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SCHISTS AND GNEISSES FROM THE MORAINES, CAPE DENISON, ADELIE LAND.

BY

A. W. KLEEMAN, M.Sc.

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VOL.		PRICE. £ s. d.
I.	CARTOGRAPHY AND PHYSIOGRAPHY. Brief narrative and reference to Physiographical and glaciological features. Geographical discoveries and Cartography. By DOUGLAS MAWSON.	
II.	OCEANOGRAPHY.	
	PART 1.—SEA-FLOOR DEPOSITS FROM SOUNDINGS. By FREDERICK CHAPMAN ...	0 6 0
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III.	GEOLOGY.	
	PART 1.—THE METAMORPHIC ROCKS OF ADELIE LAND. By F. L. STILLWELL ...	2 2 0
	„ 2.—THE METAMORPHIC LIMESTONES OF COMMONWEALTH BAY, ADELIE LAND. By C. E. TILLEY	0 1 6
	„ 3.—THE DOLERITES OF KING GEORGE LAND AND ADELIE LAND. By W. R. BROWNE	0 1 6
	„ 4.—AMPHIBOLITES AND RELATED ROCKS FROM THE MORAINES, CAPE DENISON, ADELIE LAND. By F. L. STILLWELL	0 2 0
	„ 5.—MAGNETITE GARNET ROCKS FROM THE MORAINES AT CAPE DENISON, ADELIE LAND. By ARTHUR L. COULSON	0 2 0
	„ 6.—PETROLOGICAL NOTES ON FURTHER ROCK SPECIMENS. By J. O. G. GLASTONBURY	0 3 6
IV.	GEOLOGY.	
	PART 1.—THE ADELIE LAND METEORITE. By P. G. W. BAYLEY and F. L. STILLWELL.	0 1 6
	„ 2.—PETROLOGY OF ROCKS FROM QUEEN MARY LAND. By S. R. NOCKOLDS.	0 8 6
	„ 3.—GRANITES OF KING GEORGE LAND AND ADELIE LAND. By H. S. SUMMERS and A. B. EDWARDS. Appendix by A. W. KLEEMAN	0 3 9
	„ 4.—ACID EFFUSIVE AND HYPABYSSAL ROCKS FROM THE MORAINES. By J. O. G. GLASTONBURY	0 2 6
	„ 5.—BASIC IGNEOUS ROCKS AND METAMORPHIC EQUIVALENTS FROM COMMONWEALTH BAY. By J. O. G. GLASTONBURY	0 5 6
	„ 6.—CERTAIN EPIDOTIC ROCKS FROM THE MORAINES, COMMONWEALTH BAY. By J. O. G. GLASTONBURY	0 1 6
	„ 7.—SCHISTS AND GNEISSES FROM THE MORAINES, CAPE DENISON, ADELIE LAND. By A. W. KLEEMAN	0 12 0

PART 7.

SCHISTS AND GNEISSES

FROM

THE MORAINES, CAPE DENISON, ADELIE LAND.

BY

A. W. KLEEMAN, M.Sc.

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Plates IX-XIII.]

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*62842—A

CONTENTS.

SCHISTS AND GNEISSES FROM THE MORAINES.

BY

A. W. KLEEMAN, M.Sc.

I. INTRODUCTION.

THE rocks to be described in this section comprise schists and gneisses collected from the moraines at Cape Denison. The terms "schist" and "gneiss" are used in a general way so as to cover those metamorphic rocks, both of igneous and of sedimentary origin, which display schistosity and foliation. The more basic igneous types, the amphibolites and the calc-silicates, have already been described elsewhere. All the rocks described in this section have been altered by Regional Metamorphism as defined by Harker (1932, p. 177). Dynamic Metamorphism can be included in the scope of Regional Metamorphism as the lower limit in which pressure reaches its maximum and temperature its minimum. (Diagram see Harker, p. 183).

From evidence adduced elsewhere it is believed that the granodiorite seen *in situ* at Cape Denison had been intruded and completely solidified before the onset of metamorphism. It is equally likely that the amphibolites at Cape Denison also antedate the metamorphism. The granodiorite had, no doubt, produced its own aureole of contact metamorphism but the regional metamorphism would obliterate this as it is the nature of regional metamorphism to destroy all structures and textures which are not in equilibrium with it.

The Rocks as they existed before this regional metamorphism are to be grouped as follows :—

I. The granodiorite and associated igneous rocks which include (1) aplites and pegmatites and (2) basic intrusions now appearing as amphibolites.

II. The metamorphic rocks of the granodiorite aureole.

III. A sedimentary series intruded by the granodiorite but not within its aureole :

(1) Phyllites as exposed at Cape Hunter.

(2) Quartzites, etc.

(3) Calcareous rocks which occur abundantly in the moraines at Cape Denison and which are thought to have come from an area to the south west of Cape Denison.

In addition to these are some granitic rocks which had been injected during metamorphism. Some had been injected before the attainment of the maximum and some after, so that they can be seen in all gradations from granites simply altered by metamorphism to rocks in which the effects of pressure during solidification are only too evident.

Of all these classes, the rocks *in situ* at Cape Denison, the granodiorite and the amphibolites have been dealt with by Dr. Stillwell (1918). The granitic rocks associated with the granodiorite so far as they are found *in situ* are also described in this paper. The amphibolites and related rocks from the moraines are the subject of two papers; one by Stillwell (1923) and the other by Glastonbury (1940 a). The calc-silicates are the subject of two papers ; one by Tilley (1923) and the other by Glastonbury (1940 b). Coulson (1925) has described a suite of schists rich in magnetite and garnet.*

The rocks of the metamorphic aureole have been altered and inasmuch as they cannot be collected *in situ* are indistinguishable from those types formed by the regional metamorphism of the phyllites and will be described with them in this paper.

Specimens of the aplites and pegmatites belonging to the granodiorite, when found in the moraines are not readily to be distinguished from the later granitic following which was introduced during the period of Regional Metamorphism and consequently these two classes will be described together in the second portion of this paper.

II. THE REGIONALLY METAMORPHOSED SEDIMENTARY ROCKS.

The area from which these rocks were collected is believed to lie to the south-west of Cape Denison, for the movement of the ice is recorded as N 32° E. At Cape Hunter there is a series of schists which strike in the direction S 20°E so that if they continued on the same line of strike they would pass to the southward of Cape Denison. Thus it would appear that the original sediments from which the highly metamorphosed rocks found in the moraine were derived are similar to the rocks found *in situ* at Cape Hunter. We must assume from this that Cape Hunter is only on the fringes of the metamorphic province and that the grade of metamorphism increases as the rocks are traced inland. No doubt the intrusion of granites and pegmatites, boulders of which are found in the moraine, added to the complexity of the metamorphism by introducing volatiles such as boron and water vapour.

The only sediments to be seen in the limited area exposed at Cape Hunter are phyllites but there is no doubt that there are in the series quartzites as well as calcareous slates and other mixed types.

The rocks of this group will be described under the following headings :—

(1) Argillaceous rocks.
(2) Argillaceous rocks altered by the addition of volatiles.
(3) Semi-calcareous argillaceous rocks.
(4) Impure arenaceous rocks.
(5) Unusual types.

*This report by Kleeman was completed for publication early in 1935. Subsequent to that date other petrological reports on sections of the Expedition rock collections were completed.

(1) The Argillaceous Rocks.

These rocks are the metamorphosed equivalents of the slate series at Cape Hunter. The descriptions are arranged in order of increasing metamorphism as shown by the appearance of the various index minerals, biotite, garnet and sillimanite. (Barrow, 1912; Tilley, 1925).

There are few rocks typical of the Chlorite Grade in this collection, although chlorite has been produced by retrograde metamorphism in some specimens. The phyllites found *in situ* at Cape Hunter (Stillwell 1918, p. 126) have the appearance of having just passed out of the Chlorite Grade into that of Biotite. Most of the rocks found in the moraine at Cape Denison are of a higher grade and belong to the Biotite, Garnet and Sillimanite Grades. There are, however, some few specimens which contain chlorite but, with one exception, they are all products of retrograde changes in rocks that have been elevated to the Biotite Grade. Moreover, these rocks all contain a garnet that is suspected to contain a large proportion of the spessartite molecule and for this reason they will not be described with the normal representatives of the class. The exception mentioned above shows every indication of being a normal Chlorite Schist and is described below.

No. 290 is a crenulated chlorite sericite schist. The only minerals visible in the hand specimen are chlorite and sericite. There is a well developed schistosity, but contemporaneous folding has thrown the lammellae into a series of gentle folds.

The rock is very fine grained and has a lepidoblastic structure. Quartz makes up about 50% of the rock and occurs in grains about 0·02 mm. across. The chlorite and sericite form flakes about 0·06 × 0·01 mm. in size. There are also many quartz grains about 0·15 mm. in diameter but most of these have recrystallised to a mosaic of smaller grains. Magnetite has attained a porphyroblastic development and forms crystals about 0·30 mm. across.

The quartz is recrystallised and is clear and free from all inclusions. The sericite is clear white and has a high birefringence. It is mostly concentrated into bands which are almost all sericite. The many flakes all extinguish together and under crossed nicols give the appearance of one big crystal. The chlorite is green and pleochroic from light yellowish green to an emerald green. It is in small flakes which have clear cut edges against the quartz and presents a striking contrast to the ragged chlorite developed by the alteration of the biotite in such rocks as 458. It has a low birefringence. The accessories are magnetite and apatite. The magnetite forms large sub-idioblastic grains and the apatite small rounded grains.

The estimated mineral composition is Quartz 50%, Sericite 30%, Chlorite 15%, Magnetite and Apatite.

The structure is very fine and is that of a low grade schist or phyllite. The directional element is well shown in the sericite which has become concentrated in bands and is elongated parallel to the schistosity. The chlorite is associated with the quartz in bands relatively free from sericite. The crystals are not orientated in any one direction although taken in the mass the effect is to increase the schistosity slightly. The rock is completely recrystallised but is still within the Chlorite Zone.

The rock is a *Chlorite Sericite Schist.*

No. 236 is representative of the Biotite Zone, and is a two-mica schist. It is a dark grey rock with a moderate schistosity. When cleaved it shows numerous large but ragged crystals of muscovite up to 1 cm. in length, which give a mottled appearance to the cleavage face. The biotite flakes are less conspicuous but more abundant. Quartz and felspar are the only other recognisable minerals.

Under the microscope the quartz and felspar look more abundant than in hand-specimen and are seen to constitute more than half of the rock. The average grain-size of the quartz and felspar is about 0·15 to 0·30 mm. The mica is somewhat larger, the average for biotite being $0{\cdot}45 \times 0{\cdot}15$ mm., while some of the larger muscovite crystals are in excess of $1{\cdot}0 \times 0{\cdot}30$ mm. The quartz and felspar crystals are roughly equidimensional with but a slight tendency to be elongated parallel to the schistosity. The micas show a fair degree of parallelism and give the schistosity to the rock. There is no obvious banding discernible in this section. The structure of the rock is is seen in Plate IX, fig 2.

The biotite is brown, X = light golden brown, Y = Z = dark greenish brown. Some pleochroic haloes are to be seen around grains which appear to be zircon. There no sign of alteration in the biotite.

The muscovite forms large clear flakes which are usually intergrown with biotite. The muscovite always exerts its greater crystalloblastic force and grows across and through the biotite crystals.

The quartz is clear and unstressed and has few inclusions.

Plagioclase is present in considerable amount and has the composition of $Ab_{70}An_{30}$. Orthoclase cannot readily be distinguished from the plagioclase but appears to be present in smaller amount than the plagioclase. Both felspars are clear and perfectly fresh.

The accessories are apatite, zircon and magnetite.

From the mineralogical composition (see page 211) the rock appears to have been an argillaceous sediment to which a considerable amount of fine detrital quartz and felspar had been added during the processes of sedimentation. This has a notable effect on the course of subsequent metamorphism in that plagioclase appears in the early stages of metamorphism instead of being delayed to the latter stages of the Garnet Grade as it would be in normal argillaceous rocks (Harker, 1932, pp. 228-9). In this respect it resembles the argillaceous quartzites (Harker, op. cit., p. 248).

The rock is a *Quartz Felspar Mica Schist.*

No. 53 is a rock which has just reached the garnet stage. It is a fine-grained grey rock with a well developed schistosity. The cleavage face is shiny because of much muscovite and has a knotted appearance due to small clumps of biotite.

The structure is lepidoblastic. The mica flakes have a common direction of elongation and most of the quartz grains are elongated parallel to this direction. The schistosity is broken by larger " books " of biotite which are set across the lamellae and force them apart. The average size of the quartz grains is 0·09 × 0·04 mm. and that of the muscovite flakes 0·13 × 0·02 mm. The small flakes of biotite are somewhat larger than the muscovite flakes and the larger " books " average 0·55 × 0·20 mm. There is no tendency toward segregation of the quartz and the micas into separate bands. The structure of the rock is shown in Plate IX, fig. 1.

The quartz is stressed to a slight degree and shows undulose extinction. It is free from dust inclusions but contains small grains of tourmaline and magnetite. There does not appear to be any felspar in the rock but some untwinned, unweathered grains may be present.

The biotite is greenish brown in colour and has X = very light yellow, Y = Z = brownish green. The colour is not nearly so deep as it is in some of the more highly metamorphosed rocks (cf. 813 and 521). It is biaxial negative with a very small optic axial angle. It contains many pleochroic haloes surrounding inclusions of zircon and monazite. The larger " books " are poeciloblastic and contain many grains of quartz and a few of tourmaline and magnetite. The muscovite is typical metamorphic muscovite and forms well shaped flakes which are idioblastic against the biotite.

The garnet is very pale pink and is perfectly isotropic. The grains average 0·30 mm. in diameter and contain many inclusions of quartz and magnetite.

The accessories are tourmaline, magnetite and apatite. The tourmaline and the apatite form small subidioblastic crystals. The tourmaline is pleochroic in shades of green. The magnetite is fairly common and occurs as xenoblastic crystals smaller than the quartz and elongated parallel to the schistosity.

The rock was originally a siliceous slate rich in sericite. The original chlorite formed big crystals across the schistosity and the later biotite has psuedomorphed it. The garnet is just beginning to form and is in crystals much smaller than those in later rocks.

The mineral composition is given on page 211.

The rock is a *garnetiferous two-mica quartz schist.*

No. 161 is a typical quartz mica schist in which the presence of a few scattered garnet crystals shows the elevation to the Garnet Grade. It is a dark grey rock with a rude cleavage due to the parallelism of the mica. The abundance of quartz and felspar is evidenced by the absence of a good cleavage.

In thin section the structure is granoblastic modified by the parallel arrangement of the biotite. There is no elongation of the quartz and felspar grains. The average grain-size is between 0·1 and 0·2 mm. The ratio of elongation of the biotite is about 4 to 1.

The quartz is clear and free from strain shadows. It contains a few strings of dust inclusions and a few small grains of apatite and zircon.

