AUSTRALASIAN ANTARCTIC EXPEDITION

1911-14.

UNDER THE LEADERSHIP OF SIR DOUGLAS MAWSON, O.B.E., B.E., D.Sc., F.R.S.

SCIENTIFIC REPORTS.

SERIES A.

VOL. III.

GEOLOGY.

PART V.

MAGNETITE GARNET ROCKS FROM THE MORAINES, CAPE DENISON, ADELIE LAND,

BY

ARTHUR L. COULSON, M.Sc., F.G.S.

WITH TWO PLATES.

PRICE: TWO SHILLINGS.

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CONTENTS.

I.—INTRODUCTION.

The rock specimens, which are described below, are part of the collection obtained by the Australasian Antarctic Expedition from the glacial moraines at Cape Denison, Adelie Land. They are schists and gneisses which are chiefly characterised by an abundance of either magnetite or garnet or both. One specimen of epidote-magnetite-schist, No. 989, shows well-developed glacial striæ.

The descriptions are presented in order of relative predominance of magnetite to garnet. In the first two examples, garnet is absent but it forms 40 per cent. of the rocks towards the end of the series. The paper is concluded with the description of an interesting type containing tourmaline, magnetite, and cordierite.

The terms "gneiss" and "schist" are used in the sense defined by Holmes.* Grubenmann's usage† of the terms "texture" and "structure" is adhered to. In this, the structure is understood to be determined by the form and relative size of the components of the rock. He adds that the structures appear to be functions of the chemical composition of a rock, and of the magnitude of the temperature and pressure and the time interval during metamorphism; and are also dependent on the strength, ability, and speed of crystallisation of the minerals developed. The texture is the spacial arrangement of the constituents, and he states that the textures are not so much dependent on the nature of the rocks as upon external circumstances.

II.—PETROGRAPHY.

1. Mineral Composition.

Rosiwal determinations of some of the specimens have been made in order to express quantitatively their mineralogical content. These measurements were made on sections cut at right angles to the schistosity and the results are expressed in Table I. Generally it was found expedient to determine the quartz and felspar together. In Table I below, iron ore includes magnetite, ilmenite, pyrite, &c., while "p" signifies the presence of a mineral in small quantities. A Rosiwal determination of a magnetite-garnet rock from Broken Hill, New South Wales, is added for comparative purposes.

In some rocks, mostly of fine-grained nature, the magnetite percentage alone was determined. These form Table II, and Table III gives the specific gravities of the remaining specimens. The figures for the various minerals as stated in percentages present.

Table I.

Rock number	149	304	814	245	288	102	348	B.H.
Specific gravity	3·29	2·99	3·07	3·27	2·97	3·33	2·98	3·81
Iron ore	23·0	11·9	14·7	17·9	6·2	21·2	8·4	42·5
Garnet	12·2	7·9	12·6	15·6	6·3	40·8	20·5	23·5
Quartz	58·3	65·1	65·8	55·6	32·4‡	36·0	29·0	19·8
Felspar					45·0‡	...	29·0	...
Cordierite	...		...	...	...	...	...	...
Mica	5·5	14·7	6·6	9·2	9·7	...	13·1	...
Apatite	1·0	0·4	0·3	1·2	0·4	2·0	p.	14·2
Epidote	...	...	p.	0·5	p.	...	p.	...
Zircon	p.	p.	p.	p.	p.	...	p.	p.
Calcite	...	...	...	...	...	...	p.	...

* "The Nomenclature of Petrology." A. S. Holmes, London, 1920, p. 107.

† "Structur und Textur der Metamorphischen Gesteine." U. Grubenmann, Fort. der Min., Krist. und Pet., Band II, 1912, p. 209.

‡ Approximate.

TABLE II.

Rock number	576	912	294	55	889
Specific gravity	3·12	3·31	3·14	3·11	3·13
Iron ore	23·4	32·4	33·0	18·9	26·9

TABLE III.

Rock number	765	926	296	989	527 (A)	933	827	181
Specific gravity	3·97	2·93	2·94	2·93	3·00	2·83	3·26	2·96

2. DESCRIPTION OF ROCK SPECIMENS.

No. 765.—This is a dark, heavy, and fine grained rock, composed of a mass of magnetite, hematite, and quartz, through which run bands of quartz and minute hematite flakes. Small fragments of the rock are strongly magnetic. Its specific gravity is 3·97, the highest for the group.

Microscopically, the quartz occurs in very fine grains, which show strain polarisation colours and which contain myriads of inclusions of micaceous hematite or "eisenglimmer." While eisenglimmer occurs abundantly within the quartz bands, magnetite is the chief constituent of the rock. The structure is granoblastic and the texture is schistose. The rock is a *Magnetite-Schist.*

No. 926.—This is a dark greasy-looking rock, extremely fine grained and possessing a well-developed crystallisation-schistosity.

Biotite is one of the chief constituents, occurring in very minute flakes and showing no trace of any alteration to chlorite. Magnetite is fairly abundant and with quartz makes up the bulk of the remainder of the rock; it is usually xenoblastic in form and generally of small dimensions. Quartz shows strain polarisation and contains minute inclusions of magnetite, and epidote. This latter mineral is disseminated through the rock in minute roughly circular grains. Calcite occurs in moderately large masses and surrounds epidote, quartz, magnetite and biotite; the characteristic cleavage is well developed. The structure is lepidoblastic to granoblastic and the texture is schistose. The rock is a *Biotite-Magnetite-Schist.*

No. 576.—This is a gneissic type in which magnetite, epidote, biotite, quartz, and pink orthoclase can be recognised in the hand specimen. The structure is heteroblastic. Magnetite is important and occurs in xenoblastic individuals with a roughly parallel alignment. Garnets are rare; they cannot be recognised in the hand specimen and are confined to certain bands in the section. Such as are present are the fragmentary remains of large crystals which have been mostly altered to chlorite, quartz, and magnetite. This is a common alteration in the suite of specimens and will be dealt with later. The colour scheme of the biotite is X, light green, Y and Z, dark green. Sometimes it has altered to chlorite, frequently showing the indigo blue polarisation colours of clinochlore, and magnetite. Quartz is abundant and shows cataclasis and strain polarisation. Orthoclase felspar is common but much kaolinized and sericitised. Epidote occurs in numerous granular aggregates, usually almost opaque, and a very strong light is necessary to observe its characteristic polarisation colours. Apatite is common as small rounded grains. The rock is *Micaceous-Magnetite-Gneiss.*

No. 912.—This is a schistose type, dark-coloured, and easily cleaved. It is extremely fine grained and it possesses a lustrous appearance owing to the presence of white mica. Flakes of the rock are strongly magnetic.

Microscopically, the structure is lepidoblastic. Magnetite crystals, which constitute nearly a third of the rock, are xenoblastic in outline, especially in the larger grains. Occasional minute flakes of micaceous hematite (eisenglimmer) are recognised and ilmenite is intergrown with the magnetite. Garnets are moderately abundant but they are small and much fractured and contain inclusions of magnetite. Green biotite is common and sometimes exhibits pleochroic halos which are too indistinct to measure. Quartz is an important constituent and contains fluid and magnetite inclusions. The fluid inclusions generally have an arrangement parallel to the schistosity. Scaly sericite, chlorite, epidote, and accessory apatite form the remainder of the rock, which may be called a *Magnetite-Schist.*

No. 296.—This is a dark greasy-looking rock, extremely fine grained and traversed by a few lenticular bands composed mostly of quartz and epidote. It possesses a very definite crystallisation schistosity.

The structure is both granoblastic and lepidoblastic. Magnetite is extremely abundant, occurring in little xenoblastic individuals with linear development and also in larger porphyroblastic grains (up to 0·3 mm.). It is disseminated through the rock as well as segregated in thin bands. Small red flakes of micaceous hematite also occur. Garnets are very small and idioblastic, their averages absolute diameter being about 0·4 mm. Quartz is the most abundant constituent and reduces the specific gravity (2·93) below the average. Biotite is present as small flakes, while epidote is restricted to certain bands as xenoblastic grains. Felspar is absent. The rock is *Quartz-Magnetite-Schist.*

No. 989.—Macroscopically the rock is dense and dark-coloured, being traversed by a few epidotic bands. Little porphyroblasts of magnetite can be seen in the ground mass of the rock.

