographed* under crossed nicols. Mag. 60 diams.

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* The micro-photographs appearing in these plates were prepared by H. E. E. Brock.

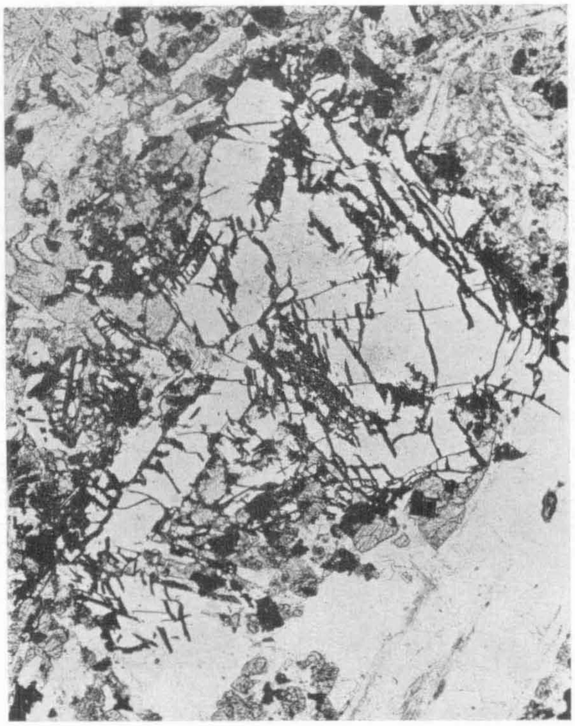

Fig. 1.

Fig. 2.

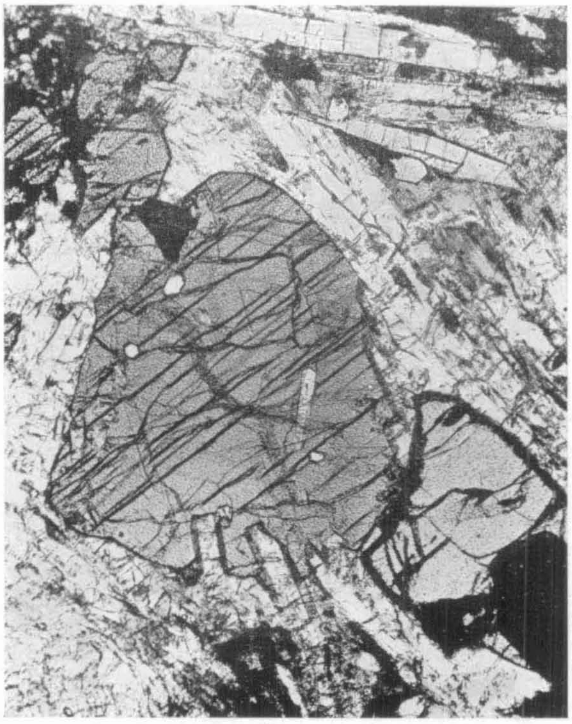

Fig. 3.

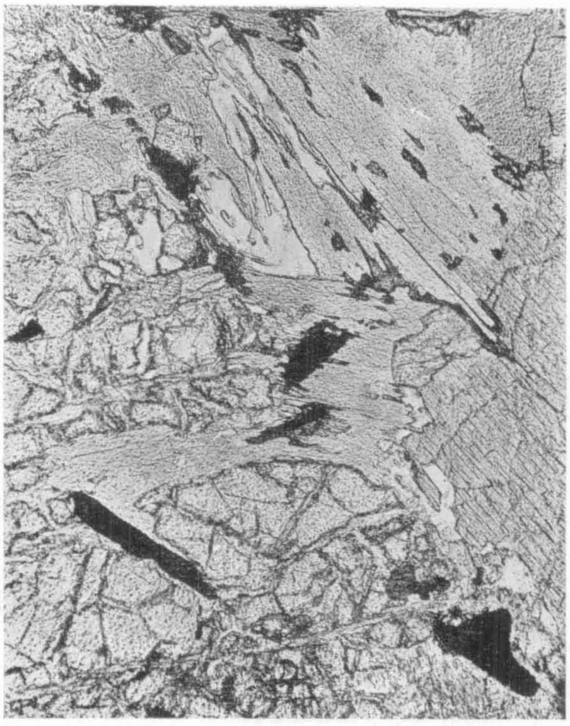

Fig. 4.

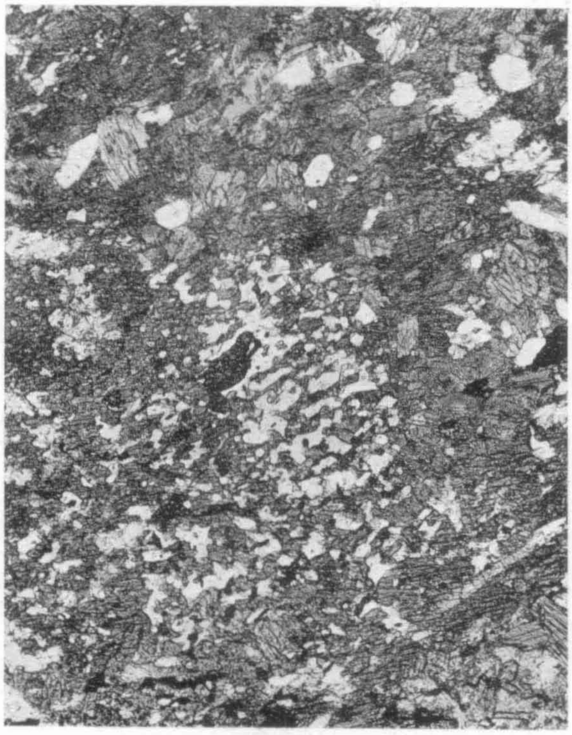

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

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