Most of the felspar is plagioclase of a composition near $Ab_{70}An_{30}$. It is clear and unweathered but has a certain amount of "dust" along twin planes and around the edges.

The biotite is very similar in appearance and pleochroism to that in 236 but has a slight greenish tinge in the lightest position. A few grains are altered to chlorite.

The garnet is light pink and perfectly isotropic. It occurs as large irregular grains with inclusions of quartz, biotite and apatite. In some cases it appears to have grown around a portion of the mass of the rock. It is probably almandine.

Magnetite forms a few relatively large crystals, in some cases well crystallised, but for the most part xenoblastic.

The accessories are apatite and zircon.

The mineral composition is given on page 211.

The rock is a *garnet biotite quartz schist.*

No. 526A is a garnet biotite gneiss in which quartz is much less abundant than in the preceding rocks. Biotite constitutes the bulk of the rock and gives a well developed schistosity but the garnets have forced the foliae apart producing an augen structure.

The garnet is pink and isotropic and contains numerous inclusions of quite large crystals of quartz and biotite. Some of the smaller crystals are xenoblastic but the larger crystals are irregularly shaped. Its Refractive Index is about 1·787 which indicates a composition of about 65% Almandine and 35% Pyrope.

The biotite is dark reddish brown X = very light yellow, Y = Z = dark reddish brown. Pleochroic haloes around minute crystals of zircon are common.

Quartz is the only other mineral present in any quantity.

Felspar is not present.

The rock is notable because of the evidence of structural rearrangement due to retrograde metamorphism. The rock had originally been a garnet biotite gneiss in which the biotite had formed crystals of about 0·20 × 0·50 mm. The garnet crystals contained large included crystals of quartz and biotite. The biotite crystals had a ratio of elongation of 2·5 to 1 showing high temperatures and medium stress. At some time during the waning stages of metamorphism the stress factor became dominant and the rock was subjected to metamorphism corresponding to the lower part of the Biotite Zone. This resulted in crushing and granulation of the rock. The garnet grains were cushioned by the mass of mica around them and so preserved but the quartz and biotite were crushed and drawn out. The temperature was still sufficient for these to be recrystallised. One large crystal of quartz was bent round into an S shape and recrystallised (see Plate IX, fig. 3). The biotite was shredded and wrapped round the garnets. Some of the biotite crystals are preserved, cushioned by a mass of flakes many of which are less than 0·05 × 0·02 mm. in size.

The mineral composition is given on page 211.

The rock is a *garnet biotite gneiss.*

No. 238 is a rock which is typical of the lower stages of the Sillimanite Zone where sillimanite is beginning to form at the expense of the micas. It has the appearance of a typical quartz mica schist except that it contains a golden brown mica. Sillimanite cannot be seen in hand-specimen.

The structure is granoblastic modified by the parallelism of the mica. Quartz and felspar, which constitute the bulk of the rock, have a grain-size of between 0·15 and 0·25 mm.

The quartz has a few inclusions but is quite clear and unstressed.

The felspar is mainly plagioclase $Ab_{80}An_{20}$. The twinning is obscure but Albite and Pericline twins can be seen. Some microcline is also present. The felspars are all perfectly fresh.

Biotite forms well developed crystals with ratio of elongation 5 to 1. Pleochroism is strong, X = very light yellow Y = Z = dark reddish brown. It is biaxial negative with a very small optic axial angle. There are some striking pleochroic haloes up to 0·08 mm. in diameter developed round crystals of zircon.

Muscovite is present in small amount. It is usually intergrown with the biotite when it exerts its greater crystalloblastic force against the biotite.

Sillimanite can be seen developing at the expense of both micas. The earliest stage is the formation of small needles of sillimanite inside the crystals of mica (see Plate X, fig. 1). These increase both in size and abundance until they form a mat of more or less parallel needles through which the original colour of the original mica can still be seen. In the next stage, better illustrated in the next rock, No. 521, when the mica has completely disappeared, the sillimanite is aggregated into bunches not unlike sheaves of wheat, in which the needles in the middle of the "sheaf" have grown together in one crystal while the ends of the needles are quite free.

Tourmaline is present in small crystals pleochroic from colourless to yellow.

The mineral composition is given on page 211.

The rock is a *sillimanite quartz biotite gneiss.*

No. 521 is a coarser mica sillimanite gneiss in which the sillimanite has segregated with quartz into knots and lenticles about 8 mm. in diameter. Muscovite and biotite are in small flakes with little apparent orientation. A few crystals of garnet can be seen.

Under the microscope the rock is seen to have that directionless texture common to the higher stages of metamorphism. The quartz grains are about 0·25 mm. in diameter and those of biotite a little bigger.

The quartz is mostly clear but in the sillimanite knots it is crowded with needles of sillimanite. There is no shadowy extinction.

The felspar which is quite fresh is basic oligoclase, $Ab_{70}An_{30}$, accompanied by some orthoclase.

The biotite is biaxial negative with a small optic axial angle. The pleochroism is X = light golden yellow, Y = Z = dark greenish brown. Minute crystals of zircon induce pleochroic haloes.

The muscovite is biaxial negative, 2E = 65° approximately. It contains zircon crystals which do not produce pleochroic haloes in thin section but which cause light yellow haloes in thicker flakes chipped out of the rock.

Sillimanite occurs in knots together with quartz and some little mica (see Plate X, fig. 2). It forms irregular bunches and sheaf-like aggregates of fine acicular crystals. It can be seen developing from the mica but in most cases the sillimanite areas contain little mica.

The garnet is ordinary pink almandine and is not abundant.

Tourmaline, O = blue green, E = light pink, is also present.

The usual accessories zircon, apatite and magnetite are not abundant.

The mineral composition is given on page 211.

The rock is a *sillimanite quartz mica gneiss*.

No. 1233 is similar to No. 521 but has been subjected to greater stress so that the knots are drawn out to lengths four or five times their widths. The micas have a common orientation not noticed in No. 521. The schistosity is linear rather than planar. Small clear garnets are to be seen.

Under the microscope the rock is seen to be of coarser development than No. 521. This is especially noticeable in respect to the sillimanite, which forms crystals up to 0·1 mm. in diameter. The grain-size of the quartz is very variable but the average appears to lie about 0·20 mm. The biotite is about 0·3 × 0·1 mm.

The most obvious difference from No. 521 is the absence of muscovite. The quartz is unstressed but in some areas is crowded with sillimanite. There is some little felspar mostly oligoclase with a little orthoclase. It is fresh and unaltered. The biotite is similar to that in No. 521. Pleochroic haloes are well developed. The garnet forms small xenoblastic crystals.

The sillimanite has formed good crystals. The needles noted in Nos. 238 and 521 have all disappeared and instead are small but definite crystals which, as the section is cut perpendicular to the schistosity, exhibit prismatic cross sections with a pinacoidal cleavage (see Plate X, fig. 3). Few of the crystals are less than 0·003 mm. in diameter and some of the bigger are 0·45 × 0·05, giving a ratio of elongation of about 10 to 1.

Magnetite is rather common as an accessory.

The other accessories are apatite, zircon and tourmaline.

The mineral composition is given on page 211.

The rock is a *sillimanite quartz biotite gneiss.*

No. 813 is another high grade sillimanite gneiss. It differs from the two foregoing in that it has a strongly marked schistosity. In cut surfaces sillimanite can be seen in lenticular streaks about a millimetre wide and 2 cm. long. Biotite, quartz and garnet are visible in hand specimen, and a few pink grains on a weathered surface suggest felspar.

The microscopic appearance is typical of these high grade schists. The quartz which constitutes about 50% of the rock has a grain-size of about 0·4 mm. The biotite crystals are about 0·8 mm. long and appear much bigger than the quartz. The sillimanite is in lenticles of needle-like crystals.

The quartz is clear and with few sillimanite inclusions.

Some felspar is present, mostly acid plagioclase $Ab_{70}An_{30}$. It is twinned on the Albite and Pericline laws.

Biotite is strongly pleochroic, X = very light yellow, Y = Z = dark greenish brown. There are some well developed pleochroic haloes around zircon crystals.

Sillimanite is plentiful and usually has some biotite associated with it. It shows less tendency to be scattered through the quartz and is usually segregated into lenticles of fine needles. That it is derived from the biotite is apparent from the presence of some altered biotite in these lenticles.

Garnet forms large irregular pink grains some of which have been fractured and "healed" by recrystallisation. The garnet has small inclusions which tend to be aligned parallel to the schistosity.

Of the accessories magnetite is not rare and apatite and zircon are present.

The mineral composition is given on page 211.

The rock is a *sillimanite quartz biotite gneiss.*

A notable feature of this rock is that it has undergone weathering. The slide shows a zone 5 to 7 mm. in from the edge of the specimen in which the biotite has been altered to chlorite. The nature and cause of this alteration is of interest because there are several other rocks in this suite in which all of the biotite has been completely changed to chlorite.

The biotite is replaced by chlorite, muscovite and epidote. The chlorite has that peculiar " ultra " purple typical of it. It is faintly pleochroic in green and contains brown pleochroic haloes around crystals of zircon. It contains some granular epidote formed as a by-product of the change. Muscovite is intergrown with the chlorite. Most of it is original but some appears to have been derived from the reaction.

The sillimanite also has undergone alteration. A lenticle of sillimanite when followed toward the weathered portion of the slide gives way to a mass of micaceous material which is probably near to sericite in composition. The alteration of the sillimanite and of the biotite appears to have penetrated about equal distances into the rock.

No. 811 is a similar rock to No. 813 but seems to have attained a slightly higher grade of metamorphism. The foliation has been twisted and sharply folded giving a herring-bone structure which is seen in weathered surfaces. There is less biotite and more quartz than in No. 813 but otherwise the rocks are much the same. There is in part of the specimen a vein of clear " moonstone " felspar which has been buckled and folded.

The grain-size although variable is of the same order as in No. 813 and the appearance under the microscope apart from the less biotite and the coarser sillimanite is similar.

The quartz contains lines of inclusions in which the inclusions are somewhat larger than those previously noted. Some of the inclusions can be seen to be fluid and to contain bubbles of gas within. These inclusions are not nearly so numerous or so well developed as in rocks formed under pneumatolytic conditions.

The biotite and garnet are the same as in No. 813.

The sillimanite wisps have been replaced by crystals which although definite are still small. Larger crystals, however, are common with their nearly square prisms and 010 cleavage. One crystal is twinned on the 010 the twinning being more of the nature of an intergrowth in which two crystals have grown together on the 010 giving a re-entrant angle.

The accessories are magnetite, apatite and zircon.

The mineral composition was not determined as it is very close to that of No. 813.

The rock is a *sillimanite quartz biotite gneiss*.

	No. 236	No. 53	No. 161	No. 526A	No. 238	No. 521	No. 1233	No. 813
Quartz	51·5	43·4	57·2	15·5	52·7	48·4	63·3	36·2
Felspar	22·0	...	21·0	...	17·4	7·4		15·0
Biotite	20·7	14·4	17·2	67·4	21·7	20·8	17·4	29·6
Muscovite ...	4·0	37·6	...	...	1·4	14·2	...	...
Garnet	...	0·3	2·8	16·7	...	p.	0·8	6·0
Sillimanite ...	...	...	...	...	6·8	8·4	11·5	12·2
Apatite	0·9	0·2	0·1	0·1	p.	0·5	p.	p.
Magnetite ...	0·7	4·0	1·7	0·3	p.	0·2	7·1	1·0
Zircon	p.	p.	p.	p.	p.	0·1	p.	p.
Tourmaline ...	...	0·1	...	...	p.	p.	p.	...

The mineral compositions given above were obtained on slides cut perpendicular to the schistosity, using a Leitz Integration Table and are in volume percentages. The figures for quartz and felspar are not strictly accurate owing to the fact that much of the felspar is untwinned and quite fresh. They do however, give a good indication of the relative proportions of the two minerals. Sillimanite by reason of it being scattered through quartz grains in fine needles does not give precise results.

The ten rocks just described comprise a suite showing the range of metamorphism and its effect on argillaceous rocks. The composition of the original rock can be estimated from the compositions in the table above. Omitting No. 526A and No. 53 the average of the rest shows the original rock to have had about 50% quartz, 20% felspar, and 30% micas. Thus the rock was a rather siliceous shale in which there was 30% micaceous material in the form of finely divided chlorite and sericite. The remainder of the rock was composed of very finely powdered quartz and felspar which was too fine to be separated from the argillaceous material when the original rock was deposited.

The metamorphism has pursued its normal course. It is notable that in rocks of this class garnet is not common and that even where sillimanite is developed garnet does not exceed 6%. This appears to be due to the fact that an excess of sericite in the original sediment used up all of the chlorite to form biotite before the garnet zone was reached. This leads one to suspect that biotite is stable up to the sillimanite zone and that garnet when it does appear is derived from the chlorite rather than from biotite (Harker, 1932, p. 219; Tilley 1926, p. 434). The formation of sillimanite is the first sign of any instability in the micas. There does not appear to be any selective action, the sillimanite needles appearing at the same time in both micas but once started the muscovite is the more quickly broken down.

No. 526A is a variant in which chlorite and sericite were much more common. The rock reached the garnet zone with an excess of chlorite which then formed garnet.

No. 53 differs in that it contained a larger amount of sericite and thus forms a more typical muscovite schist.

There are in addition to those rocks described above several which although of a similar nature and appearance have been altered either by retrograde metamorphism or by simple weathering. As the rocks were not collected *in situ* it is difficult to decide which has occurred but No. 813 with its weathered face suggests that simple weathering may have been responsible. This weathering may have occurred since the rock was left on the moraine but it is much more probable that the rock was weathered when it was collected by the glacier.

No. 458 is a dense hard black rock with a well developed schistosity. It has the appearance of having just passed out of the phyllite stage. The only recognisable minerals are the micas which give a sheen to the cleavage face and magnetite which forms porphyroblasts visible on the cleaved faces.

In thin section the rock is seen to be banded due to differences in composition of the various layers of the original rock. The bands are about 5 mm. wide and are distinguished by their content of magnetite, the bands being alternately richer (up to 30%) and poorer in this constituent. Garnet is concentrated in the bands poor in magnetite.

The rock is very fine grained, the average size of the quartz grains being about 0·07 mm. The structure is granoblastic modified by the parallelism of the micas. The constituent minerals are quartz, magnetite, muscovite, chlorite, garnet, epidote and apatite.

The quartz is clear, unstressed and free from inclusions.

There is a considerable amount of felspar now represented by a mass of micaceous alteration products.

Muscovite is developed in small flakes 0·07 × 0·014 mm. size. It is typical muscovite and not merely sericite produced by alteration of other minerals. The chlorite results from the weathering of the biotite of the rock. It is light green in colour and is weakly pleochroic. It shows a weak interference figure which is psuedo-uniaxial and negative. Some crystals show ultra blue polarisation while portions of the same crystals may show yellows and oranges of the first order (D.R. = 0·01). There are brown pleochroic haloes around crystals of zircon. They are greenish brown in their darkest position but are typically less intense than those in the biotite of other rocks. Much epidote is developed between the lamellae of chlorite formed in the breaking down of the biotite. The original biotite was in flakes larger than any other constituent and in this resembles No. 53 (see p. 205). It contains many inclusions of quartz and apatite.