The structure is granoblastic and the texture is schistose. In most respects the rock is similar to the preceding quartz-magnetite-schist, No. 296. The garnets, however, show two kinds of alteration, one of which has produced chlorite and the other epidote. Both changes can be observed in all stages of completion. The biotite is irregular in shape and frequently contains inclusions of recrystallised quartz. It has no very definite relationship to the schistosity and shows all stages of alteration to chlorite with concomitant production of magnetite. Epidote occurs in granular aggregates in addition to that formed directly from the garnet, and the rock may be called an *Epidote-Magnetite-Schist.*

No. 527. (A).—This is somewhat similar to the micaceous magnetite gneiss, No. 576, in the hand specimen and shows a very contorted banding. Pink orthoclase is prominent.

The main structure is granoblastic but relic, zig-zag and lenticular structures are observed microscopically. Magnetite is abundant and mostly in irregular xenoblasts, while a few flakes of micaceous hematite may be observed. A few garnet relics have survived the alteration to quartx, magnetite, and chlorite. In some cases the outline of the original garnet is preserved (Plate II, fig. 1). Much of the chlorite has been derived from the garnet but part has arisen from the alteration of biotite with the accompanying production of magnetite. Muscovite is sometimes intergrown with chlorite Fine granular quartz grains contain inclusions with an arrangement parallel to the schistosity. Orthoclase is present as large relic crystals which are simply twinned and untwinned. Epidote and apatite are present. The rock is a *Chlorite-Magnetite-Gneiss.*

No. 933.—The hand specimen is a well-laminated greenish rock with an abundance of biotite, chlorite, and muscovite. Biotite and chlorite form flaky aggre gates which give the rock a spotted appearance. Quartz occurs in convolute veins which follow the schistosity for some distance and then break across it. The laminae of the rock are curved at one end as the result of bending and shearing rock movements which may have accompanied the infiltration of the quartz.

The structure is lepodoblastic but relic and cataclastic structures are also present. Magnetite is abundant. Small garnets show the usual development of quartz, magnetite, and chlorite, when examined under the high power, but not nearly to the same extent as in No. 527 (A). Quartz occurs both in large grains in the vein and in small grains with an elongation parallel to the schistosity. It exhibits strain polarisation and the larger grains show cataclasis. Biotite contains a few pleochroic halos around minute zircons and muscovite is very abundant. Granular epidote is largely intergrown with chlorite. The siliceous veins contain biotite and magnetite and relic felspars which are much kaolinised and penetrated by newly formed quartz. The twin lamellae can sometimes be picked out (Plate II, fig. 2). The rock is a *Mica-Magnetite-Schist* and has the lowest specific gravity of the group (2·83).

No. 294.—This is an interesting magnetite-schist with contorted banding. In part slight shearing movements have resulted in the fracturing of the bands. Thin quartz veins cut across the bands and are later than the fundamental metamorphism.

The structure of the rock is granoblastic and the texture is schistose. Magnetite forms approximately one-third of the rock. Garnets have been fairly common but are mostly altered. By far the greater part of the chlorite is derived from the biotite which was originally very abundant. Epidote is present and quartz is common. In the veins, the quartz shows brush polarisation and a larger grain size. Felspars are present but they are so completely kaolinised that it is impossible to identify them.

No. 55.—This is a fine grained, dark, heavy crystalline rock of specific gravity 3·11. It possesses a strongly developed crystallisation schistosity. Glistening white mica on the cleavage planes gives a lustrous appearance to the rock. Fragments of the rock are strongly magnetic.

The structure is both granoblastic and lepidoblastic. Magnetite is abundant and ilmenite is also present as shown by the presence of white leucoxene. Hematite occurs but the bulk of the 18·9 per cent. of iron ore is magnetite. Garnets are abundant, the chief alteration being magnetite, though chlorite is also formed. A green variety of biotite is very common and usually associated with muscovite, which appears to be a later product than the biotite. The latter is much altered to chlorite. Quartz shows strain polarisation and sometimes its recrystallisation has split flakes of biotite from their parent crystals. Felspar is present but is largely kaolinised. It sometimes exhibits the remnants of a fine twinning. Apatite is present. The rock is a *Mica-Magnetite-Schist.*

No. 889.—This specimen possesses a moderate crystallisation schistosity. On one side there is a well-developed shear face along which abundant ilmenite is developed. In the mass of the rock, blue cordierite can be seen.

Two sections were made of this rock, one of which was at right angles to the schistosity. The magnetite percentage (26·9) was obtained from the latter section. Intergrown with the magnetite, is a fair amount of hematite but ilmenite is not abundant in the sections. The rock was originally rich in garnet which has been mostly altered to a mass of quartz, magnetite, and either biotite or muscovite. Biotite is usually accompanied by felspar and shows alteration to magnetite. Magnetite has also been developed along a series of sub-parallel lines in the garnet (Plate II, fig. 3), and where these meet, the alteration is complete.

The biotite is a greenish-brown variety and contains numerous pleochroic halos. Occasionally there is a slight development of chlorite from biotite but a much commoner alteration has produced magnetite and muscovite. The last mineral appears to be derived from either the garnet or the biotite. Cordierite is abundant in the section cut at right angles to the schistosity. It is distinguished from quartz by faint pleochroic spots and its pronounced signs of alteration. The bulk of the felspar is andesine but some is more calcic, probably approaching labradorite. One fine example of a crystal of andesine shows a graphic intergrowth with quartz. Apatite is abnormally biaxial in its interference figure. The structure is heteroblastic and the rock is a *Magnetite-Garnet-Schist.*

No. 149.—This rock shows a pronounced gneissic banding. It is a medium grained rock and flakes readily owing to the amount of mica. Quartz, garnet, felspar, mica, and magnetite can be recognised and the mineral proportions are given in Table I. Magnetite with intergrown ilmenite forms 23 per cent. of the rock. The ilmenite is recognised by its alteration to leucoxene. Sphene is doubtfully present. Garnet, magnetite, and also apatite contain inclusions of one another. Some garnets are idioblastic and others show evidence of resorption. Quartz, plagioclase, and orthoclase are present in approximately equal proportions. The plagioclase, is mostly labradorite, and, like the orthoclase, is slightly kaolinised. Quartz contains numerous opaque inclusions of iron oxide.

The biotite is interesting. It is a yellowish-brown variety occurring in large sporadic flakes which contain radioactive inclusions surrounded by beautiful pleochroic halos (Plate II, fig. 4). All the inclusions are of considerable dimensions relative to the halos which surround them and their longer and shorter axes have been measured. The radii of the halos in the following table are the average of two or three measurements of the distance from the edge of the inclusion to the outer edge of the halo. A 4 cm. (× 45) objective lens was used in conjunction with a Beck micrometer eye-piece and the measurements given below are in millimetres.

TABLE IV.

Radius of Halo.	Remarks.	Dimensions of Nucleus.	Remarks.
·043	Indistinct	....	....
·040	Very distinct	·035 x ·020 ...	Wedge-shaped.
·040	Very distinct	·040 x ·040 ...	Circular.
·039	Very distinct, slight difference in colour, being lighter near nucleus.	·033 x ·033 ...	Circular.
·039	Lighter area next nucleus (to about ·009mm. from the edge).	·039 x ·031 ...	Rectangular, straight extinction.
·038	Very distinct	·026 x ·020 ...	Wedge-shaped, straight extinction (?)
·024	Fairly distinct	·042 x ·037 ...	Oval.
·017	Distinct	·010 x ·010 ...	Circular.
·016	Indistinct	·020 x ·016 ...	Oval.
......	Indistinct	·033 x ·020 ...	Oval.
......	Indistinct	·020 x ·013 ...	Oval.

In the measurements made by Joly* a correction is made for the nucleus on the assumption that the nuclei are zircon and that they are sensibly spherical. In this rock, however, the nuclei are too large and such corrections would not be valid. The halos are remarkable even in colour, but in two cases there is an appreciable difference in colour, which, however, is too slight for accurate measurement. The inclusions show high order polarisation colours and appear to have straight extinction, thus suggesting zircon.

* "Genesis of Pleochroic Halos." J. Joly. Lond. Roy. Soc., Phil. Trans., Series A, vol. 217, pp. 51–79, 1917.

Joly and Fletcher* give the radii of halos in biotite as follows :—

Uranium—Ra C	Ra A	Thorium—Th C.	Th X
·0326	·0222	·0397	·0263

On the basis of these measurements the first six halos in the above Table IV are probably due to Th C and the origin of the others is doubtful.

The structure of the rock is heteroblastic and it may be called a *Magnetite-Garnet-Gneiss.*

No. 147.—Part of this specimen is a dark magnetite gneiss and part is a light-coloured acidic rock. It exhibits a pronounced example of lenticular structure.

The acidic part shows large crystals of quartz, fibrous sillimanite, magnetite, biotite, plagioclase, and orthoclase. The dark banded part contains abundant magnetite, garnet, quartz, cordierite, and felspar. Magnetite is more abundant in the dark part than in the light, but is especially plentiful at the junction.

In the dark gneissic portion the magnetite encloses cordierite, apatite, and sillimanite. Ilmenite and rutile are also present. Garnet, which is absent from the acidic part, contains inclusions of quartz, magnetite, and apatite, and also shows evidence of resorption. The felspar has an extinction angle of 12° and a refractive index usually greater than quartz. It thus suggests andesine. Quartz shows strain polarisation. Biotite shows evidence of resorption and sometimes contains radioactive inclusions; one perfect example has a halo with a radius of ·037 mm. and is ascribed to Th C. †

Cordierite is abundant; at times it is altered to a pinitic mica with an absence of any basal lamination, and at others it has given rise to a serpentinous product with a radial arrangement and brush polarisation. Sillimanite is usually intergrown with the biotite and appears to have developed from it, more especially in the acidic part. It occurs in the fibrous form and also in stouter prisms, with the slowest ray parallel to the prism axis. Orthoclase and andesine occur in the acidic part. Some crystals of epidote are present with a darker margin which shows higher polarisation colours and stronger pleochroism than the central portion. They usually adjoin magnetite crystals and the darker margin contains a greater percentage of iron. The structure of the gneissic part is heteroblastic and the rock is a *Magnetite-Garnet-Schist.*

No. 827.—This is a gneissic type with a discontinuous banded structure, the various bands differing greatly in mineral content. The following minerals can be identified in the hand specimen :—Quartz, magnetite, blue cordierite, felspar, sillimanite, biotite, and pink garnet. The distribution of the magnetite is especially irregular. A central band through the rock is composed of magnetite, altered cordierite, pink garnet, and quartz. Biotite is plentiful on both sides of this band.

* "Pleochroic Halos." Phil. Mag., 6th Series, Vol. XIX, p. 633, 1910.

† Jolly and Fletcher, *op. cit.*, *p.* 633.

Magnetite has crystallised out later than the biotite and it appears to have split off fragments of biotite by crystallisation between the cleavage flakes. The magnetite does not appear to have been derived from the biotite as there is a general absence of any minerals accompanying such a change. Flakes of green chlorite with a magnetite are rare. Garnets usually show round edges due to resorption. Quartz is abundant and shows strain polarisation. Apatite is present, and possible cyanite. Little sillimanite and no felspar can be observed in the section on account of the very variable distribution of the minerals in the rock. Fragments from the hand specimen show that the felspar is an acid plagioclase. Cordierite gives rise to a yellowish alteration product. One large zircon crystal, ·20 x ·15 mm., with uniaxial figure and high colours, is observed. The structure is heteroblastic and the rock is best described as a *Magnetite-Garnet-Gneiss*.

No. 181.—This is a distinctive and banded variety with numerous dark porphyroblasts of magnetite (Plate I, fig. 1). Their longer axes are parallel to the well-developed schistosity and at times measure 14 x 7 mm. One large elongated crystal of tourmaline is noted which possesses the trigonal cross-section and characteristic absorption. A green chloritic mica is the only other mineral occurring in large masses. A similar rock is illustrated (Plate 1, fig. 2), in which the magnetite porphyroblasts have been elongated into a pronounced linear structure.

Microscopically the rock is composed of bands of minute quartz and garnet, quartz, and felspar and biotite crystals. The magnetite individuals are studded with numerous inclusions of garnet, biotite, quartz, and altered felspar. A little rutile is intergrown with the magnetite and occasionally there is a slight alteration to limonite. Garnets are numerous but their size is small; some of the grains, especially the smaller ones, show anomalous double refraction. When a band of quartz and garnet meets a magnetite porphyroblast, it divides into two and surrounds the porphyroblast. Green biotite is common and associated with green chlorite. There is a distinctive yellowish-brown biotite which is rare relative to the green variety. Muscovite is present in small amount. Plagioclase and orthoclase are present and the former ranges down to andesine. The felspar is frequently kaolinised. Epidote is present. Some crystals suggest cordierite but there is an absence of brown pleochroic spots. Quartz is abundant, while apatite is a common accessory. No tourmaline is present in this section. The rock is a *Porphyroblastic-Magnetite-Garnet-Gneiss*.

No. 304.—This is a schistose rock, to which is attached, like No. 147, part of a coarsely crystalline vein or lens composed of quartz, felspar, garnet, magnetite, and also micaceous hematite.

Magnetite forms 11·9 per cent. of the rock and it contains inclusions of garnet, biotite, apatite, quartz, and cordierite. Hematite is present and a little limonite has developed from the magnetite. No ilmenite is noted and no reaction obtained for titanium. Garnets form 7·9 per cent. and are usually idiomorphic. Biotite is abundant, forming 14·7 per cent., and frequently includes quartz and zircon. Quartz is abundant and contains numerous inclusions of garnet, magnetite, and zircon and also fluid inclusions. It shows strain polarisation and is at times difficult to distinguish from cordierite; the latter is usually recognised by the pleochroic brown spots. Such extinction angles as can be measured for the felspars are high, and these, in conjunction with a high refractory index, suggest labradorite. Though most of the felspar is clouded, there is occasionally a clear fresh felspar with an extinction angle of 10 degrees and a low refractive index which is probably albite. No sillimanite is present. The structure of the rock is granoblastic and the specimen may be called a *Magnetite-Garnet-Gneiss.*

No. 814.—This is a banded type in which the bands are narrower at the centre of the specimen than at either end. They are composed of quartz, garnet, biotite, felspar, and magnetite, and the pink colour of certain bands is due to a predominance of garnet.

Magnetite with a little intergrown hematite forms 14·7 per cent. of the section. No ilmenite occurs and no reaction was obtained for titanium. The magnetite frequently contains inclusions of quartz, biotite, and garnet and there is sometimes a rim of magnetite around a garnet crystal, while cracks in the garnets may be filled with magnetite. Garnet, which was one of the first minerals to be formed, has an average grain size of about 0·25 mm., forming 12·6 per cent. of the section. Quartz and felspar constitute nearly two-thirds of the rock. Quartz shows strain polarisation and is relatively clear with respect to the felspar; it frequently contains inclusions of apatite, zircon, and garnets. The felspar is only slightly altered and ranges from andesine to labradorite. A little orthoclase is present. The felspar contains inclusions of quartz, magnetite, and apatite. The biotite is a brown variety with numerous inclusions of garnet, apatite, and sometimes magnetite. The structure is granoblastic and the rock is a *Magnetite-Garnet-Gneiss.*

No. 245.—This is a dark schistose type in which magnetite, garnet, biotite, and quartz can be identified macroscopically.

Magnetite is an important constituent of the rock and a fair amount of ilmenite is intergrown with it. Chemical tests on this and the following specimen (No. 288) indicates the presence of titanium. Magnetite crystals enclose quartz, biotite, and garnet. Garnets (15·6 per cent.) are almost as numerous as magnetite (17·9 per cent.) and are more idioblastic though they are smaller in size (0·14 mm.) Some have been altered to quartz and micaceous products and others have produced epidote, as in No. 989. Quartz and felspar are abundant. Numerous minute gaseous inclusions in the quartz have a roughly parallel arrangement, but there are other small reddish inclusions which are possibly hematite or rutile. Both orthoclase and plagioclase are present; the latter is mostly andesine but some approaches labradorite in composition. Microcline with its typical cross-hatching is observed and the felspar is generally free from alteration. Green biotite forms 9·2 per cent. and shows pleochroic halos around minute zircons. Apatite and epidote are noted. The rock is a *Magnetite-Garnet-Schist.*

No. 288.—This rock is very similar to No. 245 in the hand specimen except that it contains some moderately large porphyroblasts of magnetite.

The garnets are mostly of smaller dimensions (0·07 mm.) than in the preceding No. 245 and they are sometimes enclosed in the magnetite. The larger porphyroblasts of magnetite are confined to certain bands; they are elongated parallel to the schistosity and contain inclusions of quartz and appear to have a little rutile intergrown with them. Felspar is the most abundant mineral present and it is much altered to an aggregate of micaceous minerals and epidote. Relics of microcline with cross-hatching are present but the greater part of the felspar is a plagioclase of composition between andesine and labradorite. Quartz shows strain polarisation and cataclasis. Biotite is greatly altered to chlorite and secondary magnetite. Muscovite has also been developed from biotite and is not symmetrically disposed to the schistosity planes. A little bleached biotite and accessory apatite occur. Granoblastic, porphyroblastic, and cataclastic structures are the chief ones present. The rock is a *Garnet-Magnetite-Schist.*

No. 102.—This is a massive type with dominating garnet. Most of it is fine grained but in parts the crystals of garnet and quartz attain considerable size.