Garnet is found in irregular crystals 0·2 to 0·3 mm. in diameter and contains many inclusions of quartz and magnetite.

Apatite is abundant in small clear grains and is particularly concentrated in one band.

Magnetite forms 20% of the rock by volume and occurs as xenoblastic crystals and aggregates. It is so abundant that small chips of the rock can be picked up readily by a small magnet.

The mineral composition is given on page 217.

This rock may be compared with some from the Cape Denison moraines which have been described elsewhere (Coulson, 1925). Of these 55 and 912 are similar in many respects but Coulson does not give the mineral composition of these rocks.

The rock is a *magnetite quartz chlorite schist.*

No. 762 is a rock very similar in appearance and mineral composition to 458. It shows on a face that has been etched by snow-blast a banding due to differences in the composition of the laminae of the sediment. The cleavage face has a finely spotted appearance due to minute garnet crystals. The thin section shows a marked similarity to 458. The banding is not so well-defined and the bands grade into one another. The main point of difference is that the biotite is less completely weathered. The apparently unaltered biotite is green with X = light greenish yellow, Y = Z = yellowish green, and has a high birefringence. It is probably the first stage in the chloritisation of biotite in which the mineral loses its colour without any noticeable lowering of the birefringence. Much of the biotite has reached the final stage of weathering in which it exhibits ultra blue polarisation colours. The garnet of the rock is in relatively large and ragged crystals and contains inclusions of magnetite. The rock is so similar in all other respects as to make further description unnecessary.

The rock is a *magnetite quartz chlorite schist.*

No. 130 is a dark grey rock in which the individual minerals are not visible to the naked eye. It has a well developed cleavage and has a sheen on the cleavage face due to innumerable mica flakes. It is almost identical in hand-specimen with No. 458.

The thin section shows a fine schistose rock in which the average grain-size is about 0·06 mm. The schistosity is almost entirely due to the parallelism of the biotite flakes and the elongated magnetite grains as the quartz and felspar show no signs of elongation parallel to the schistosity. There is also banding due to the lamination of the rock. The bands are alternately rich in magnetite and chlorite, in muscovite, quartz and magnetite, and in quartz. They are about 5 to 10 mms. wide and merge one into the other. This composition banding is for the most part parallel to the schistosity but in one portion of the slide the banding as expressed by one band rich in muscovite and apatite is seen to have been bent and folded in a manner comparable to that seen in certain varve shales. That the folding is pre-metamorphic is shown by the fact that the biotite flakes in the folded band are strictly parallel to those in adjacent parts of the rock where the bedding is not disturbed, and that it is contemporaneous with sedimentation is supported by the fact that the banding on each side of the disturbed area is undisturbed and parallel.

The constituent minerals are magnetite, quartz, felspar, muscovite, chlorite, garnet and apatite. The quartz is in small grains, clear except for a few small inclusions of magnetite. The muscovite is in clear white flakes with a high double refraction. All of the flakes over a large area are so perfectly parallel as to extinguish as one. The chlorite is essentially similar to that in No. 458 and shows the same unmistakable signs of having been derived from original biotite. Garnet is uncommon but there are two or three ragged crystals in the slide. Apatite is abundant in small clear grains and is particularly common in one band. Magnetite is very abundant and forms black slightly elongated xenoblastic crystals. As in No. 458 it is so abundant that small chips of the rock can be picked up with a hand magnet. The mineral composition is so similar to that of No. 458 that an exact determination of the percentages of the several minerals is unnecessary.

The rock is a *magnetite quartz chlorite schist.*

No. 391 appears to be almost identical with No. 458 in hand-specimen but differences are apparent under the microscope. Of these the most notable is a great decrease in the amount of magnetite and an increase in the amount of muscovite. It is banded, bands 8 mm. wide rich in muscovite alternating with bands 2 mm. wide deficient in muscovite. The structure is intermediate between granoblastic and lepidoblastic. The grain-size is about 0·06 mm.

After the ubiquitous quartz muscovite is the most abundant mineral and occurs in numerous small flakes, with a common orientation.

Chlorite is again present and is similar to that in No. 458.

Garnet is rather less abundant. It is pink and isotropic. The epidote is mostly the iron-free zoisite but the larger crystals have quite a considerable amount of iron.

Tourmaline is present pleochroic from light to dark green.

The approximate mineral composition is given on page 217.

The rock is a *quartz muscovite magnetite schist.*

No. 737 is another rock similar to Nos. 458 and 391. In hand specimen it is identical with them.

The banding in thin section is closer and less well defined. The structure is granoblastic modified by the parallelism of the micas.

The quartz is clear but in some places shows undulose extinction due to strain.

Muscovite is well developed and is very conspicuous. It is intergrown with the biotite now completely altered to chlorite. The flakes are of somewhat larger size than in the two previous rocks.

Garnet is rather more abundant than in No. 458 and occurs in small idioblastic grains.

Magnetite and epidote are both present, the latter derived from the biotite.

The mineral composition is given on page 217.

The rock is a *quartz garnet mica schist*.

No. 552 is a dark coloured rock in which the bedding is shown up by a few lighter coloured bands. These bands show that the rock has been contorted and folded into a series of gentle folds of small amplitude. There are no minerals visible to the naked eye but the rock has the dull green appearance of a chloritic phyllite. There is no cleavage due to schistosity.

The grain-size is much smaller than in the previously described rocks, and averages about 0·02 mm. Chlorite and sericite are both more abundant and the rock has the composition of a typical phyllite. The structure is lepidoblastic.

The quartz is free from inclusions but shows strongly undulose extinction. The sericite is in small white flakes and is slightly ragged in appearance. It has a moderate birefringence. In some bands it makes up 50% of the rock and is interlaced in a manner more typical of a phyllite than of a more highly metamorphosed type. The chlorite is green and pleochroic and has a low birefringence. It contains brown patches which have a high birefringence and indicate a retrograde change from biotite to chlorite. It forms irregular flakes five or six times the size of the sericite. Garnet is common in relatively large crystals about 0·15 to 0·20 mm. across. The garnet is colourless and perfectly isotropic. Many of the crystals show a well developed crystal shape and exhibit six-sided cross-sections. The crystals contain included grains of quartz and magnetite. Magnetite is not uncommon as ragged elongated xenoblastic crystals. The accessories are some small grains of apatite and an occasional small crystal of zircon.

The estimated mineral composition is quartz 55%, sericite 25%, chlorite 10%, garnet 5% and magnetite 5%.

The rock is a *garnet chlorite sericite schist*.

No. 1260 is one of those rarer types in which the schistosity is at an angle to the composition banding. It is a dark green phyllitic rock with an indefinite lamination and a rather imperfect schistosity. A cut face at right angles both to the schistosity and to the lamination shows a puckering and gentle folding of the laminae. This is seen more effectively in the thin section and it is obvious from the way in which the schistosity crosses the folded laminae that this puckering was accomplished before the maximum stage of metamorphism.

The structure of the rock is lepidoblastic. There is no foliation due to schistosity but all of the mica is arranged in a common direction at an angle of about 45° with the laminae. The quartz grains are elongated parallel to the schistosity and have an average size of about 0·015 mm. They are clear and contain a few included mineral grains. Stress conditions are reflected in the fact that most of the grains have undulose extinction.

The sericite is in small ragged crystals. In the more quartzose bands they wrap round the quartz grains and in the more micaceous bands they form a mat in which the quartz grains are enclosed. The flakes are not well crystallised and have the properties of sericite and form a striking contrast to the well crystallised flakes in rocks such as Nos. 458 and 762. Chlorite is not abundant in the rock. It is in small pleochroic green flakes, but whether it is original or derived from biotite it is impossible to decide. It is considered unlikely that a rock of such fine grain could have reached a stage of metamorphism even as high as the biotite grade. There are in the rock a great number of small garnet crystals, the average size of which would be about 0·015 mm. These are of the same order of size as the other constituents of the rock but their superior relief makes them the most conspicuous mineral in the rock. Most of the grains exert their own crystal shape and are free from inclusions of quartz and magnetite. Magnetite is again rather abundant as elongated xenoblastic crystals. The accessories are apatite and tourmaline. The apatite is not uncommon but the tourmaline is quite rare.

The estimated mineral composition is quartz 50%, sericite 35%, chlorite 5%, garnet 5% and magnetite 5%.

The rock is a *garnet sericite schist.*

These seven rocks comprise a group characterised by their fineness of the grain, by the alteration of the biotite and, with one exception, by the presence of garnet. The mineral compositions of three of the rocks of which measurements have been made with the Integration Table are given in the table below. In others because of the fineness of the grain the mineral percentages have been estimated and are given in the description of the rock. In three of the rocks the amount of magnetite is high and lies between 15% and 20% while in the others the amount is in the vicinity of 5%. In all except perhaps No. 1260 the chlorite is derived from the biotite and in No. 762 the change can be seen in progress. It is the garnet that introduces the anomaly. It is considered unlikely on account of the fine grain of the rocks that they have been ever raised to a grade of metamorphism as high as the garnet grade and for this reason it is postulated that they contain a significant amount of the spessartite molecule. Unfortunately it is impossible to isolate grains which do not contain so much magnetite as to render any chemical test indecisive. It is significant that Coulson in describing some rocks which are very similar (Coulson, 1925) found the same minute garnets in a rock (No. 348, p. 291) which contained some 8·23% of manganese. His conclusions are that in many of these fine grained rocks the garnet is a highly manganiferous one.

It is more than a coincidence that all of the low grade schists from these moraines should present these characteristics and it is most likely that all of these rocks came from an area in which the same local conditions obtained and hence rocks of similar composition have reached a similar stage both in progressive metamorphism and in the later retrograde changes. It is also probable that the effects of retrograde metamorphism were largely confined to the one area. Comparison may be made with an area in Unst where Read (1934) has shown that this zone of chloritization is sharply marked from the unaltered metamorphic rocks and is of limited extent.

	No. 458.	No. 391.	No. 737.
Quartz, Felspar	59	63	66
Magnetite	19	5	5
Chlorite...	12	11	16
Muscovite	5	20	19
Garnet	5	p.	4
Epidote...	p.	p.	p.
Apatite	p.	p.	p.
Tourmaline	...	p.	p.

(2) Regionally Metamorphosed Rocks in which there has been notable accession of Volatiles and Silica.

In this group are those argillaceous rocks which in addition to suffering regional metamorphism have been altered in composition by the introduction of—

(1) volatiles, water and boron;

(2) volatiles and silica.

Rocks of the first class are noted by the presence of large crystals of muscovite and an abundance of tourmaline often as small crystals just visible to the naked eye.

As an example of the introduction of water alone and that in moderate quantity can be cited No. 236 which has already been described under the normal regionally metamorphosed rocks. It is more than likely that the large size of the muscovite crystals in this rock is due to an abundance of volatile but there has been no notable addition of water, and tourmaline is absent.

No. 162A has reached a further stage where muscovite is developed to a greater extent and tourmaline in abundance indicates the addition of boron. In hand-specimen it is not unlike No. 236. It is a dark grey rock with abundant large flakes of muscovite on the cleavage faces. Biotite is as plentiful as the muscovite but in smaller flakes in the mass of the rock.

The structure as seen in thin section is gneissic. The quartz and felspar have become slightly elongated parallel to the schistosity. This is offset by the fact that the micas, and the muscovite in particular, show a tendency to grow transverse to the foliation. The average grain-size of the quartz is about 0·10 to 0·15 mm. The biotite is a little larger and the muscovite occurs in crystals up to 2·0 × 0·5 mm.

The quartz is clear and contains inclusions of biotite, zircon and sillimanite. There are also a few strings of liquid inclusions.

The felspar is mostly plagioclase $Ab_{80}An_{20}$. It is usually untwinned and is always somewhat altered.

The biotite is brown; X = very light brown, Y = Z = dark brown. It contains some pleochroic haloes around crystals of zircon. Much of it has been altered to chlorite, which is similar in its properties to that described in the altered portions of No. 813.

Muscovite is very abundant and is quite unweathered. It is, however, decomposing with the formation of sillimanite. It is usually intergrown with the biotite (chlorite) and shows its greater crystalloblastic strength.

Garnet is present in small quantity in the form of large ragged crystals.

Sillimanite can be seen developing at the expense of the micas. It has reached the stage of wisp-like aggregates (see No. 238 and Plate X, fig. 1). In places the sillimanite has been weathered and has altered to a mass of small flakes of some micaceous material. As the sillimanite is in fine needles this alteration product forms very small crystals. In aggregate they are very light yellow with strong absorption parallel to the long axis of the flakes. The double refraction is high as a small crystal shows orange of the first order.

The alteration product is probably sericite.

Tourmaline occurs in notable quantity. It forms idioblastic crystals with pleochroism typical of tourmaline found in pegmatites and veins amongst the moraine material from Cape Denison. It displays its greater crystalloblastic force against the garnet.

Magnetite is present in small xenoblastic crystals.

The mineral composition is given on page 219.

The rock is a *two-mica sillimanite gneiss.*

No. 914 illustrates the notable development of muscovite which occurs in rocks of this nature. In hand-specimen it is similar to No. 162A but differs in that the muscovite forms lenticular crystals about 10 mm. in diameter and 4 mm. in thickness. These lenticles are arranged parallel to the foliation.

In thin section the muscovite is seen to dominate the structure. The rock is foliated but the muscovite thrusts the foliae apart.

The muscovite is clear and colourless but is in places breaking down to form sillimanite. It is biaxial negative 2E = 65° to 70°. There are several faint yellow pleochroic haloes around crystals of zircon. The muscovite forms small crystals in the mass of the rock as well as the larger " books."

The original biotite is almost completely altered to chlorite as in No. 162A.

Sillimanite is well developed and has formed mostly from the muscovite. It occurs mainly in sheaf-like bunches which grow together in the middle. It can be seen altering to that micaceous mineral observed in other slides. This mineral has positive elongation, straight extinction and a birefringence similar to sercite. It can be readily distinguished from sillimanite by its much lower relief.

Garnet forms small subidioblastic crystals, pink and isotropic, with a few inclusions.

Tourmaline is similar to that in No. 162A but is not very abundant.

Quartz is recrystallised and some has segregated into lenses under the action of the abundant volatile. It is possible that some little quartz has been introduced with the volatiles. It contains strings of inclusions and abundant needles of sillimanite.

Magnetite forms xenoblastic crystals elongated parallel to the schistosity.

Zircon and apatite are accessories.

The mineral composition below is recalculated. The slide had 52% of muscovite but the rock as a whole did not seem to contain more than 40%.

The rock is a *sillimanite muscovite gneiss*.

The mineral composition of the rocks of this class is given below. No. 236 is added for comparison as representing the original rock before the addition of the volatiles.

	No. 236	No. 162A	No. 914
Quartz	51·5	32·2	29
Felspar	22·0	16·6	8
Muscovite	4·0	21·1	40
Biotite	20·7	20·1	12
Sillimanite	...	3·4	6
Garnet	...	p.	1
Tourmaline	...	2·9	p.
Magnetite	0·7	3·8	4
Apatite	0·9	p.	p.
Epidote	...	...	p.
Zircon	p.	p.	p.

These figures show clearly the increase in the amount of muscovite. The apparent decrease of quartz can in part be explained as due to the addition of volatile. There is a real decrease in the amount of felspar and it is probable that some of the felspar has broken down to form muscovite. It appears, however, that in the last stages of metamorphism the rocks had a drier environment as the muscovite has decomposed with the formation of sillimanite. This change could not proceed as readily as it has in No. 914 in the presence of so much water-vapour as would be necessary to produce 40% of muscovite. No. 256 and No. 550 represent rocks into which silica has been introduced in addition to the volatiles. They are similar in appearance but No. 550 is traversed by numerous quartz veins.

No. 256 is a transition between the rocks of the previous class and No. 550. The rock has recrystallised in the presence of abundant quartz and has become saturated with it, but the quartz has not formed any distinct veins traversing the rock. It is a fine-grained rock with porphyroblasts of muscovite. The smaller biotite flakes serve to mark the foliation and can be seen bending round the muscovite crystals.

The grain-size is very irregular, the quartz varying between 0·2 and 1·0 mm. with no preponderance in any particular size. The muscovite forms more or less spherical crystals about 10 to 15 mm. in diameter and the biotite 0·5 to 1·0 mm. in length.

The muscovite is colourless in thin section but has a marked absorption $X < Y = Z$. It is biaxial negative, $2E = 65°$ to $70°$. It contains inclusions of zircon which induce pleochroic haloes. The muscovite occurs in smaller flakes in the mass of the rock as well as in larger crystals. In the larger muscovite crystals are inclusions of quartz, which in turn contain fine needles which appear to be sillimanite but are too small to be positively identified.

Biotite is brown X = light yellow, $Y = Z$ = dark greenish brown. It contains some good pleochroic haloes around crystals of zircon.

Garnet occurs in small idioblastic crystals which although not plentiful (1 to 2%) seem more abundant because of their small size.

There are a few scattered crystals of felspar, but most of the felspar has been changed to mica, although this change is not apparent in the slide.

Quartz is abundant and shows no sign of undulose extinction or other such evidences of stress. It is crowded with inclusions which are arranged in strings orientated perpendicular to the foliation. Under high magnifications they are seen to be liquid and to contain each a small gas bubble.

Magnetite forms irregular grains elongated parallel to the schistosity.

Apatite and zircon occur sparingly as accessories.

The mineral composition was not determined as it is impossible to obtain a representative section, but is close to that of No. 914, with the exception of the tourmaline which is more abundant, and of sillimanite which is absent in this rock.

No. 550 is a rock similar to No. 256 but with the addition of numerous quartz veins intruded along the schistosity. These veins vary in thickness from 1 mm. to 20 mm. They do not contain other silicates except some small garnets and some muscovite which seem to be derived from the intruded rock rather than from the invading liquids.

Under the microscope the vein quartz can be seen to be of much larger grain-size than the quartz of the argillaceous portion. It contains many strings of liquid inclusions which in places are very closely spaced. The largest of these are more than 0·004 mm. in mean diameter and may contain gas bubbles 0·002 mm. in diameter. The smallest which could be seen (0·0004 mm.) still seemed to have bubbles in them. These strings of irregular inclusions are typical of quartz of igneous rocks and pegmatitic veins, and are taken as indications that the quartz has been derived from igneous sources. (Mackie, 1896).

The structure of the rock is dominated by the quartz foliae and by the muscovite crystals which force the foliae apart. In grain-size it is somewhat larger than No. 256 as the quartz has been recrystallised and the muscovite has grown larger.

No felspar could be detected in the slide.

The muscovite is similar to that in No. 256 but shows brighter pleochroic haloes. It contains inclusions of magnetite, garnet and tourmaline.

Biotite is notably absent.

Garnet is common as small idioblastic crystals scattered through the rock and also included in the mica.

Magnetite is present in appreciable quantity.

Tourmaline is less common than the garnet and magnetite and is similar in colour and pleochroism to that in No. 256 (O = greyish pink, E = dull olive-green).

The mineral composition was not determined as it would not be representative but inspection shows muscovite and quartz to be the most abundant with garnet and magnetite (2 to 3%), tourmaline, and apatite and zircon accessories.

The rock is a *muscovite gneiss*.

The three rocks No. 914, No. 256 and No. 550 show to an increasing degree the introduction of quartz. In No. 914 the rock has been recrystallised with the addition of little quartz. No. 256 has had addition but no more than it could absorb without the formation of veins. In No. 550 excess quartz has formed veins intruded along the foliation. The introduction of the quartz is clearly linked up with the introduction of the volatiles but is probably a later stage of injection.

(3) Regionally Metamorphosed Semi-calcareous Argillaceous Rocks.

In this group are placed those rocks which contain calcite in sufficient quantity to exercise a notable effect on the reactions which take place during metamorphism but which do not contain sufficient calcite to react with all the argillaceous material to form a calc-silicate rock. The greatest amount of calcite which could be present is in the neighbourhood of 40%. However any rock with more than 20% of calcite would produce so much amphibole (or its equivalent) as to place it in the class of amphibolites. Thus a semi-calcareous argillaceous rock may be defined as an argillaceous rock which contains calcite but not in sufficient quantity to convert more than 50% of the available argillaceous matter into amphibole or its equivalent. The rocks from Cape Denison moraines which belong to this suite have but a moderate amount of calcite and like the rocks of the normal argillaceous series contain a considerable quantity of admixed quartz and felspar.

No. 930 is typical of the first stage in which mica and epidote represent the argillaceous and calcareous portions respectively. It is a dark green rock with a massive structure and little schistosity. On a polished surface faint banding may be seen due in part to primary sedimentary banding but accentuated by schistosity.

In thin section the banding can be seen but is not well developed. The rock is extremely fine grained the average grain size being less than 0·015 mm. except for a few sporadic quartz grains and some biotite which, in areas where it has begun to recrystallise, forms flakes of 0·05 mm. The structure is intermediate between granoblastic and lepidoblastic. Under the microscope with moderate magnification, 80 diams., the rock seems to consist entirely of biotite in a cloudy mass of quartz. Examination of this ground-mass under oil-immersion shows the cloudiness to be due to a great number of minute crystals of zoisite. The zoisite is identified by its general appearance and the presence of some larger crystals of undoubted zoisite.

The biotite is dark greenish brown, X = colourless to light greenish brown, Y = Z = dark brownish green. The birefringence is high and the rock does not seem to be at all altered. The biotite is similar to that noted by F. C. Phillips in the Green Beds of the Scottish Dalraidan (Phillips, 1930).

There is no calcite present as the original calcite has been used up in the formation of the zoisite.

The quartz of the rock is fine grained and clear but contains the inclusions of zoisite which give a clouded appearance under the lower magnifications.

No felspar could be detected but some might quite easily be present amongst the fine-grained mass of quartz.

Some few allogenic grains of apatite and some xenoblastic crystals of magnetite were observed.

The rock is crossed by several narrow quartz veins. These veins contain radiating groups of chlorite crystals which can be distinguished from the biotite of the rock by their form and much lower birefringence. It is light green with a weak pleochroism and a birefringence of about 0·01. It has all the appearance of primary chlorite and not altered biotite.

The estimated mineral composition of the rock is quartz 60%, biotite 30%, zoisite 10%.

The rock is a *zoisite biotite schist.*

No. 1258 is almost identical with No. 930 in hand-specimen and is so close in composition that any detailed description is unnecessary. The only difference of note is that it is of a slightly finer grain.

No. 1257 represents the next stage in metamorphism after No. 930. No additional minerals distinctive of a higher grade of metamorphism have been developed but the grain size is notably coarser. It is a dark fine grained rock in which there are no minerals visible to the naked eye. There is a well developed banding but the rock is not cleavable.

The banding is seen in thin section to be the original lamination of the rock and not due to any schistosity or foliation impressed by metamorphism. These bands are richer or poorer in epidote and some of the bands contain 30% of this constituent. This is due to banding during sedimentation in which some bands were richer in calcite than others. The schistosity is expressed by the parallel arrangement of the biotite flakes and is at an angle of about 70° to the banding (see Plate XI, fig. 1). The limits of diffusion are too narrow in the grade of metamorphism to which this rock has been subjected to allow of any notable migration of the epidote.

The minerals present are quartz, biotite, epidote, calcite and magnetite. The quartz forms grains about 0·03 mm. in diameter ; the biotite flakes 0·08 × 0·02 mm. ; and the epidote smaller grains, usually less than 0·01 mm. The calcite is in bigger grains ranging from 0·06 to 0·20 mm. in size.

The quartz is in equidimensional grains which are free from undulose extinction and from inclusions. There is no felspar present.

The biotite is green and similar in colour to that in No. 1211 to be described below. The pleochroism is X = very light yellow, Y = Z = dark brownish green.

The epidote is a very light green and is an iron-poor variety. The high relief is distinctive and some of the larger grains have the more positive characters of epidote.

The calcite is distributed through the rock as irregular masses. It is biaxial and negative and has an optic axial angle of about 25°. This cannot be due to heating to a high temperature as is suggested by Walker and Parsons (1925). It is probable that the transformation takes place at a much lower temperature under high pressures and other favourable conditions.

Magnetite is distributed through the rock as subidioblastic crystals about 0·03 to 0·04 mm. in diameter. There are also a few grains of apatite.

The estimated mineral composition is quartz 45%, biotite 35%, epidote 20%, magnetite and apatite.

The rock is an *epidote biotite schist.*

No. 686 is a rock of similar mineral composition to No. 1257 but one in which garnet indicates its elevation to a higher grade of metamorphism. The presence of much magnetite has had the effect of increasing the iron content of the epidote from iron-poor in No. 1257 to iron-rich in No. 686. The grain-size is larger because of the greater intensity of metamorphism. It is a banded rock in which the banding is due to the epidote. The bands rich in epidote are a lighter but more vivid green than those poor in epidote and rich in magnetite.

The banding can readily be observed in thin section and is seen to be due to the uneven distribution of the chlorite, epidote and magnetite, all of which are abundant in the rock. The average grain-size of the rock is 0·05 mm. with the quartz a little smaller and the epidote and magnetite somewhat larger.

The quartz is clear and free from inclusions but shows undulose extinction.

The biotite is in the process of weathering to chlorite. Some of it still has the brown colour but most of it has become blotched with green and some has completely altered. The least altered crystals still have the high birefringence of biotite while in the blotchy crystals the brown areas have high and the green areas low birefringence. Ultra blue is not uncommon in the most altered crystals.

Some muscovite is intergrown with the biotite in small flakes.

Epidote is common in grains with a yellowish green colour and high relief. The birefringence (0·035) indicates the presence of about 13% of Fe_2O_3.

Garnet is light in colour and quite isotropic. It forms larger crystals than the epidote but in ordinary light is difficult to distinguish from it. It is present to the extent of occasional crystals only.

The apatite of the slide is practically all confined to one band of which it forms perhaps 15%. It forms small clear crystals with moderate relief.

Magnetite is very common as xenoblastic crystals elongated parallel to the schistosity.

There are in this slide several quartz veins and a fault. The veins are composed entirely of quartz and do not contain any other minerals except a few crystals which have been broken from the edges of the veins. The banding and the quartz veins are alike cut by the fault which is marked by a thin vein of quartz and a segregation of magnetite.

The mineral composition is as follows :—

Quartz	42·4%
Magnetite	23·8%
Biotite (including some muscovite) ...	23·4%
Epidote	9·3%
Apatite	1·2%

The presence of epidote shows it to be a semi-calcareous argillaceous rock but the chlorite makes it ambiguous. If as is most likely the alteration of the biotite is the only change of a retrograde nature the rock would be classed in the garnet zone. The only essential difference between this and No. 930 lies in the presence of garnet. It is certain, however, that the 24% of magnetite would have a profound effect on any further metamorphism, and thus place the rock in a class of its own.

The rock is a *magnetite epidote biotite garnet schist.*

No. 1211 shows the beginning of the reaction between calcite and the biotite to form amphibole. In the rocks of this class garnet would develop before the amphibole but a shortage of chlorite when the rock reached the garnet zone would rule it out.

It is a black massive rock with no perceptible banding. The only mineral visible to the naked eye is the amphibole which forms small dark green crystals scattered through the rock with a common orientation.

In thin section it is seen to be of coarser grain-size than No. 930 and to average 0·03 mm. The zoisite is much finer than this average and the amphibole much larger, crystals of the latter being up to 2 mm. in length.

The quartz is unstressed and is free from all inclusions except the zoisite crystals which are still very numerous.

No felspar could be detected.

The biotite is similar to that in No. 930. It has X = colourless to light green, Y = Z = dark greenish brown.

The zoisite is in larger crystals than in No. 930 but is still very small. It forms prismatic crystals 0·020 × 0·008 mm. which by their relief, low double refraction and lack of colour are distinctive. Some larger crystals are green in colour indicating a moderate tenor of iron.

The amphibole is blue green, X = greenish yellow, Y = emerald green, Z = greenish blue, X < Y < Z. It has an extinction angle of 20° ($Z \wedge c$). It forms relatively large crystals which resemble, only on a smaller scale, the amphiboles described by Adams and Barlow (1910, p. 168). These large crystals look like aggregates of smaller crystals but are in perfect optical continuity (see Plate X, fig. 4). This shape is a consequence of the origin of the amphibole. The biotite and calcite from which it forms constitute less than half of the rock and thus when the crystals of amphibole grow they enclose large areas of quartz and zoisite. There are in parallel growth with the amphibole large crystals of biotite which show that locally there is not enough calcite within the limits of diffusion to convert all of the biotite into amphibole. The reaction relation between the biotite and the amphibole is shown by the fact that although the rock is rich in biotite there is around each amphibole crystal a zone about 0·05 mm. wide in which there is no biotite. This suggests that the limit of diffusion of the biotite into the amphibole is in this rock 0·05 mm.

Magnetite is present in small quantity.

Calcite is associated with the amphibole but is not common. It is probably some original calcite which was not used up in the reaction with the biotite.

There are two aggregates of granular sphene about 0·1 mm. in diameter. They are brown in colour and have the typical strong absorption.

The approximate mineral composition was determined as follows:—

Quartz	47%
Biotite	34%
Zoisite	17%
Amphibole	2%

The rock is a *zoisite biotite amphibole schist.*

The rock has just reached the amphibole stage as is shown by the reaction of the calcite and biotite to form amphibole. The large size of the biotite crystals associated with the amphibole is no doubt due to the amount of carbon-dioxide released by the reaction.