Garnets form 40·8 per cent. of the rock and occur as irregular masses traversed by numerous cracks along which iron ore occurs (Plate II, fig. 5.) When the garnet is altered to chlorite, a larger amount of iron ore is developed. Garnet is also intergrown with magnetite and quartz; and all three minerals contain inclusions of one another. Limonite is present as a pseudomorph after magnetite and there is a fair amount of rutile intergrown with the magnetite; this is red by reflected light and probably absorbs the 1·14 per cent. of TiO_2, in the rock. Apatite is more abundant than usual and occurs chiefly with the magnetite. Quartz is abundant and contains numerous inclusions of minute iron ore individuals arranged in parallel lines. A few zircon crystals occur. The structure is diablastic and the texture is massive. It is *Garnet-Quartz-Magnetite Rock.*

No. 348.—This is a schistose variety with bands of minute pink garnets and clear quartz, which show up well from the otherwise greenish-black rock. Scattered through the rock are occasional porphyroblasts of magnetite and in this respect the specimen resembles Nos. 181 and 288.

Garnets are numerous and form one-fifth of the rock but the average size of the grains is only 0·06 mm. The chemical analysis shows that this rock contains 8·23 per cent. of MnO and it is probable that this is contained in the garnet. Magnetite occurs both as xenoblastic and idioblastic individuals which generally have their longer axes parallel to the schistosity. Felspar and quartz are present in equal proportions. The felspars are almost entirely kaolinised and their original nature is somewhat indefinite; such extinction angles as are measurable indicate andesine but orthoclase is also present. Quartz contains gaseous, garnet, and magnetite inclusions and shows strain polarisation. Green biotite is commonly altered to chlorite. Epidote and calcite, both probably derived from the alteration of the felspars, as well as apatite and zircon, are present. The structure is both porphyroblastic and granoblastic and the rock is a *Garnet-Magnetite-Schist.*

3. Chemical Characters.

The table below (Table V) contains the results of three chemical analyses. A fourth analysis of the Broken Hill rock, the mineral composition of which is given in Table I, is given for comparative purposes.

Table V.

	I.	II.	III.	IV.
SiO_2	50·35	53·73	57·78	31·34
Al_2O_3	16·18	11·57	12·01	8·34
Fe_2O_3	13·57	13·15	7·35	32·10
FeO	5·57	14·41	4·98	6·75
MgO	1·78	2·11	1·79	0·94
CaO	1·94	1·79	2·85	7·54
Na_2O	3·14	0·15	1·70	0·11
K_2O	0·89	absent	1·47	0·05
H_2O + ...	0·50	0·80	0·69	0·52
H_2O —	0·98	0·62	0·52	0·63
TiO_2	0·49	1·14	0·73	0·40
CO_2	absent	absent	n.d.	0·01
ZrO_2	trace	trace	0·06	absent
P_2O_5	0·48	0·53	0·16	4·67
SO_3	......	absent	absent	trace
F	......	......	......	trace
Cl	......	......	......	0·09
S	trace	0·16	absent	absent
Cr_2O_3	absent	absent	absent	absent
NiO, CoO	absent	absent	trace	trace
MnO	4·12	0·24	8·23	7·08
BaO	absent	absent	trace	trace
SrO	trace	absent	0·06	pres. (spect.)
Li_2O	......	......	......	absent
V_2O_3	......	......	......	0·02
CuO	......	......	......	trace
	99·99	100·40	100·38	100·32
				less O = Cl 0·02
Specific gravity ...	2·96	3·33	2·98	3·809

I. No. 181, Porphyroblastic magnetite-garnet-gneiss, Adelie Land. Analyst, A. L. Coulson.
II. No. 102, Garnet-quartz-magnetite rock, Adelie Land. Analyst, A. L. Coulson.
III. No. 348, Garnet-magnetite-schist, Adelie Land. Analyst, A. L. Coulson.
IV. Quartz-garnet-magnetite rock, Broken Hill, New South Wales.* Analyst, W. G. Stone.

The analyses are noteworthy for their low silica as there is abundant free quartz in each case. Felspar is an equally important constituent in Nos. 181 and 348 where appreciable alkalies are present. Felspar is not recorded in No. 102 or in the Broken Hill specimen and the total alkalies are extremely small. The remarkable high content of magnetite and garnet is reflected in the high total iron. Lime and magnesia are extremely low and reflect the paucity of ferromagnesian minerals. Magnesia is

* "Geology of the Broken Hill District," E. C. Andrews. Mem. 8, Geol. Surv., N.S.W., p. 172.

almost wholly contained in the mica and the lime in the felspar and apatite. Practically no lime and magnesia is available for the garnet. In No. 102, which contains 40·8 per cent. of garnet, it can be clearly inferred that the garnet is an iron-alumina variety. In No. 181 there is 4·12 per cent. of MnO which probably replaces part of the FeO in the garnet. No. 348 contains an exceptional amount of 8·23 per cent. of manganese and the composition of the garnet may approach that of spessartite. Qualitative tests indicate the presence of considerable manganese in the chlorite magnetite schist 527A and in the magnetite garnet schists and gneisses Nos. 304, 814, 245, and 288. Rutile is recorded in Nos. 181 and 102 and may account for part or all of the titanium content. Qualitative tests revealed a fair amount of titanium in the similar rocks Nos. 245 and 288, but it proved to be absent in Nos. 304 and 814. In No. 245 the titanium percentage is ascribed to ilmenite.

Comparison with the chemical analysis of the Broken Hill rock shows great similarity. The lower silica and higher total iron of the Broken Hill rock corresponds with lower quartz and garnet percentages and higher iron ore than No. 102. Its high manganese content is a marked point of resemblance with No. 348. It is distinct, however, in its high lime and phosphorus which correspond with the measured percentage (14·2) of apatite. Its large excess of Fe_2O_3 over FeO appears to indicate more hematite than in the Antarctic types.

4. Summary of Petrographical Characters.

The following rocks have been described :—

Magnetite-schists	Nos. 765, 912, 294.
Biotite-magnetite-schist	No. 926.
Chlorite-magnetite-schist	No. 527A.
Mica-magnetite-schists	Nos. 55, 933.
Mica-magnetite-gneiss	No. 576.
Quartz-magnetite-schist	No. 296.
Epidote-magnetite-schist	No. 989.
Magnetite-garnet-schists	Nos. 889, 147, 245.
Magnetite-garnet-gneiss	Nos. 827, 181, 149, 304, 814.
Garnet-magnetite-schists	Nos. 288, 348.
Quartz-garnet-magnetite rock	No. 102.

Quartz, felspar, and mica are the chief minerals present in the rock suite in addition to the abundant magnetite and garnet which characterise the group. The quartz usually shows strain polarisation colours and a cataclastic structure. In a number of cases minute inclusions have a definite alignment within the individual quartz crystals which is generally parallel to the planes of schistosity.

Felspar is an important constituent, though it is totally absent in the magnetite-schist No. 912, in the quartz- or epidote- or mica-magnetite-schists Nos. 296, 989, 933, and in the quartz-garnet-magnetite rock No. 102. Orthoclase is a common constituent but microcline only occurs in the magnetite-garnet-schist No. 245, and the garnet-magnetite-schist No. 288. The plagioclase ranges from albite to labradorite and it commonly happens that an acidic and a basic plagioclase are present. Generally the felspars are much kaolinised and sericitised.

Cordierite is not common but is observed in four magnetite-garnet schists and gneisses No. 889, 147, 827, and 304. Such crystals as are seen in these sections do not exhibit any measurable pleochroic halos.

Biotite is a very common constituent, the usual variety being green in colour. Muscovite is present in some sections, notably in the chlorite-magnetite-schist No. 527A, the mica-magnetite-schists Nos. 55, 933, and the epidote-magnetite-schist No. 889. Chlorite is an important mineral and usually owes its origin to the alteration of biotite or garnet. Epidote is abundant in some of the magnetite schists but it loses importance as the ratio of garnet to magnetite increases. Apatite is a common accessory, as also is zircon.