Nos. 930 and 1211 are very similar both in appearance and mineral composition and differ mainly in the excess calcite in No. 1211 which formed the amphibole and in the coarser grain size of the latter. No rocks of this suite with a higher grade of metamorphism have been collected from the moraines but it is quite possible that such rocks have been found and placed in with the similar rocks of igneous origin (see Glastonbury, 1940 a).

In addition to the rocks described above there is another which has suffered retrograde metamorphism.

No. 1214 is a rather massive dark green phyllitic rock. It has a definite banding and a fair cleavage parallel to it. The only recognisable minerals are muscovite and chlorite which can be seen on cleavage faces.

Under the microscope the structure is lepidoblastic. The grain size is fine, the quartz being 0·025 mm. and the micas though longer and thinner are of the same order. Magnetite is of porphyroblastic development.

Quartz is unstressed and free from all inclusions. It is usually elongated parallel to the schistosity. Felspar is absent.

Muscovite occurs in small well developed flakes with moderate relief and high birefringence. It has recrystallised from the original sericite of the rock.

The chlorite is altered from the biotite of the rock. It is green with moderate pleochroism and low birefringence, and is similar to the chlorite described in other retrograde rocks.

Epidote is scattered through the rock and is rather common in some bands. Its green colour and its birefringence (about 0·03) indicates a considerable tenor of iron (about 10% Fe_2O_3).

A few irregular crystals of garnet are present. They have been shattered and drawn apart during the retrograde metamorphism.

The accessories are magnetite and apatite, the former in considerable amount. In addition there are a few sporadic tourmaline crystals.

The rock has been faulted probably at the same time as it suffered the retrograde changes. The faulting can be seen in thin section by the displacing of the different bands.

The mineral composition was not determined but a rough estimate gave quartz 50%; muscovite 30%, chlorite 15% and epidote 5%.

The rock is an *epidote mica schist.*

No. 955 is a rock similar to those described above and is important in that it is one of the few erratics found at Cape Hunter. It is a black rock with no minerals or structure visible to the naked eye. There is no schistosity and the rock breaks with an irregular fracture.

Under the microscope there is to be seen a rough schistosity. The micas are all parallel to the schistosity and the other minerals, and the epidote in particular is elongated parallel to the schistosity. There are, however, many large crystals of felspar which, although elongated, force the trains of mica apart and so disturb the schistosity. The average grain-size is about 0·03 mm. but the larger grains of felspar are as much as four times as large.

The quartz has been recrystallised and although free from inclusions shows undulose extinction. The felspar is all in the larger grains. One grain shows microcline twinning and all appear to be perthitic.

The biotite is green and has the pleochroism, X = very light greenish yellow, Y = Z = dark olive green. It is thus similar to that in No. 1211. There is also some muscovite but it is not so plentiful as the biotite. It occurs in well-formed flakes which are usually bigger than the biotite flakes and which are always idioblastic against the biotite.

The epidote is a very light yellow green in colour and is slightly pleochroic. It occurs in small grains with a high relief and a birefringence of about 0·012 to 0·015. These properties indicate about 5% of Fe_2O_3 in the mineral.

There is also present some calcite which has not been used up in the reaction to form epidote. It forms small irregular masses associated with the sphene and epidote.

The accessories are sphene, ilmenite, apatite and tourmaline. The sphene forms crystals with the typical brown colour and absorption and also aggregates around grains of ilmenite. The ilmenite forms xenoblastic grains scattered through the rock. The apatite and tourmaline are quite rare.

The rock is an arenaceous calcareous shale in which metamorphism has followed the course normal to the semi-calcareous argillaceous rocks. The felspar has had no effect on the reactions which have taken place. The argillaceous matter has recrystallised to form biotite and muscovite and reacted with the calcite to form epidote. The rock is still in the Biotite Grade.

The minerals in order of abundance are quartz, biotite, felspar, epidote, muscovite, ilmenite, sphene, apatite and tourmaline.

The rock is a *quartz epidote mica schist*.

(4) Regionally Metamorphosed Impure Arenaceous Rocks.

There are seven specimens which represent the metamorphosed sandstones but of these only one, No. 287, has been subjected to metamorphism of any advanced grade. The nature of the original rock is seen in the six slightly metamorphosed specimens. They are all fine-grained greenish quartzites, and are seen under the microscope to consist of quartz and felspar and more or less carbonate. Of the six slightly metamorphosed specimens, four show no reaction between the calcareous and argillaceous portions.

No. 538 is typical of the first group. It is a fine-grained granoblastic rock composed essentially of quartz and felspar in equal proportions. The average grain-size is about 0·07 mm.

The quartz is usually clear and free from inclusions of all kinds but some grains contain a few gas-liquid inclusions. The felspar is usually cloudy due to post-metamorphic weathering but is not much altered by the metamorphism. There are present microcline, orthoclase and plagioclase but as most of the felspar is untwinned and as the edges of the grains are obscured by reconstituted argillaceous material it is difficult to determine in what proportions each is present. Some of the felspars had been weathered before the rock had consolidated and where this is so the sericite formed by the weathering has combined with some iron to form a green chloritic mica. There are also numerous allogenic flakes of mica, both biotite and muscovite. The biotite is dark brown and slightly weathered in appearance. The muscovite is rather more plentiful than the biotite. Some of the flakes have been bent during the formation and metamorphism of the rock.

The only other allogenic minerals are the so-called heavy minerals which in this rock include epidote, zircon, sphene and magnetite. Of these the most numerous is epidote. It forms small grains which are rounded and irregular and but rarely show any semblance of their crystal shape. The epidote has a weak green pleochroism and a moderate to low birefringence. Sphene is next in abundance and like the epidote forms irregular grains. Some of the grains contain cores of magnetite. The zircon crystals are small and are distinguished by the high relief and high birefringence. Some of the grains retain their crystal shape but have been fractured or have had one end broken off. Ilmenite is much less common than the other three minerals but occurs in small weathered grains which are white in reflected light. There are also a few small crystals of tourmaline.

A small amount of argillaceous cement in the rock has crystallised to form tiny authigenic crystals of chlorite.

The rock is a *felspathic quartzite.*

The other rocks are but variants of this type.

No. 960 is similar in many respects to No. 538 but contains in addition some authigenic calcite. This calcite is not abundant and forms irregular grains scattered through the rock. Sphene is more abundant and epidote less abundant, and there is much less allogenic mica. The grain-size is slightly larger.

No. 463 is a darker green than the other rocks and contains an occasional band rich in mica which gives to the rock a flaggy parting. It contains about 15 to 20% of calcite which in this instance forms an authigenic cement for the allogenic grains of quartz and felspar. The heavy minerals are not so plentiful nor so diverse as in No. 538 but the allogenic muscovite is abundant. The rock had not the same amount of argillaceous cement that the previous rocks had and so lacks the small authigenic micas. The average grain-size is about 0·04 mm.

No. 681 has a pronounced banding due to variation in the mineral composition. Some bands which are noticeably richer in calcite than the rest have a structure similar to that of No. 463, but others less rich in calcite are more like No. 538. The heavy minerals are also concentrated in bands. The assemblage is similar in numbers and variety to the assemblage in No. 538.

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In No. 1267 and No. 228 the calcareous and argillaceous materials which together formed the matrix between the sand grains have combined to form epidote. That the rocks have not yet reached a high grade of metamorphism is shown by the fact that the quartz and the felspar which make up the bulk of the rock have not started to recrystallise.

No. 1267 is a compact grey-brown coloured quartzite, in which there are no individual grains visible to the naked eye.

The thin section shows a fine-grained quartzite consisting of felspar and quartz and of authigenic epidote. The quartz and felspar are in angular grains with an average size of about 0·10 mm. The epidote is in grains of the same size but has had perforce to fill the interstices between the quartz and felspar grains.

The quartz is clear and unstressed and only occasionally contains a few inclusions of the gas-liquid type. The felspar is always slightly weathered and is shaded brown in transmitted light. Little of it however is so badly weathered as to obscure its nature and it is probable that the weathering is postmetamorphic as is the case of No. 538. Most of it is untwinned and appears to be orthoclase but about a quarter of it shows by its twinning to be oligoclase. There is both muscovite and biotite in the rock and both appear to be allogenic. The biotite is completely altered to chlorite but the muscovite is of course unaltered. The other allogenic minerals are the accessories sphene, apatite and zircon.

The matrix which surrounded the grains is both calcareous and argillaceous. Thus when the rock was metamorphosed it formed epidote and quartz. The epidote is in irregular grains with a fair relief. The birefringence is about 0·02 but the colour is only a very light yellow. Occasional grains of basic felspar have broken up to albite and zoisite, and some of the quartz of the matrix has recrystallised but the bulk of the rock has not recrystallised.

The rock is an *epidotic quartzite.*

No. 228 is a darker rock than No. 1267 and also differs in that it contains recognisable flakes of muscovite. The thin section shows it to have coarser, less angular grains but reveals the great similarity in mineral composition. The average grain-size of the quartz and felspar is about 0·20 mm. The grains are less angular and the quartz is more abundant than in No. 1267. In other respects, in mineral composition and in the reaction to form epidote the rocks are strictly comparable. Here as in No. 1267 some of the felspar has recrystallised with the separation of the calcic phase as epidote.

The rock is an *epidotic quartzite.*

Despite the slight differences in metamorphism the six rocks described above are very similar in the broader details. The component grains of the rocks are angular to sub-angular and this fact coupled with the mineral assemblage points to a glacial or fluvioglacial origin. Most of the felspar was unweathered at the time of metamorphism as only such as now contains mica was weathered before the metamorphism.

This would not be the case in a rock derived from purely fluvial sources. In four of the rocks the matrix has crystallised to form chlorite and in two more to form epidote but it is only in No. 287 that the rock as a whole has recrystallised.

No. 287 has the appearance of a fine-grained quartzite. It has a light green colour due to small disseminated crystals of tremolite which, however, are not visible to the unaided eye.

Under the microscope it is seen to consist almost entirely of quartz, felspar and tremolite. The structure is granoblastic and the grain-size about 0·15 mm. It differs from the other rocks in this class in that it is entirely recrystallised.

The quartz is clear and notably free from inclusions. The grains have simple edges against one another and show no sign of undulose extinction.

The felspar is both plagioclase and microcline. The plagioclase has the composition of oligoclase. The microcline has a well developed twinning pattern, and is much more abundant than the plagioclase.

The amphibole is as abundant as the microcline. It is quite colourless in thin section. The extinction angle $Z \wedge c$ is about 18° and the birefringence 0·025. These properties point to tremolite containing a little iron.

Much less abundant than the tremolite is a brown mica. It is lighter than normal biotite, $X =$ colourless, $Y = Z =$ brown, $X < Y < Z$. It is an iron-free variety of phlogopite. One crystal has a pleochroic halo which is a darker brown than the mica in all positions but that of maximum absorption.

Calcite is associated with the tremolite and appears to be the result of dedolomitisation.

Sphene forms small dark brown grains with a high relief and strong absorption.

Zircon is the only accessory.

The mineral composition is—

Quartz, Felspar	78·7%
Tremolite	16·8%
Calcite	3·1%
Biotite	1·2%
Sphene	0·1%

The rock is a dolomitic sandstone which has undergone the normal alteration for a rock of its type. It had a composition similar to that of No. 960 but contained more carbonate. There was some little argillaceous matter also present as evidenced by the presence of biotite and it was this argillaceous matter which reacted with the dolomite to produce tremolite. The excess calcite recrystallised as such. The epidote so abundant in the less metamorphosed specimens has disappeared.

The rock is a *tremolite granulite*.

(5) Unusual Types of Metamorphosed Sedimentary Rocks.

This group contains several rocks which are entirely unrelated to each other. They are placed in this group because they will not fit into the classification of the previous pages.

No. 750, the first in this group, is an argillaceous rock containing a certain amount of arenaceous material. The ground mass of the rock is argillaceous but some larger grains of quartz and felspar have been introduced during sedimentation, and have modified the structures normal to this type of rock. In hand specimen the rock is dark green and although phyllitic is rather more massive than is typical. There are no minerals readily recognisable.

The gritty nature of the rock is apparent in thin section. The structure is lepidoblastic, modified by the augen of quartz and felspar. The ground mass is very fine grained, the mica flakes, which constitute its bulk, being less than 0·007 mm. across their shorter diameter. There are also a few porphyroblasts of biotite and muscovite up to 0·1 mm. across. The augen are of a larger size and range from 0·2 to 0·7 mm. in diameter.

Of the augen the quartz is clear and free from inclusions. It commonly shows undulose extinction due to stress and occasionally one large grain has recrystallised to a mosaic of smaller grains. The larger grains have at times assumed a lenticular shape which appears to have been induced by the metamorphism. Where this is so the quartz has been dissolved at pressure points on the grains and redeposited in optical continuity with the original grain. In some instances the two parts do not correspond and what appears to be a single grain in ordinary light can be seen in polarised light to consist of an outer and an inner ring.

The felspar grains have not recrystallised or been fractured but have retained their original shape. The plagioclase is quite clear but contains many inclusions, some set along the twin planes and others scattered indiscriminately through the grain. These crystals are too small for satisfactory determination but appear to be due to the unmixing of the various molecules. Some are micaceous and appear to be derived from the potash molecule and other are probably zoisite representing the calcic molecule. Apart from this the plagioclase is quite unaltered and has the composition of acid oligoclase. It is commonly twinned on the Albite and more rarely the Pericline Laws. Orthoclase is much less common than the plagioclase.

The ground-mass of the rock is composed of small flakes of biotite and muscovite together with a considerable amount of quartz.

The quartz is clear but shows shadowy extinction. A few grains of felspar could be detected in the fine material.

The biotite when it forms large flakes is greenish brown, X = light greenish-brown, Y = Z = dark green-brown. The larger flakes are often bent and sometimes broken. Muscovite is clear and colourless and makes up much of the rock as small well crystallised flakes. Occasional larger crystals of muscovite are intergrown with the biotite.

The presence of one crystal of garnet in the slide is anomalous but as the crystal is fractured and in view of the fact that there are many sand grains in the rock, it can be regarded as allogenic.

There is some epidote of a type not rich in iron, but it is not very abundant.

The accessories in order of abundance are magnetite, apatite, tourmaline and pyrites. The tourmaline is pleochroic in shades of green.

The mineral composition was not determined but minerals in order of abundance are quartz, muscovite, biotite, felspar, magnetite, epidote, etc.

Originally the rock was a shale into which were deposited during sedimentation small grains of quartz and felspar. During the subsequent metamorphism the larger grains were shielded from the effects of crushing by the cushioning of the mica flakes. Thus these grains retained their original shape while the mass of the rock had undergone recrystallisation.

It could be called a *gritty mica schist.*

Nos. 575 and 1255 are two separate specimens from the moraine but are so similar as to suggest that they represent the same rock type. No. 1255 is a large specimen about 22 × 12 cms. and 7 cms. thick across the bedding. The bedding is marked out by layers of garnet and of biotite and magnetite. The whole rock apart from the magnetite layers is coloured pink by the garnet, although some bands can be seen richer in garnet than others. The magnetite also forms large crystals from 1 to 5 mm. across which cross the banding. The dark bands do not abut up against the magnetite crystals but leave a zone about 0·5 mm. wide around the crystals which is free from any black minerals. Muscovite forms large poeciloblastic crystals which cut across the schistosity. Tourmaline occurs as large scattered black crystals. Quartz makes up the bulk of the rock.

Under the microscope the most obvious mineral is the garnet. It forms crystals which range in size from 0·002 to 0·10 mm. with 60% between 0·01 and 0·06 mm., 30% below 0·01 mm. and the rest above 0·06 mm. Their abundance can be gauged from the figure (see Plate XI, fig. 2) in which there are no more than the average. One portion of the slide chosen at random contained over 60 crystals to the square millimetre. Another in which they are very abundant contained over 160 to the square millimetre.

The garnet is colourless to light pink in thin section. Most of the crystals are idioblastic but occasionally some are rounded. They are distributed through the quartz grains which make up the bulk of the rock and are also included in the biotite and muscovite in such a manner as to suggest that they just stayed in position while the rest of the rock recrystallised around them.

The biotite is greenish brown, X = light golden yellow, Y = Z = dark greenish brown. It is a biaxial negative with a very small optic axial angle.

The muscovite is not so abundant as the biotite but forms large poeciloblastic crystals often several millimetres long. It encloses crystals of garnet, quartz and magnetite.

The quartz is in grains about 0·15 mm. diameter and encloses crystals of garnet and magnetite.

Some felspar can be observed amongst the quartz as clear untwinned grains. A few grains which have twinning on the Albite Law indicate a composition of albite-oligoclase.

Magnetite occurs both as small crystals (0·10 mm) scattered through the rock and as porphyroblasts (5 to 10 mm.). The zone around the porphyroblasts in which there are no small crystals of magnetite is readily noticed and averages 0·5 mm. in width. This apparently represents the limits of diffusion of the magnetite in towards the larger grains.

The accessories are apatite, zircon and tourmaline.

The structure of the rock suggest that it was originally a fine grained sandstone in which the grains were about 0·05 to 0·10 mm. diameter. Many of the grains were garnet and magnetite and as is usual in sands were much smaller in size than the quartz grains. The detrital origin of the garnets is further supported by the fact of their being concentrated in certain bands. There was a considerable amount of argillaceous matter which has produced the micas.

The approximate mineral composition is Quartz and Felspar 70%, Biotite 10%, Garnet 10%, Muscovite 5% and Magnetite 5%.

The rock is a *metamorphosed garnet sandstone.*

No. 575 is so similar in all respects to 1255 as to make further description unnecessary. It is weathered, the biotite being altered to chlorite and the felspar to a mass of micaceous flakes.

III. THE REGIONALLY METAMORPHOSED ACID IGNEOUS ROCKS.

The rocks of this section are for the most part granites, granodiorites, aplites and pegmatites. They have been affected by varying degrees of metamorphism which coming at different stages in the cooling of the magma have produced a diversity of results which all but defy systematic classification. Of the rocks which were solid before the onset of metamorphism some have been crushed and rolled out by pressure without any notable rise in temperature while others caught in the rising thermal gradients have been transformed into gneisses without any perceptible cataclasis. In two instances the mother liquor has been squeezed out of a partly solidified magma leaving a rock of a peculiar composition. Thus each rock or group of rocks must be treated on its merits. For convenience in description they have been placed in the following groups :—

(1) Mylonites and Cataclasites.

(2) Rocks in which crushing has been accompanied by or followed by a rise in temperature and consequent Regional Metamorphism.

(3) Granite gneisses formed by flowing without crushing.

(4) Tourmaline bearing rocks.

(5) Gneisses formed by the intrusion of granites during the period of orogenic stress.

Of these groups the first four cover the types produced in rocks already completely solid at the time of metamorphism, and the last includes all those produced by the metamorphism of still liquid or viscous magma.

It is impossible to make these groups separate and distinct and there are some rocks which could as easily have been placed in one group as in another. It is believed, however, that the classification and grouping in the following pages is the most satisfactory possible under the circumstances.

(1) Rocks in which Cataclasis is dominant.

There are four examples showing the successive stages in the formation of a mylonite.

No. 1213 has been crushed and fractured at a low temperature and consequently has not recrystallised. In hand specimen it is dense and black and has no minerals recognisable to the naked eye. The thin section shows the rock to be a typical cataclasite. Faults and fractures can be seen running across the rock in several directions and such grains as are not completely crushed show strain shadows in the polarisation.

The quartz has been granulated but some few larger grains persist in which there are strings of liquid inclusions. These inclusions are of a minute size but under high magnifications can be seen to contain gas bubbles. The larger grains have strong strain shadows and a few have been recrystallised to a mosaic of smaller grains.

Most of the felspar has been altered but a few crystals of plagioclase remain. The felspar seems to have been altered to a mass of micaceous flakes. This is not the sericite usual in such cases but a pale biotite, which is pleochroic from colourless to light brown. It forms small flakes scattered through the rock and with quartz replaces the felspar. Some larger flakes may represent original biotite in the rock. Some little muscovite is also present.

Magnetite is scattered about the rock and has the appearance of having been set free by the breaking down of the felspar.

The rock has really no structure. It is simply a mass of crushed fragments cemented by the recrystallisation of some of the quartz and everywhere clouded by minute biotite flakes, and by magnetite grains.

It is difficult to decide with any certainty the nature of the original rock. However the presence of liquid-gas inclusions in the quartz favours the assumption that the rock was igneous, probably a granite (Mackie, 1896). It is also probable that the rock suffered in retrograde changes during the cataclasis and a slight rise in temperature has been responsible for the subsequent formation of the biotite.

The rock is a *cataclasite.*

No. 1243 represents the higher grade in which both temperature and pressure were considerably greater than in No. 1213. Thus although the rock is more finely crushed there is not the alteration of the felspar noticed in No. 1213. The original composition of the rock is that of a basic granite or granodiorite.

In hand-specimen the rock has a rolled out appearance and is seen to consist of foliae of white quartz and pink felspar marked out by streaks of chlorite and epidote. It has a fine surfaced greasy appearance typical of halleflintas. There are two sets of faults traversing the rock, one parallel to the foliation and the other at right angles to it.

The crushing has been more effective in some places than in others resulting in foliae of felspar in which few individual grains exceed 0·015 mm. and none 0·08 mm., being intercalated with foliae in which large relic crystals are set in a finer matrix. The larger crystals are fractured and often dragged apart. One crystal orientated approximately normal to the "a" axis, is broken up into segments each differing slightly in optical orientation from the others. The fractures are marked out by dust inclusions and are developed in a plane which approximates to the 011. Other crystals show the same effects to a lesser extent and in all the cracks are close to the 011. The felspar comprises both plagioclase and microcline in about equal amounts. The microcline is clear and unaltered but the plagioclase ($Ab_{90}An_{10}$) is dusted with minute particles too small to be determined. The more mobile quartz has dissolved under pressure and segregated into foliae in which the grains are either lenticular or broken up into mosaics of equidimensional grains.

The original ferromagnesian of the rock is represented by chlorite and epidote. This alteration occurred during the metamorphism of the rock so that the alteration products have been drawn out into streaks by the crushing and are intimately bound up in the structure of the rock. The chlorite is rather strongly pleochroic from light yellow to green. It has abnormal interference colours—purple, violet and brown—with a retardation of less than 100 millimicrons. The epidote is mostly in the form of small grains less than 0·01 mm. in size, which in the mass because of their small size and high refractive index appear almost opaque. Larger grains scattered through the rock have the birefringence and pleochroism of pistacite. The chlorite and epidote are drawn out to form long thin lines between the foliae of felspar. They are not so straight not so continuous as in the more perfect mylonite No. 199 to be described below.

Apatite is present as relatively large crystals (0·1 to 0·3 mm.) associated with the chlorite epidote bands. Some of the grains have been broken and dragged apart and the spaces filled with quartz and epidote.

The rock was crushed under a considerable depth of cover and at a temperature high enough to allow the quartz to recrystallise yet not too high to prevent the breaking down of the biotite.

The rock is a *mylonite gneiss.*

No. 494 is a rock of about the same grade of crushing as No. 1243. It is a light pink rock with a greasy streaky appearance typical of these rocks. There is a considerable amount of sericite associated with slippage planes through the rock.

The structure revealed by the microscope is similar to but coarser than that of No. 1243. The difference appears to lie in a slightly higher temperature of metamorphism resulting in coarser crystallisation. The rock consists of quartz, felspar and sericite and is derived from the crushing of a granite. The quartz is all recrystallised and is clear and free from undulose extinction. The felspar on the other hand has not recrystallised and when it crushed it has broken down into a mass of minute grains. The sericite is usually in masses of small flakes but occasionally it has recrystallised to muscovite. The only other mineral is magnetite. It is apparently one of the first minerals to crystallise coming after quartz but before microcline. There are a few crystals of zircon preserved by being included in the felspar grains.

The quartz of the rock is completely recrystallised and is of fairly uniform grain-size of about 0·10 mm. The felspar is crushed but not recrystallised so that it is in all sizes from large crystals 5 to 10 mm. in length to the finest powder. The large crystals all have the properties of microcline-microperthite. Most of the crystals are fractured and the cracks filled up with fine crushed material. The crystals break up into lenticular pieces with their long directions parallel to the direction of flowage of the rock. The sericite is derived from the shearing of the felspar and forms large lenticular streaks in which the sericite is in small flakes. The muscovite is normal in all respects and is simply the recrystallised sericite.

The rock is a *mylonite gneiss.*

No. 199 is an example of the last stage in the production of a mylonite gneiss. It was crushed under an even greater depth of cover than No. 1243 and the consequent rise in temperature resulted in the almost complete recrystallisation of the rock. In hand specimen it has the appearance of a cherty slate and it contains no recognisable minerals. There are several lighter bands in the black rock which are due to the rolling out of lighter areas in the original rock. The black colour of the rock is due to the presence of finely divided biotite.

The quartz is clear and contains very few inclusions. It does not show strain shadows as it appears to have been all recrystallised during the metamorphism. Large crystals have been drawn out into lenticular aggregates in which the boundaries of the individual grains are perpendicular to the length of the lenticle.

The felspar is more common as augen but there is no doubt that there is much felspar with the quartz in the crushed mass. The augen have frequently been fractured and healed with very fine recrystallised quartz. The twinning of the felspar has been confused and rendered useless for the purpose of determination by the crushing but appears to indicate the presence of both plagioclase and microcline. Perthitic intergrowths have developed owing to the strain.

The biotite is concentrated in bands of extremely small flakes following the direction of the foliation. The average size of the mica flakes is about 0·005 mm. but here and there are patches of larger flakes. From these are obtained the pleochroism X = very light brown, Y = Z = greenish brown. A few large crystals (0·05 mm.) of muscovite are associated with the biotite bands and are usually set across the foliation.

Accessories are zircon, apatite, epidote and magnetite.

The amount of rolling out differs in the various bands; in some places the banding is nearly perfect while in others the quartz and felspar augen are set in a mass of finer material which has protected them from crushing. In the more micaceous bands there are the same differences; in some areas bands of biotite alternate with bands of crushed quartz and in others augen of quartz and felspar are bedded in and wrapped round with biotite flakes.

The augen range from 0·2 to 0·6 mm., the finer material averages 0·1 mm. whilst the finest is all below 0·01 mm. The structure is that of a mylonitised crystalline rock, probably a granite. There is no definite proof that this was an igneous rock but the composition and the presence of perthitic felspar suggest that such was the case.

The structure is illustrated in Plate XI, figs. 3 and 4.

The rock is a *mylonite gneiss.*

These four rocks show progressive stages in the formation of mylonites by simple crushing without any significant rise in temperature, No. 1213 crushed by powerful orogenic stresses with but slight hydrostatic pressure has become a mass of rock fragments clouded by alteration products and cemented by some slight recrystallisation of the crushed quartz. The rock was actually in the zone of weathering at the time of the crushing and hence shows the effects of weathering contemporaneous with the metamorphism. No. 1243 was metamorphosed at a greater depth in the earth's crust and consequently was subjected to a greater hydrostatic pressure and a slight rise in temperature. Instead of the angular fragments that made up No. 1213 the rock has been broken down into small grains and in places into the finest powder. The greater depth of cover has prevented the agents of weathering from affecting the rock so that the felspars although crushed are not altered chemically. No. 494 represents the same stage of crushing as No. 1243 but a higher temperature is reflected in the increased recrystallisation of quartz. The quartz has recrystallised to the same stage as in No. 199 but the crushing has not been as intense. No. 199 exhibits the next stage of this crushing and represents the last stages in the production of a mylonite. In some parts of the slide lenticular fragments of felspar are preserved by being cushioned amongst the more finely crushed material. In other parts of the rock in which the crushing has been more intense the quartz and felspar have been rolled out into ribbons. In most cases these are separated by a thin film of mica or in some instances not even that (Plate XI, fig. 4).

(2) Rocks in which Cataclasis is not so Evident.

This group includes those rocks in which the effects of crushing are not so evident and in which a later rise in temperature has resulted in recrystallisation and reorganisation of the rock. In them cataclasis has been superseded and to some extent obscured by the normal processes of the higher grades of Regional Metamorphism. These conditions are reflected in mortar structure in which large strained crystals are surrounded by finer crystals derived from the crushing and in the presence of some mineral which indicates metamorphism of a notable grade. Many of the rocks do not show any signs of gneissic structure in hand specimen and it is not until they are examined under the microscope that the true nature of the rock is evident. Others, however, have been crushed and recrystallised to quartz mica schists in which the recrystallisation has obliterated the effects of crushing.

The Granodiorite Gneiss of Cape Denison is an example of a granitic rock which has been crushed and to some extent recrystallised. Stillwell (1918, p. 85) states that the orthoclase has been transformed to microcline and that the felspars commonly have shattered edges. It is, therefore, to be expected that similar specimens should be found in which the granulation is more complete and in which metamorphism has produced minerals typical of the higher grades of metamorphism.

No. 369 is probably one of these more highly metamorphosed granodiorites. It has a broad foliation produced by alternations of light and dark bands representing the more felspathic and more micaceous portions of the rock.

Quartz and felspar make up the bulk of the rock and reflect the origin of the rock. In less micaceous bands felspar crystals ranging from 0·5 to 1·0 mm. in size are set in a matrix of crushed quartz of average grain size less than 0·1 mm. In the more micaceous bands both felspar and quartz crystals are surrounded by masses of biotite flakes. The quartz is almost entirely recrystallised and is free from all inclusions except a few dust and magnetite inclusions.

The felspar is mostly plagioclase with the composition of basic oligoclase. Twinning is not often developed but twins on both albite and pericline laws can be observed. Most of the crystals have a ghost twinning in which the twin lamellae start from the side of a crystal but peter out before they reach the middle of the crystal. In others the lamellae are bent and show the effects of stress while the rock was at a temperature high enough to inhibit crushing. There is quite a considerable amount of plagioclase in the crush mass but as the indices of refraction are almost equal to those of the quartz it is difficult to estimate how much is actually present. Microcline is also present but is not abundant.