Magnetite usually has ilmenite or hematite or rutile intergrown with it. Limonite, pyrite, and sphene also occur but the latter two minerals are not common. The percentage of iron ore ranges from 33·0 in the magnetite-schist No. 294 to 6·2 in the garnet-magnetite-schist No. 288. In most cases the crystals of magnetite are xenoblastic rather than idioblastic. In Nos. 181, 288, and 348 there are magnetite porphyroblasts and in the example in Plate I, fig. 2, a pronounced linear structure has developed from the porphyroblasts. As the porphyroblasts of magnetite have their longer axes parallel to the schistosity and contain numerous inclusions of garnet, quartz, and biotite, all of which originated during, or were recrystallised by, the metamorphism, these porphyroblasts evidently arose at the time of major metamorphism, when the conditions of pressure and temperature probably corresponded to Grubemann's meso zone of metamorphism. The chloritisation of the biotite and the kaolinisation of the felspars probably arose under later conditions of epi zone metamorphism. Stillwell * has applied a conception of metamorphic differentiation to clots of biotite and epidosite in amphibolite dykes at Cape Denison. It is possible that the same conception can be applied to the magnetite porphyroblasts, in which case they are due to local segregation of iron ore arising as a direct consequence of the metamorphism. In many instances in the suite of rocks described, magnetite has been considered as arising partly from the result of epi zone processes on the garnet and mica.

Garnet is a less constant constituent than the magnetite. It is absent in some specimens and ranges up to 40 per cent. in No. 102, where it dominates the colour of the

* "The Metamorphic Rocks of Adelie Land." F. L. Stillwell. Aust. Ant. Exp. Scientific Reports, Series A, Vol. III, Part 1 (1918), p. 58–71.

rock. The commonest alteration of the garnet is the production of chlorite, quartz, and magnetite which is especially well displayed in the chlorite magnetite schist No. 527A. The reaction can be illustrated by the equation—

$$\underset{\text{Garnet.}}{2\ MgFe_3AlSi_3O_{12}} + 4\ H_2O \rightleftarrows \underset{\text{Chlorite.}}{H_8Mg_2Fe_3Al_2Si_3O_{18}} + \underset{\text{Quartz.}}{2\ SiO_2} + \underset{\text{Magnetite.}}{Fe_3O_4}.$$

The two arrows going in opposite directions means that the equation representing a reaction is reversible.

In this composition of the garnet the ratio of Mg to Fe is assumed to be as 1 to 2, and the ratio of Fe to Al as 1 to 1. The chlorite is also assumed to be an isomorphous mixture of the two silicate molecules, $H_4(MgFe)_3Si_2O_9$ and $H_4(MgFe)_2Al_2SiO_9$ in the proportions of 1 to 1. Chemical work has indicated, however, that the garnet contains manganese in many cases where this change is observed. On alteration, it is probable that the manganese enters the composition of magnetite rather than the chlorite, producing manganmagnetite, the composition of which is expressed by $(FeMn)O, Fe_2O_3$.

While quartz, chlorite, and magnetite are the usual alteration products of garnet, magnetite was the sole recognisable product, in some cases thus indicating the migration of quartz and chlorite. In the magnetite-garnet-schist No. 889, there is a production of quartz, magnetite, and either biotite or muscovite. This may have been attained by a reaction between garnet and the microcline or orthoclase in the following manner :—

$$\underset{\text{Garnet.}}{Fe_3Al_2Si_3O_{12}} + \underset{\text{Orthoclase.}}{KAlSi_3O_8} + 2\ (OH) \longrightarrow \underset{\text{Muscovite.}}{H_2KAl_3Si_3O_{12}} + \underset{\text{Quartz.}}{3\ SiO_2} + \underset{\text{Magnetite.}}{Fe_3O_4}.$$

Stillwell * gives the following reaction which may be applicable to the case in which biotite is produced :—

$$\underset{\text{Garnet.}}{2\ (MgFe)O, CaO, Al_2O_3, 3SiO_2} + \underset{\text{Orthoclase.}}{2\ KAlSi_3O_8} \rightleftarrows \underset{\text{Biotite.}}{(KH)_2(MgFe)_2Al_2(SiO_4)_3}$$
$$+ \underset{\text{Anorthite.}}{CaAl_2Si_2O_8} + \underset{\text{Quartz.}}{SiO_2}.$$

The anorthite molecule is considered to enter into, or be derived from, the composition of the plagioclase which then becomes relatively more basic or more acid according to the direction of the action. It is doubtful whether there is sufficient lime in the garnet to give rise to anorthite in the present case.

Grubenmann † illustrates the production of quartz and biotite from garnet and orthoclase by an equation in which sillimanite is produced. The latter mineral does not appear in the present case.

Tilley ‡ interprets the reaction as follows :—

$$\underset{\text{Biotite.}}{H_4K_2Mg_2Fe_4Al_6(SiO_4)_9} + \underset{\text{Quartz.}}{3\ SiO_2} \rightleftarrows \underset{\text{Orthoclase.}}{2\ KAlSi_3O_8} + \underset{\text{Garnet.}}{2\ Fe_2MgAl_2(SiO_4)_3} + 2\ H_2O.$$

* *Op. cit.*, p. 158.

† "Die Kristallinen Schiefer." U. Grubenmann. Berlin, Vol. I (1904), p. 52.

‡ "The Granite-Gneisses of Southern Eyre Peninsula." C. E. Tilley, Q.J.G.S., Vol. lxxvii, Pt. 2 (1921), p. 94.

It was noted that epidote was sometimes developed as a result of the alteration of the garnet. Van Hise * gives the following equation for the development of epidote from a lime-iron-alumina garnet—

$$2\ Ca_3Al_2Si_3O_{12}.\ Ca_3Fe_2Si_3O_{12} + 5\ CO_2 + H_2O = 2\ HCa_2Al_2FeSi_3O_{13} + 5\ CaCO_3 + 3\ SiO_2 + k\ \text{(heat liberated)}.$$

In the rocks under discussion, however, calcite is only present in No. 348 where it appears to be derived from calcic plagioclase. In the epidote-magnetite-schist No. 989 and the magnetite-garnet-schist No. 245 epidote is developed from the garnet but there is no free calcite. The above equation therefore represents a garnet with more lime than in the garnets of these rocks.

Van Hise* records that in all cases of alteration of garnet, quartz appears among the secondary minerals. In these rocks magnetite is also as general.

III.—POSITION IN GRUBENMANN'S CLASSIFICATION OF CRYSTALLINE SCHISTS.

The described rocks can be considered in two groups—(1) those in which magnetite is the most important constituent; and (2) those in which garnet and magnetite are equally important.

The members of the first group can be placed in the group of iron oxide rocks (magnetite rocks) which forms Grubenmann's XIth group. The presence of garnet, quartz, plagioclase, orthoclase, biotite, magnetite, &c., and the occurrence of homoblastic and diablastic structures, which are sometimes almost obliterated by later epi structures, all necessitate some form of deep-seated metamorphism. In addition, a transference to epi zone conditions is suggested in some cases by the hydrous minerals associated with the kaolinisation and sericitisation of the felspars and with the development of chlorite and magnetite from garnet and biotite. Thus the magnetite schists and gneisses Nos. 576, 912, 933, 294, and 55 are considered to be epi-meso rock types, but may fall into the family of epi-magnetite rocks of Order III. In Nos. 989, 527A, and 889 the first metamorphism may have resulted from either meso or kata conditions. No. 889, a magnetite-garnet-schist containing cordierite, may be related to the aluminous silicate gneisses (Group II) and the family of kata garnet gneisses. Nos. 765, 926, and 296 appear to be pure meso zone types and belong to Order II, meso magnetite rocks and micaceous hematite schists (Group XI).

* "Treatise on Metamorphism." C. R. Van Hise. Geol. Surv., U.S.A., monograph 47, 1904, p. 305.

The analysed specimens belong to the second group, and Tables VI and VII give the molecular percentages of the constituent oxides, the group values and the projection values according to Ozann's scheme.*

TABLE VI.

	I.	II.	III.	IV.
SiO_2	56	58·3	61·8	64·4
Al_2O_3	9	11·0	7·6	7·8
FeO	27	21·1	24·8	18·5
CaO	4	2·4	2·2	3·4
MgO	......	3·1	3·5	3·0
K_2O	3	0·6	......	1·1
Na_2O	1	3·5	·1	1·8

TABLE VII.

Group and Projection Values.	I.	II.	III.	IV.	V.
S	56	58·3	61·8	64·4	20·0
A	4	4·1	0·1	2·9	0·0
C	4	2·4	2·2	3·4	0·4
F	27	24·2	28·3	21·5	80·0
M	0	0·0	0·0	0·0	2·5
T	1	4·5	5·3	1·5	0·0
K	0·9	1·1	2·1	1·4	0·3
a	2·2	2·7	·07	2·1	0
c	2·2	1·6	1·4	2·4	0
f	15·6	15·7	18·5	15·5	20

I. No. 149, Magnetite-garnet-gneiss.
II. No. 181, Porphyroblastic magnetite-garnet-gneiss.
III. No. 102, Garnet-quartz-magnetite rock.
IV. No. 348, Garnet-magnetite-schist.
V. Mean values of Grubenmann's XIth Group.

The values for No. 149 have been obtained from the Rosiwal analysis in Table I on the assumption that biotite has the composition $K_2FeAl_2(SiO_4)_3$, that the garnet is almandine and that quartz, orthoclase, and labradorite are present in equal proportions

* Grubenmann, *op cit.*, 1910, pp. 134–6.

in the rock. The values for the other rocks are obtained directly from the chemical analyses in Table V. The projection values are plotted in the triangular diagram, fig. 1.

An examination of the group values of the garnet-magnetite rocks in Table VII shows that these rocks do not fit in any of Grubenmann's groups of crystalline schists. Column 5 gives the mean group values of Group XI, the iron oxide rocks and these show outstanding differences, especially in regard to S and F, with the corresponding values of the garnet-magnetite rocks. Wide as are the variation limits assigned to some groups of the crystalline schists, it appears impossible to include these garnet-magnetite rocks without the creation of a new group. It may, therefore, be advisable to add a new group of garnet magnetite rocks, just as two new groups have been created (1) for certain manganiferous rocks in India. Hezner has added a manganese silicate group which is naturally united to the lime silicate rocks by all its chemical, mineralogical, and genetic relations, and also a new manganese oxide group which best follows the XIth Group of iron oxide rocks.

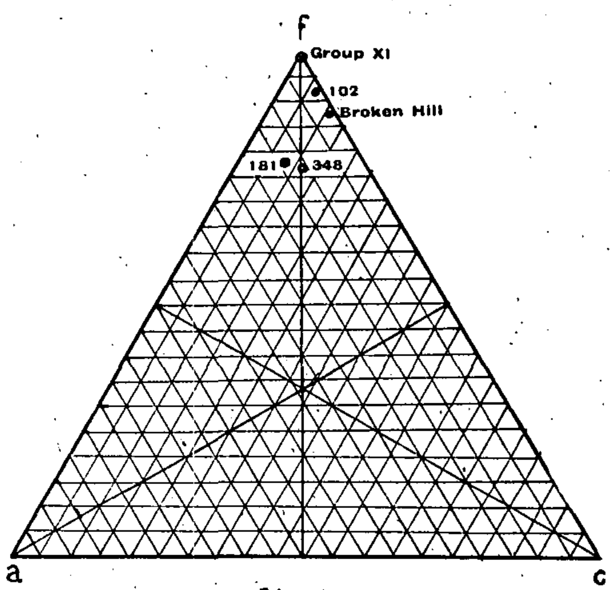

Fig. 1.

Nos. 149, 181, and 348 would be types of a new garnet magnetite rock group, while No. 182 would be somewhat abnormal. The chief minerals of such a group are garnet, magnetite, and quartz. Other minerals which may be present are biotite, felspar, cordierite, sillimanite, and epidote. Ilmenite, rutile, and hematite may be intergrown with magnetite. Kata zone types are represented by Nos. 149, 827, and 304. Meso zone types include Nos. 149, 814, and 245, while Nos. 181, 288, and 348 have apparently been subjected to epi zone metamorphism as well as meso zone metamorphism.

On the other hand, if, as will appear likely, igneous emanations are concerned in the formation of these magnetite garnet gneisses, it becomes doubtful whether any attempt should be made to fit them into Grubenmann's classification of the crystalline schists.

* "Uber manganreiche Kristalline schiefer Indiens." L. Hezner, Neues Jahrbuch fur Minerologie, &c., 1919, p. 28.

IV.—GENERAL DISCUSSION.

As the specimens are morainic boulders there is no field evidence bearing on the question of their origin. The nature and character of the magnetite-schists Nos. 912 and 294, the quartz-magnetite-schist No. 296, the epidote-magnetite-schist No. 989, the mica-magnetite-schists Nos. 55 and 933, and possibly also the garnet-magnetite-gneiss No. 827 indicate that they very more likely to be derivatives of sedimentary rocks rather than igneous rocks. The probability is not so high in the case of the garnet-magnetite rocks. The evidence of the chemical analyses of the three specimens in Table V is not decisive. There is a considerable excess of alumina over the 1 to 1 ratio with the lime and alkalies and this, combined with the mineral content, suggests derivation from a sediment. On the other hand, CaO is in excess over MgO in two analyses and Na_2O is in excess of K_2O. Less weight is attached to these points and in general it is believed that a sedimentay rather than an igneous origin is to be ascribed to the whole class. Yet the chemical composition is clearly not that of a common sediment.

An interesting comparative occurrence is the quartz-garnet-magnetite-schist from Broken Hill, New South Wales. It occurs* in the neighbourhood of the Broken Hill lode in discontinuous lenses along bands which dip conformably with the associated garnet-sillimanite-gneisses. A specimen from a locality, one mile south of Menindie-road, 4 miles south of Broken Hill, has been studied. It is a schistose rock composed of magnetite, garnet, quartz, and apatite in the proportions given in Table I. It may be noted that the proportions of iron ore to garnet are approximately the reverse of that in No. 102, its nearest relative among the Cape Denison specimens. While No. 102, with 2 per cent. of apatite, is comparatively rich in phosphorus, this is greatly exceeded by the Broken Hill specimen with 14·2 per cent. of apatite.

The chemical analysis of the Broken Hill type is quoted in Table V, and the negligible alkalies, the low magnesia, and high iron are strong points of resemblance. The differences in silica percentages correspond with differences in the amount of quartz. The percentages of lime and phosphorus are much higher than those in No. 102. corresponding to the abundant apatite. The Broken Hill type contains 7·08 per cent. of manganese and is comparable with the 8·23 per cent. in No. 348, where the garnets are manganiferous.

There are thus striking resemblances between the Broken Hill type and the garnet-magnetite specimens from Cape Denison. The Broken Hill type is described by Andrews† as a lode formed from emanations given off, apparently at a depth, from igneous material along a crush zone, and further formed by replacement. He points out (p. 174) that the garnet-magnetite type is associated with garnet-sillimanite rocks, while the quartz-magnetite types, without garnet, are associated with mica schists. Browne‡

* "Geology of Broken Hill." E. C. Andrews. Mem. 8, Geol. Surv. N.S.W., 1923, p. 171.

† "Geology of Broken Hill District." E. C. Andrews, Geol. Surv. N.S.W., No. 8, 1922, p. 181.

‡ Appendix I of "Geology of Broken Hill District." W. E. Browne, p. 340.

believes these rocks to be pegmatitic derivatives of the gabbro magma which are intruded as a metasomatic replacement of a zone of country rock. Further, these authors appear to regard the garnet as a primary igneous mineral.

The comparison with the Broken Hill occurrence should therefore imply that the garnet-magnetite rocks are derived from an igneous source.

Another related group of rocks are the "Skarn" rocks of Norway and Sweden. Skarn* is an old Swedish mining term for the sillicate gangue of certain iron ore and sulphide deposits of Archaean age. Its use has been extended by Goldschmidt† to all lime-iron-silicate rocks which arise through the contact metamorphism of limestone, including andradite rocks, hedenbergite rocks and andradite-hedenbergite rocks. The iron ore of the skarn rocks (including garnet-magnetite rocks) is arranged in layers parallel to the schistosity or bedding. Goldschmidt is sceptical of the view that such rocks are magmatic differentiation products—a view adopted by Browne for the Broken Hill type. Goldschmidt considers them to be pneumatolytic contact rocks determined by three factors, (1) pneumatolytic action in depth, (2) presence of a limestone, and (3) absorption and enrichment of the constituents of the magmatic gases.

The skarn formation from limestone takes place through increase of silica and iron. It is supposed that iron chloride is introduced in gaseous form along joints and fissures with the result

$$2\,FeCl_3 + 3\,CaCO_3 = Fe_2O_3 + 3\,CaCl_2 + 3\,CO_2.$$

In this way the limestone collects the iron from the issuing magmatic gases. The silicon is probably introduced as a halogen compound which reacts with the calcite to form quartz. Quartz then combines with calcite forming wollastonite which, when there is sufficient iron oxide, combines to form andradite.

$$\underset{\textit{Wollastonite.}}{3\,CaSiO_3} + Fe_2O_3 = \underset{\textit{Andratite.}}{Ca_3Fe_2Si_3O_{12}}.$$

Manganese, which is a notable component of many skarn rocks, is introduced in the same way as the iron.

$$MnCl_2 + CaCO_3 = MnO + CaCl_2 + CO_2.$$

The MnO, however, generally enters the silicate.