The biotite has nearly all been shredded into small flakes similar to those in No. 199. Some larger crystals which have been protected by augen give the pleochroism X = very light brown, Y = Z = brown. Pleochroic haloes surrounding crystals of zircon are not common. There is a little muscovite included in the felspar. It is well crystallised, not the flaky sericite common to retrograde metamorphism.

The sillimanite is in the form of bunches of very small needles derived in all probability from the sericite formed in the crushing of the rock. The biotite and the muscovite have not been affected and from the appearance of the sillimanite it is probable that the rock has just reached the sillimanite zone.

There are several small crystals of epidote, light in colour but with a fair relief and a moderate birefringence.

The accessories are zircon, apatite and magnetite, the latter being more abundant in the micaceous bands.

The rock is a *granodiorite gneiss.*

No. 1231 is a typical augen gneiss in which crushing has been the dominant feature. The augen are all microcline and the other minerals, quartz and biotite, are crushed and wrapped round the augen. These microcline augen are about 10 × 5 mm. and constitute ½ to ⅓ of the face of the specimen. Around each crystal is a zone of recrystallised felspar and quartz which has grown upon the microcline and produces a dull ring around the bright cleavage faces of the large microcline crystal.

Under the microscope the rock is seen to have the mineral composition of a syenite. This may have been the original composition of the rock but it is more probable that some of the original quartz of the rock had migrated during the metamorphism. The microcline augen are very conspicuous and dominate the structure of the rock. As was noticed in hand specimen they are all twinned on the Carlsbad law. The ring of recrystallised felspar around the augen is not so obvious as in hand specimen but it can be recognised and is seen to consist of microcline with a little quartz.

The microcline is perthitic and in addition to the perthite inclusions contains round grains of quartz and plagioclase. Neither the microcline nor the perthite is weathered but the plagioclase inclusions are clouded with decomposition products.

The plagioclase has the composition of $Ab_{85}An_{15}$. In addition to the inclusions in the microcline it forms small round grains in the crushed material surrounding the augen.

The quartz makes up less than 10% of the rock and is chiefly confined to the more micaceous bands.

Both biotite and muscovite are present, the former being the more abundant. The biotite was present in the original rock before the metamorphism and is included in the microcline augen. It occurs as large well formed crystals and as smaller flakes which appear to be derived from the shredding of the larger crystals. The larger crystals contain inclusions of zircon and monazite which induce pleochroic haloes. The pleochroism of the biotite is X = light golden yellow, Y = Z = dark brown to opaque. Some flakes have been weathered, the alteration taking the same course as in No. 525 (q.v.). Muscovite is usually intergrown with the larger flakes of biotite. It has the properties of normal muscovite and has an optic axial angle 2E = 65°-70°.

Garnet is not common but there are a few large crystals sporadically distributed. It does not appear to have been formed in the primary crystallisation of the rock but to have been caused by the metamorphism.

Magnetite forms two generations of crystals, the first a primary crystallisation of large subidioblastic grains and the second of smaller grains formed during metamorphism.

The other accessories are zircon and xenotime. It is difficult to distinguish between these as the xenotime is colourless and neither mineral shows crystal form. They are usually associated with the clots of mica.

The approximate mineral composition is microcline 60%, biotite 15%, plagioclase 12%, quartz 8%, muscovite 5%, magnetite, zircon and xenotime.

The rock is an *augen gneiss.*

No. 390 has been crushed much more intensely than No. 1231 but at a temperature high enough to prevent mylonitisation. It is very fine grained rock with a close and well developed banding. Occasional lighter bands denote a leucocratic patch in the original rock and at one end of the specimen is a band of black rock which represents a patch rich in ferro-magnesian.

Under the microscope a miniature augen structure is seen. Although the average grain size is less than 0·01 mm. the felspar grains form augen 0·02 to 0·03 mm. across. The banding so noticeable in the hand specimen is due to this augen structure and to a tendency to foliation in the quartz. The micas wrap round the felspar augen and the quartz foliae and have no constant orientation.

The quartz forms small lenticular foliae which sometimes consist of a single stressed crystal although in the majority of instances the foliae have been recrystallised to a granular mosaic.

Most of the felspar is microcline but some oligoclase could be detected. The felspars are nearly all untwinned and are only slightly weathered. Some of the microcline shows its characteristic cross-hatching but most of it could only be determined by its refractive index and an occasional extinction angle.

The biotite forms very small shreds interwoven with the quartz and felspar. A few larger crystals about 0·005 mm. in length have pleochroism X = light yellow, Y = Z = dark greenish brown.

There are a few relatively large garnet crystals. They are isotropic and colourless and are probably almandine.

The accessories magnetite, apatite and zircon are sparsely distributed.

The rock shows signs of drastic crushing and recrystallisation. The augen of felspar do not seem to have recrystallised as they would never have grown so much bigger than the quartz. The quartz has recrystallised and segregated into lenticles which really give the foliation to the rock. The individual grains of mica do not exhibit much parallelism but in the mass they have the effect of increasing the schistosity of the rock.

The rock is a *granitic gneiss*.

No. 277 is a granite gneiss in wich metamorphism reached its maximum at a time when the rock was completely solid but before it had had time to cool. The granite was intruded under great hydrostatic pressure and probably the garnet in the rock is the original primary crystallisation of the ferro-magnesian. The garnet forms large pink crystals in a white rock. The felspar is opaque and white and can easily be distinguished from the vitreous quartz. It has no tendency to elongation parallel to the foliation. The quartz forms small lenticular foliae 2 mm. thick and 10 to 15 mm. long, spaced about 5 mm. apart. Occasional large crystals of microcline break up this arrangement.

The quartz shows undulose extinction and gives every indication of having been subjected to stress while cooling. It contains many strings of inclusions orientated perpendicular to the length of the quartz lenticle. The inclusions are both dust and liquid, some of the latter containing gas bubbles.

The dominant felspar is a perthitic microcline. The typical cross-hatching is not seen in the larger crystals but the smaller recrystallised grains in the crushed areas have a well developed twinning. The sodic phase in the perthite separates out in irregular patches and gives the rock an " untidy " appearance. This effect is increased by the crushing of the microcline in some areas and the formation of sutured edges between the grains. In the more highly crushed areas much of the microcline has been recrystallised and the albite set free to form separate small crystals. The felspar is not weathered to any extent but some of the microcline looks cloudy in ordinary light.

The garnet forms large pink grains which are perfectly isotropic. It is altered along cracks and at the edges to biotite. The biotite is brown with X = light yellow brown, Y = Z = brown. It is in turn altered to chlorite which is faintly pleochroic in green and shows ultra blue polarisation colours.

The minerals in order of abundance are microcline, quartz, plagioclase and garnet.

This rock was metamorphosed soon after solidification and before it had had time to cool to any great extent. The quartz was thus segregated into foliae while in a mobile state and such felspar as was crushed was able to be recrystallised.

The rock is a *garnetiferous gneissic granite.*

This rock bears a striking resemblance both in hand specimen and in thin section to rocks collected by the British, Australian and New Zealand Antarctic Research Expedition from the rock outcrops of Enderby Land.

No. 270 is very similar in appearance to No. 277 but some slight alteration has made the felspar a light brown in colour. The quartz foliae are more continuous than in the previous rock. The rock consists essentially of quartz, orthoclase, plagioclase and garnet.

The quartz shows undulose extinction and has sutured edges between adjacent grains. The strings of inclusions are not so abundant as in the previous rock. The plagioclase has the composition of oligoclase and is usually turbid through alteration. The alteration products are sericite, which seems to represent the potassic phase separating out of the plagioclase, and calcite. The microcline is much less weathered than the plagioclase. It is commonly untwinned and one large crystal can be seen in which the grating structure is just beginning to appear, growing outward from cracks across the felspar. It is perthitic and the sodic phase is scattered irregularly through its host.

A little biotite was present but is now all altered to chlorite.

The garnet is pink and isotropic and has a refractive index slightly above 1·79. It is probably almandine.

There is a little sillimanite developed in the crushed areas. It has replaced some sericite formed from the felspar during the crushing of the rock. It forms small but definite crystals which show the characteristic prismatic cross-sections and 010 cleavage.

This rock has been crushed and recrystallised while still hot and subsequently raised to the sillimanite grade. At a much later stage in its history it has been weathered and the felspar and biotite altered.

The rock is a *sillimanite-garnet bearing gneissic granite.*

No. 709 is similar to No. 270 but was more crushed than the previous rocks. In hand specimen it resembles No. 277 in all particulars except that it is considerably coarser in grain. The quartz foliae are more continuous than in No. 270. The garnets are big but only sporadically distributed.

Under the microscope the crushing and granulation is seen to have been more drastic than in the other rocks and is possibly due to the rock having cooled down to a lower temperature before the onset of metamorphism. The quartz has segregated into foliae but there is some in with the crushed microcline. In No. 277 the quartz of each lenticle is optically continuous but in this rock the foliae contain many separate grains. The strings of inclusions have a constant orientation at an angle to the long axis of the quartz lenticle.

The felspar is almost entirely microcline but there is some albite also present. The original grains were from 2 to 5 mm. in diameter but most of the microcline has been crushed. The crushed fragments are of all sizes from 1·0 mm. to less than 0·1 mm. but in the most thoroughly crushed areas all of the grains are below 0·1 mm. in size. The larger "relic" crystals are imperfectly twinned but the recrystallised microcline has a well developed cross-hatching. Some of these relics can be seen in the process of breaking up into lenticular pieces with areas of crushed felspar between them. It was along these crush areas on the edges of the felspar crystals that sericite was formed. This sericite has now been altered to sillimanite. The sillimanite is mostly found in the areas where the microcline is the most crushed but is also scattered through the larger microcline crystals. It has formed definite small crystals with the typical 010 cleavage, in the crush areas, and fine needles in the microcline.

Later post-metamorphic movements and a slight amount of weathering have developed sericite along one edge of the specimen. This sericite has mainly formed at the expense of the sillimanite.

There is in the slide one large crystal of garnet. The garnet is pink and isotropic and has a refractive index above 1·79. The crystal has been rounded and some crushed felspar has been moulded upon it. This suggests that the rock had crystallised as a garnetiferous granite under considerable hydrostatic pressure and that at a later stage the stress element had become predominant.

The rock is a *sillimanite-garnet bearing granite gneiss.*

No. 341 is similar in structure to the foregoing rocks but does not contain any of the distinctive minerals of metamorphic rocks. It is a white fine grained granitic rock containing patches of a pale green mica scattered through the rock along what appears to be shearing planes.

In thin section a well developed mortar structure is seen. The larger crystals have serrated edges and are twisted and bent. The rock consists almost entirely of quartz and the two felspars.

The quartz has been crushed and recrystallised to a much greater extent than the felspar. The grains are elongated in a common direction and have irregular edges one to the other. That the pressure was still operative when the rock had cooled down to a low temperature is shown by the fact that the recrystallised grains of quartz have been stressed to the extent of producing undulose extinction.

Of the felspars the plagioclase is the more abundant. It has a composition very close to albite and is usually slightly weathered. The crystals are often crushed and many are bent through an angle of several degrees as shown by the bending of the twin lamellae. The microcline shows the typical cross-hatching which is, however, rather imperfectly developed. It is weathered to the same degree as the plagioclase. There has been some "unmixing" of the felspars, resulting in the formation of perthite and antiperthite. It is often difficult to distinguish between the two but the antiperthite appears to be the more common. The antiperthite takes the form of irregular inclusions of microcline in the albite crystals.

The muscovite forms thick crystals which do not appear to have grown under any great amount of stress. There has doubtless been a period after the crushing when the effects of rising temperature tended to obliterate those due to stress and allowed the recrystallisation of the rock. Although green in the hand specimen it is quite colourless in thin section. It has the appearance and properties of ordinary muscovite; it is biaxial negative with $2E = 65° - 70°$. It is probably derived from the crushing of the felspar.

There is a small amount of scapolite, formed from the plagioclase.

The rock is a *granite gneiss.*

No. 918 is a fine grained garnetiferous granite. In hand specimen it has the appearance of an aplite but in the thin section it shows that crushing, partly contemporary and partly subsequent, which is characteristic of those granites which have crystallised under high pressure and have later been subjected to strain conditions. There is no perceptible banding or foliation either in hand specimen or in thin section. The structure of the rock differs from that of ordinary granites in that the quartz instead of being more or less evenly distributed through the rock is segregated into clumps. Few of the grains show undulose extinction, as the stress had died down before the temperature had fallen low enough to inhibit recrystallisation of the quartz.

The felspar is dominantly microcline with a few scattered grains of oligoclase. The microcline is perthitic and shows when correctly orientated a rather well developed cross-hatching. Both the felspars are altered with the separation of small micaceous flakes.

The biotite is dark with X = light straw yellow, Y = Z = dark greenish brown to opaque.

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Garnet forms large crystals which have been fractured by the stress movements in the rock and pulled apart and the space between the broken parts filled with quartz and microcline.

The accessories are magnetite and apatite.

The minerals in order of abundance are microcline, quartz, biotite, plagioclase, garnet, magnetite and apatite.

The rock is a *garnetiferous granite.*

No. 207 is of a similar appearance to No. 918 but is slightly coarser in the grain. It is a fine-grained white rock in which small garnets form dark coloured specks. The vitreous quartz can be seen in small lenticles amongst the white felspar and the rock resembles, though on a much finer scale, the gneissic granites Nos. 279 and 277.

The thin section shows the foliation of the quartz and makes more evident the metamorphic nature of the rock. The rock consists of quartz, microcline, plagioclase and garnet. The microcline, plagioclase and some of the quartz form a more or less granoblastic base through which are interspersed the lenticles of quartz. The minerals of the granoblastic portion have an average grain size of about 0·2 to 0·3 mm. and have very irregular boundaries between adjacent grains. This, combined with the microcline twinning, which is differently orientated in each grain, gives the untidy effect noted in other rocks of this nature. The quartz lenticles are as much as 4 mm. long and are about 0·2 to 0·4 mm. wide. The quartz is in optical continuity throughout the whole of the lenticle but shows rather marked undulose extinction due to stress.

The quartz contains strings of inclusions, most of which are perpendicular to the direction of foliation. The inclusions are liquid and contain mobile bubbles of gas. There are very few included mineral grains in the quartz.

The microcline is for the most part fresh or only slightly weathered. It is in small grains throughout the rock and exhibits a well developed twin pattern. There is also a considerable amount of badly weathered felspar in the rock and on comparison with the fresh microcline it has been referred to plagioclase. A few less-altered grains show multiple twinning and place the composition close to oligoclase $Ab_{80}An_{20}$.

The ferro-magnesian content of the rock is represented by the garnet. It is colourless and perfectly isotropic and contains included grains and embayments of quartz. It is slightly altered along cracks and around the edges of grains to a green chloritic mica. The garnet was in all probability a primary mineral in a magma crystallising under great hydrostatic pressure.