Goldschmidt thus considers that the skarn rocks are the result of metasomatic pneumatolytic processes acting on limestones, and their unusual composition is explained by the acquisition of material from the magmatic source.

Somewhat similar rocks at Morenci, Arizona, are considered by Lindgren‡ to have been derived from limestones by the addition of large amounts of ferric oxide and silica.

* "Nomenclature of Petrology." A. Holmes. London, 1920, p. 211.

† "Die Kontaktmetamorphose im Kristianiagebiet." V. M. Goldschmidt, Christiania, 1911, p. 211 et *seq.*

‡ "The Copper Deposits of the Clifton-Morenci District, Arizona." W. Lindgren, U.S. Geol. Surv., Prof. pap. 43, 1905, p. 160.

In the Broken Hill occurrence no associated limestone is reported, neither does the garnet of the Adelie Land specimens correspond to andradite. Yet it is interesting to note that the same moraines have yielded a number of specimens of metamorphic limestones and calc-silicates rocks.* It is known, however, that similar garnet rocks can be produced without limestone. Kemp,† in commenting on the processes of garnet formation in contact rocks of intrusive zones, concludes that, where limestone is absent, the emissions from the deeper parts of the eruptive supplies the lime and iron oxide for the garnet occurrences in such rocks as quartzites, schist, and gneiss, just as the reverse contributions of silica and iron and alumina to the limestone would lead to the same result. In the Broken Hill type it is clear that there has also been an important addition of phosphorus.

In the garnet-magnetite types from Cape Denison the garnet is a variety containing magnesium, iron, manganese, and alumina. Felspar, as noted above, is often an important constituent though it fails in the quartz-garnet-magnetite rock, No. 102. The presence of aluminous garnet in addition to felspar suggests that the garnet-magnetite formation has occurred in a rock in which there has been sufficient alumina and silica to satisfy all the alkalies and available lime for the formation of felspar, and further that the garnet-magnetite formation has occurred in the presence of excess alumina rather than excess lime. Where P_2O_5 is present or introduced, the lime would be incorporated in apatite in preference to felspar. Aluminous garnet is present in the analogous type at Broken Hill which occurs in a sedimentary series with excess alumina, expressed in abundant sillimanite. It is therefore possible that the Cape Denison types have developed in aluminous sediments similar to those which are related to the magnetite schists, Nos. 912 and 294, and the related types Nos. 296, 989 and 933.

In conclusion, it is therefore likely that the garnet-magnetite rocks of Cape Denison have resulted from the metamorphism of sediments, the composition of which has been modified by igneous emanations.

V.—TOURMALINE-BEARING MAGNETITE GNEISS.

In view of the probable role of igneous emanations in the formation of the garnet-magnetite rocks the following description of No. 252, a tourmaline-bearing and garnet-free type, has added interest.

No. 252 is a banded variety, in general fine grained, but with coarsely crystalline bands of quartz and bluish cordierite. Tourmaline is very abundant and long needles of sillimanite and black grains of magnetite are plainly seen in the hand specimen. The proportions of cordierite, magnetite, tourmaline and sillimanite are very variable. The specific gravity of the rock is 3·09.

* "The Metamorphic Limestones of Commonwealth Bay, Adelie Land." C. E. Tilley. Aust. Ant. Exp. Sci. Rpts. Series A., vol. iii, pt. II, pp. 231–243.

† "Ore Deposits at the Contacts of Intrusive Rocks and Limestones." J. F. Kemp. Journ. Geol., vol. ii, pp. 1–13.

A portion of the rock, which was very rich in tourmaline, was sectioned in a direction at right angles to the schistosity. A Rosiwal analysis resulted in the following:

Quartz, cordierite, and sillimanite	47·5
Tourmaline	30·1
Magnetite	21·4
Apatite	1·0

The tourmaline is a strongly pleochroic variety, changing from green to a reddish- or brownish-violet. The flakes show a rather infrequent cleavage and contain gas, magnetite, and minute zircon or monazite inclusions, sometimes with a definite alignment. Where these minute zircons or monazites are present, there is occasionally a distinct lightening of colour in the form of a halo around the inclusion. The colours of the tourmaline sometimes vary locally in a zonal fashion. The mineral is associated with magnetite, both occurring in bands throughout the rock.

Cordierite is abundant and exhibits a great number of well-formed pleochroic halos around inclusions of either zircon or monazite (Plate II, fig. 6.) While the experience of Joly and Fletcher* has indicated that halos in cordierite cannot be used for accurate measurement, the halos in this rock are remarkably distinct and capable of measurement. By means of a Beck micrometer eye-piece and a 4 mm. (x 45) objective, the following results were obtained, the radii given being always the distance from the outer edge of the halo to the edge of the inclusion. All measurements are in millimetres.

TABLE VIII.

No.	Radius of Halo.	Remarks.	Dimensions of Nucleus.	Remarks.
1	·041	Distinct	·020 x ·020	Circular.
2	·041	Perfect halo, very distinct	·031 x ·022 ...	Oval, oblique extinction.
3	·040	Distinct	·054 x ·030 ...	Oval, oblique extinction.
4	·040	Indistinct, passing through both cordierite and sillimanite.	·023 x ·017 ...	Prismatic, oblique extinction. Zircon.
5	·040	Indistinct, passing through both cordierite and sillimanite.	·054 x ·018 ...	Prismatic, oblique extinction.
6	·040	Very distinct, lighter in colour for about ·020 mm. from the inclusion.	·032 x ·028 ...	Oval, oblique extinction.
7	·040	Indistinct, fainter near nucleus for about ·012 mm.	·033 x ·029 ...	....
8	Large......	Indistinct	·083 x ·027 ...	Zircon.
9	·026	Fairly distinct, passing through sillimanite and cordierite.	·038 x ·015 ...	Oval, oblique extinction.
10	·021	Indistinct	·015 x ·010 ...	Oval, oblique extinction.
11	·020	Fairly distinct	·017 x ·011 ...	Oval, oblique extinction.
12	·020	Indistinct, faint at sides	·016 x ·011 ...	Oval.
13	·016	Doubtful	....	....
14	·015	Fairly distinct	·010 x ·008 ...	Straight extinction.
15	......	Indistinct	·038 x ·027 ...	Wedge shaped.

* "Pleochroic Halo." Phil. Mag., 6th series, vol. xix, 1910, p. 635.

As in the halos measured in No. 149 in biotite, corona effects are generally absent, being noted only in two cases, and Joly's correction for nuclei, based on the assumption that they are zircon and sensibly spherical, obviously cannot be made. By a comparison with the list of radii given by Joly and Fletcher, it seems probable, as the dimensions of the halos in cordierite will not differ markedly from those in biotite, that No. 1–8 owe their origin to Th C, No. 9 to Th X and Nos. 10–12 to Ra A.

The cordierite is much intergrown with long prismatic needles of sillimanite which make the measurement of halos sometimes very difficult. In places the halos are so numerous that the cordierite remains brown throughout a complete revolution of the stage. As has been noted above, the radioactive inclusions are not confined to cordierite, some occurring in tourmaline. Monazite appears to be the more common nucleus in No. 252, while zircon was the more frequent in No. 149. The cordierite is at times altered to a yellowish-brown form of biotite and at others the change proceeds, from a centre, giving a chloritic mass.

Quartz is abundant and distinguished from cordierite by the absence of halos cleavage and decomposition. Apatite is frequent but it is restricted to certain bands in which it is associated with magnetite. The structure of the rock is homoblastic, and though the nature of the different bands is very variable a general name would be *Tourmaline-Magnetite-Sillimanite-Cordierite-Gneiss.*

The absence of felspars and the abundance of sillimanite and cordierite clearly indicate that the rock has been derived from a sediment. The abundance of tourmaline indicates the action of igneous emanations and tends to confirm the similar view in regard to magnetite and apatite.

In Grubenmann's classification it would occupy a position in the Kata division of the group of aluminous silicate gneisses (Group II). Within this division there is a family of the sillimanite gneisses and the family of the cordierite gneisses, but the Cape Denison rock is clearly distinct from typical members of these families in the presence of abundant tourmaline and magnetite.

VI.—GENERAL SUMMARY AND ACKNOWLEDGMENTS.

In all twenty-two specimens have been described from Adelie Land and treated as crystalline schists. Two contain abundant magnetite and no garnet. Seven contain dominating magnetite and, together with the preceding two, are associated with the iron oxide group, No. XI, of Grubenmann's classification of the crystalline schists. In ten specimens garnet is approximately as important as the magnetite. The chemical characters of these types are widely different from any defined group of crystalline schists and a new group of garnet-magnetite rocks is suggested.

The types are probably derived from sediments whose composition has been modified by igneous emanations. Such origin is rendered the more likely by the final type which is rich in tourmaline as well as magnetite.

Measurements of pleochroic halos and nuclei have been made in both cordierite and biotite. The formation of these halos has been ascribed partly to Th C, partly to Th X and Ra A.

In conclusion, the writer desires to thank Professor W. W. Watts, of the Royal School of Mines, South Kensington, for kind assistance in the prosecution of research, and he is also specially indebted to Dr. F. L. Stillwell, at whose suggestion the work was undertaken and who has given the writer every possible assistance and unhesitatingly helped with his great experience of Adelie Land specimens.

VII.—DESCRIPTION OF PLATES.

Plate I.

Fig. 1.—No. 181, Porphyroblastic-Magnetite-Garnet-Gneiss. Photo, F. L. Stillwell. Note that the scale photographed with the specimen in this plate is graduated in inches.

Fig. 2.—No. 650, Porphyroblastic-Magnetite-Garnet-Schist, with a well-defined "linear" structure. Photo, F. L. Stillwell.

Plate II.

Fig. 1.—No. 527A, Chlorite-Magnetite-Schist, showing the alteration of garnet into a mass of quartz, magnetite, and chlorite with residual garnet. Mag. 113 diams. Photo, G. S. Sweeting.

Fig. 2.—Siliceous vein crossing the Micaceous-Magnetite-Schist, No. 933. The dark central area in the vein is felspar. Mag. 22 diams. crossed nicols. Photo, G. S. Sweeting.

Fig. 3.—No. 889, Magnetite-Garnet-Schist, showing parallel line development with garnet. Mag. 25 diams. Photo, G. S. Sweeting.

Fig. 4.—Magnetite-Garnet-Gneiss, No. 149, containing pleochroic halos around radioactive inclusions in biotite. Mag. 48 diams. Photo, G. S. Sweeting.

Fig. 5.—No. 102, a rock composed of garnet, quartz, magnetite, and apatite. Mag. 24 diams. Photo, G. S. Sweeting.

Fig. 6.—No. 252, Tourmaline-Magnetite-Gneiss, with numerous perfect pleochroic halos in cordierite. Tourmaline (dark with cross cleavage), sillimanite (fibrous) and magnetite (black) can also be seen. Mag. 34 diam. Photo, G. S. Sweeting.

[Two plates.]

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Fig. 1.

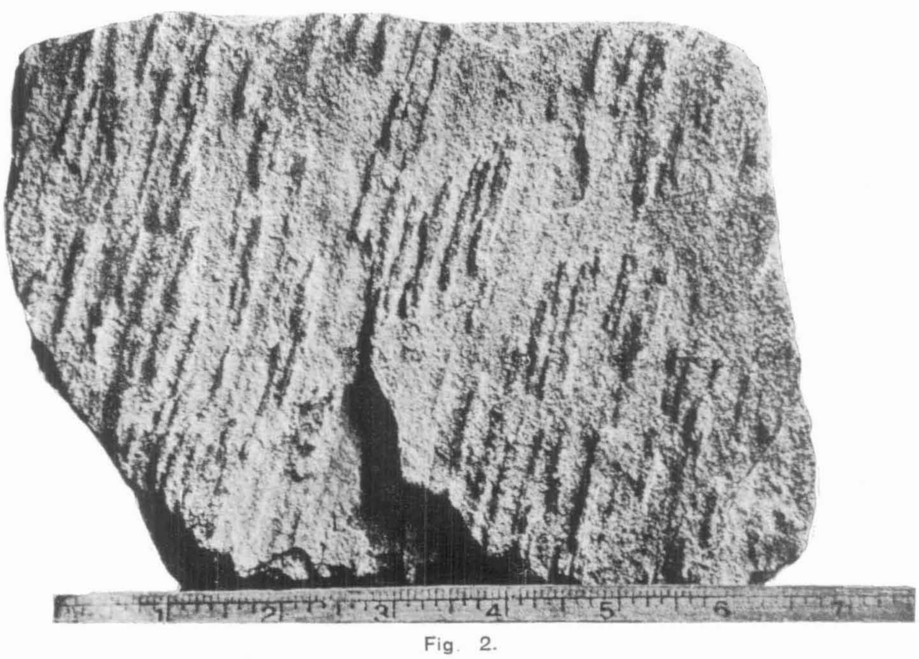

Fig. 2.

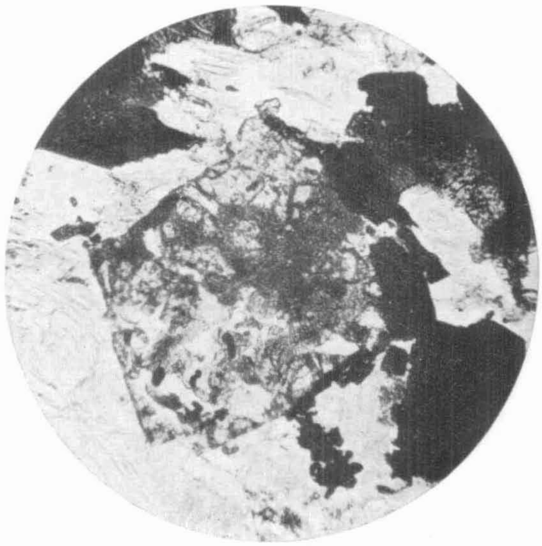

Fig. 1.

Fig. 2.

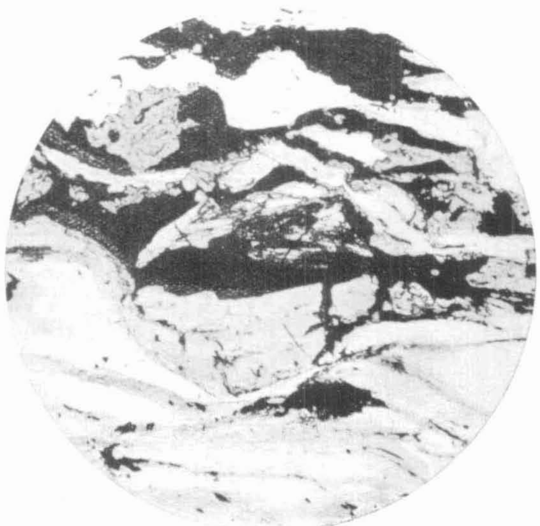

Fig. 3.

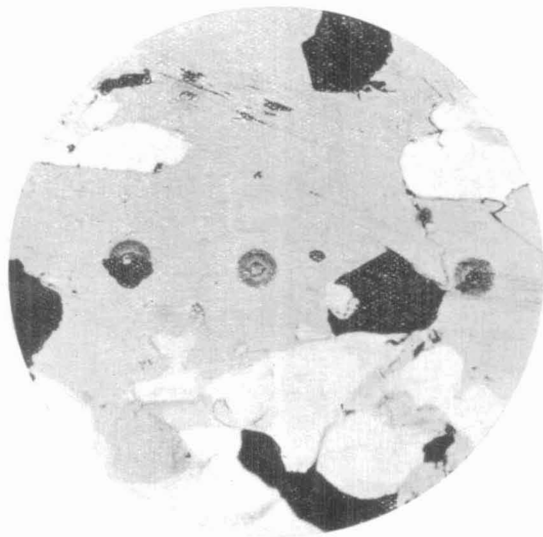

Fig. 4.

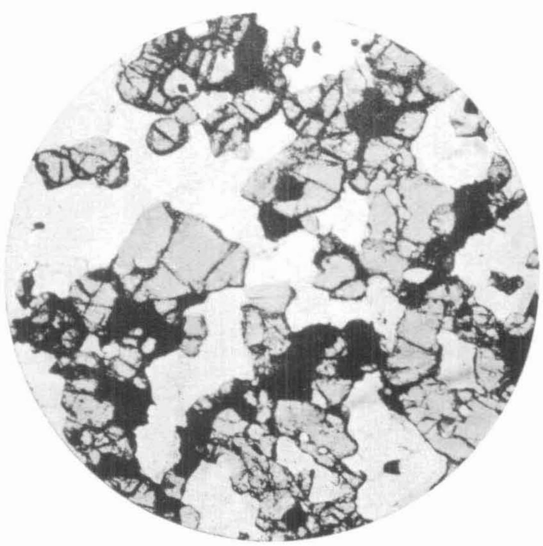

Fig. 5.

Fig. 6

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