There is a little black-brown biotite which is not directly associated with the garnet, but it appears to have been derived from the garnet rather than to have been a primary crystallisation.

There are a few sporadic, rounded grains of zircon in the slide.

The quartz, microcline and plagioclase are about equal in quantity with quartz slightly more and the plagioclase slightly less abundant. The garnet does not make up more than one per cent of the whole rock.

The rock is a *gneissic granite.*

No. 903 is a light coloured rock composed of colourless quartz and white felspar. The grain-size is medium and a small amount of mica accentuates a certain slight foliation of the leucocratic constituents of the rock.

The microscope shows a gneissic structure in which the felspar in equidimensional grains and aggregates is surrounded by the foliated quartz and by a small amount of recrystallised felspar. The quartz is strained and invariably shows undulose extinction. It contains numerous strings of inclusions mostly of the gas-liquid type. Much of the felspar is weathered and so indeterminate but some slightly less weathered shows multiple twinning. In striking contrast is the microcline which is only weathered to a very slight extent. It appears as if the microcline was stable under the conditions which obtained during metamorphism whereas the plagioclase broke down into albite, sericite and zoisite. The microcline shows a very well developed grid structure and is in addition twinned on the Carlsbad Law. There is some little biotite now completely altered to chlorite with the typical ultra-blue polarisation colours. There are also a few flakes of muscovite. Some intergrown with the chlorite is primary but much is derived from the felspar. This secondary muscovite is in quite large crystals and is distinct from the sericite which forms a mass of minute flakes. Zircons with a high relief and a zoned structure are not uncommon. Epidote is associated with the biotite—chlorite change.

The minerals in order of abundance are plagioclase, quartz, microcline, biotite, muscovite, epidote and zircon.

The rock is a granite which has been metamorphosed at some time probably not long after complete solidification. It is a *gneissic granite.*

No. 322 consists of quartz and felspar with little or no ferro-magnesian constituent. The felspar is white and the vitreous quartz standing out by comparison shows a rough foliation. There are patches in the rock where the felspar has changed to a light apple green instead of dead white.

The thin section shows a rock composed of quartz and felspar in which metamorphism has so modified the normal igneous structures as to render them obscure and unrecognisable. The grain-size is medium and extremely irregular. The felspars range from 2 mm. to 4 mm. in length but the quartz has all recrystallised to a granular mosaic in which the average grain-size varies from 0·3 mm. to 1·0 mm.

The felspars are all altered but in different ways. The weathering of the orthoclase has produced a cloudiness which appears white in reflected light but in which no recognisable mineral grains can be seen. This is the opaque white felspar seen in hand specimen. The plagioclase on the other hand has formed definite grains and flakes of mineral and is seen to be responsible for the green colour of the hand specimen. A few less weathered grains give extinction angles equivalent to a composition $Ab_{70}An_{30}$.

The quartz is recrystallised but still shows unmistakeable signs of stress. There are many strings of inclusions in the quartz and these cut across crystal boundaries and continue in the same direction through several grains. There appear to be two mutually perpendicular directions of orientation for these strings.

The only other minerals are a small amount of muscovite derived, no doubt, from the felspar and a few large crystals of apatite.

Of the three major constituents the orthoclase makes up 60% of the rock, quartz 30% and plagioclase 10%.

The rock seems to have been intruded during a period of orogenic movement and to have been metamorphosed while still hot though probably in the solid state.

The rock is a *gneissic granite.*

Nos. 214 and 79 are very similar under the microscope although differing greatly in superficial appearance in hand specimen. This difference is not due to any real difference in mineral composition but is due to the greater amount of weathering of No. 79. No. 214 is a white rock composed essentially of quartz and felspar with a few small crystals of tourmaline. No. 79 is a medium grained rock in which quartz is clear and vitreous, the plagioclase very light green and the somewhat rare orthoclase a light pink.

In the slide the rocks are similar except that in No. 79 the felspars are all weathered. There is no structural term adequate to describe the structure of this rock. Most of the felspar remains as large unrecrystallised grains varying from several millimetres to a centimetre or more in length. Many of them, however, have been fractured and have zones of crushed felspar running across them. The quartz is interstitial and shows by its structure that it has borne the brunt of the stress. It has been entirely recrystallised during a period of great stress and appears to have been squeezed out and crushed between the crystals of felspar. In places the grains have been shattered and drawn out between the felspar crystals and at a later stage the whole has been further stressed with the result that the quartz has broken into long irregular interlocking tongues. Between these there are patches of fine crushed quartz. The quartz contains strings of gas-liquid inclusions which continue without change in direction across the most disturbed areas of the slide.

The felspar comprises both plagioclase and orthoclase. In No. 214 the orthoclase is the more abundant and in No. 79 the plagioclase is dominant. The plagioclase is oligoclase. Both felspars are slightly weathered in No. 214 and completely weathered in No. 79.

Tourmaline is the only accessory in No. 214. It forms grains of considerable size and is quite unbroken. It is probable that it was introduced during metamorphism but there is not the amount of reaction noted in other rocks (see p. 259 *et seq.*). It is a dark bluish green, pleochroic from light shades to almost black.

In No. 79 muscovite has been developed at the expense of the felspar and has formed aggregates of bent and broken crystals. There is also a second generation of smaller flakes which are often arranged in radial groups.

There are none of the usual accessories in either of these rocks.

Both rocks have similar histories. In them metamorphism has acted upon a solid rock which has yielded by repeated solution and recrystallisation of the quartz. The felspar has not suffered much except by a later post-metamorphic alteration.

The rock in each case is a *gneissic granite.*

(3) Granite Gneisses formed by Flowing without Crushing.

This group includes those rocks formed by the deformation of already solidified rocks. These rocks have been subjected to stresses just as powerful as those of the previous section but at the same time have been at a temperature high enough to prevent crushing of the rock. This resulted in an even grain size as compared with the mortar structure seen in the previous group. The rocks so affected have all been granites and they have formed a series of quartz-felspar gneisses.

No. 271 is another of the rocks of the granodiorite gneiss facies. It contains much more potash felspar than the typical granodiorite, in which rock the ratio of plagioclase to microcline is somewhat in excess of the 50-50 ratio. It differs very little in appearance from the gneiss in situ at Cape Denison except that it has a more perfect foliation. The mica is concentrated into long flat oval foliae rather than into planes of foliation thus indicating stress from two directions and a relief from stress in the third. Crystals of allanite up to 5 mm. in length are sporadically distributed through the rock.

The structure as seen in thin section is that of a rock that has acquired its foliation through flowing rather than through crushing. The quartz has been segregated into foliae which together with the parallelism of the biotite give a rough cleavage to the rock. The felspars have not been crushed but have been recrystallised. The grain-size is extremely uneven varying from 0·08 mm. to 1·0 mm. and averages about 0·4 mm.

The quartz is elongated parallel to the foliation and forms big grains most of which show undulose extinction. A few strings of inclusions—mainly dust but with a few liquid inclusions—are orientated in a common direction more or less perpendicular to the length of the quartz grains.

The dominant felspar is microcline, which is slightly perthitic. The cross-hatching is not well developed but most crystals show it. The oligoclase is much less abundant than the microcline. It is more weathered than the microcline, some grains being almost obscured by the alteration products.

The biotite has X = light greenish yellow, Y = Z = dark brownish green to opaque. It is segregated into clumps and thin foliae elongated parallel to the foliation. It is altering to chlorite in which X = light greenish yellow (of the same intensity as in the biotite) Y = Z = emerald green. The chlorite has the typical " ultra " interference colours.

Some yellow green epidote is associated with the biotite. It is pleochroic in yellow and green and its high polarisation colours are those of typical pistacite.

There are a few sporadic crystals of apatite.

The minerals in order of abundance are microcline, quartz, plagioclase, biotite, epidote and apatite.

The rock is a *granite gneiss.*

No. 523 is a typical granite gneiss in which there is a parallel arrangement of the mica and a foliation of the leucocratic minerals. The schistosity is more linear than planar and a surface at right angles to the schistosity shows no definite direction of orientation. The quartz and felspar are opaque and white but the biotite gives a grey colour to the rock.

The thin section perpendicular to the foliation reveals a granoblastic texture in which the average grain size is between 0·15 mm. and 0·25 mm. The mica flakes are bigger and tend to aggregate into clumps with a decussate structure. The individual flakes are about 0·50 × 0·12 mm.

The quartz shows undulose extinction and containing a few strings of inclusions. It shows no signs of fracturing.

The felspars comprise both orthoclase and plagioclase. Much of the plagioclase is untwinned or shows only a few albite lamellae in one portion of the crystal and as both felspars have refractive indices below quartz it is difficult to estimate their relative proportions. However, tests on individual grains show that the orthoclase is much more abundant than the plagioclase. The plagioclase has the composition of $Ab_{85}An_{15}$. It contains some antiperthite in which irregular blebs of orthoclase are scattered through the plagioclase crystals. Both felspars are weathered to a slight degree but the most weathered grains are all plagioclase.

The biotite is a dark variety in which X = light golden yellow, Y = Z = very dark brown to opaque. It contains a few pleochroic haloes around colourless grains which appear to be zircon. It is biaxial negative and has a very small optic axial angle. Muscovite is much less abundant and is usually intergrown with the biotite.

Apatite forms relatively large crystals 0·1 mm. in diameter, usually associated with the clots of biotite. Other accessories are zircon, magnetite, sphene and monazite. The zircon can be distinguished by its polarisation colours and uniaxial positive sign.

The minerals in order of abundance are orthoclase, plagioclase, quartz, biotite, muscovite and accessories.

The rock shows no sign of granulation and cataclasis and presents a striking contrast to the rocks of the previous group. The crushed rocks are notable for the differences in grain-size between the crushed and uncrushed material. In this rock and in most of the rocks of this group the minerals have been recrystallised to a more or less even size. Even in No. 271 where the grain-size is uneven the variation is not nearly so great or so noticeable as in the crushed rocks.

The rock is a *granite gneiss*.

No. 525 is very similar to No. 523 except that it is light pink in colour due to some slight weathering of the felspar. Under the microscope it resembles No. 523 as closely as it does in hand specimen. Close inspection, however, reveals differences which though slight are of some importance. These differences are the absence of muscovite and the presence of two small crystals of hornblende.

The structure of the rock is similar to No. 523. The felsic constituents are a little more abundant. The quartz is clear except for a few inclusions and almost invariably shows undulose extinction.

Of the felspars oligoclase is by far the less common. The potash felspar is microcline with a rather poorly defined twinning. It is perthitic, the sodic phase appearing as irregular patches in the microcline.

The biotite is similar in colour and properties to that in No. 523 but in one part of the slide shows weathering to chlorite. The first stage in weathering produced a mineral which corresponds in colour and properties to vermiculite. The cleavage is not so perfect as the cleavage of biotite and in places the lamellae have been forced apart. It has a reddish colour and a distinct pleochroism $X =$ rich golden yellow, $Y = Z =$ deep reddish orange, $X < Y = Z$. Interleaved with it and apparently representing a further stage in weathering is green chlorite with its typical " ultra-blue " polarisation colours.

The hornblende is deep green in colour and is quite similar to that to be described later in rocks Nos. 413 and 724. Its presence is noteworthy in showing the relation between these hornblende rocks and No. 523.

Sphene is rather more common than in No. 523. It is dark grey with a strong absorption and a high birefringence.

Allanite is also present in this slide. It is light brown in colour, non-pleochroic, and has a low birefringence. Some of the crystals have an outer zone of epidote. This epidote is colourless but has a birefringence of 0·035 indicating a fairly high proportion of iron.

Accessories are magnetite and apatite.

The rock is a *granite gneiss*.

No. 336 is very similar to Nos. 523 and 525 but differs in that it has running across it a vein of pyroxene. This vein has rather a profound effect on the rock about it and is remarkable in that its effects simulate those due to weathering.

The microscope appearance of the unaltered rock is similar to that of No. 523 but this rock contains more biotite. The quartz and felspars are of the same average size 0·15 to 0·25 mm. but the biotite is larger and gives a coarser grained appearance to the rock.

The quartz has a few inclusions of very small mineral grains and of dust. It shows undulose extinction and some grains are elongated parallel to the foliation.

The felspar is clear and no more weathered than in the majority of fresh rocks. The plagioclase $Ab_{85}An_{15}$ is normally slightly more weathered than the potash felspar. It is not very abundant. The potash felspar is largely untwinned although a few sections shows the typical cross-hatching of microcline.

The biotite is greenish brown, X = very light yellow, Y = Z = dark greenish brown. It contains few inclusions of zircon but one or two large grains produce pleochroic haloes. There is one crystal of sphene intergrown with some biotite flakes and it produces a halo in the grains in contact with it. Epidote crystals may also cause these haloes. In this instance the action appears to be due to the presence of cerium in the epidote as many of the crystals contain an inner portion which resembles allanite. In one instance a composite crystal of this nature included in biotite produced a halo which followed the edge of the allanite in the centre of the crystal but did not surround a portion of the pistacite which did not contain the allanite centre.

The pistacite though colourless has a birefringence higher than zoisite. The allanite is yellow and almost isotropic.

The only other mineral present in any quantity is sphene, which forms zenoblastic crystals with the typical strong absorption.

The mineral composition is as follows :—

Quartz	33·5%
Felspar	48·0%
Biotite	17·5%
Epidote	0·8%
Sphene	0·2%
Apatite	p.

The rock is a *granite gneiss*.

Of particular interest is the vein injected into the rock and the effect it has on the rock adjacent to it. The vein consists of pyroxene, felspar and amphibole, of which the pyroxene is the most abundant mineral. The pyroxene is dull green in hand specimen and is almost colourless in thin section. It has a fair relief and a birefringence of about 0·02 and resembles in its properties diallage. Intergrown with it are prismatic crystals of amphibole.

The amphibole is green blue with X = light greenish yellow, Y = green, Z = bluish green, X < Y < Z. Parts of the crystals are lighter in colour than others. There is also some amphibole which is not intergrown with the pyroxene but which forms separate crystals. It differs from the other amphibole in that it is of a uniform and slightly lighter colour. The amphibole is on the edges of the vein between the pyroxene and the injected rock and appears to represent the result of reaction between the pyroxene and the biotite of the rock. The vein also contains plagioclase and some little epidote, both of which minerals look to have been derived from the wall of the vein by stoping.

The contact zone of the rock is also interesting. There is a zone of the rock varying from 0 to 3 mm. in width along the side of the vein in which the felspars have all been rendered cloudy by alteration. The orthoclase has been the more readily affected and contains a great many flakes of some indeterminate micaceous mineral. This mineral although it does not make up more than 10% of the felspar has the effect of completely clouding it. The plagioclase contains some irregular grains with a high relief which cannot be determined and in addition some recognisable sericite which apparently represents the small amount of potash felspar originally held in solid solution in the plagioclase. It is not likely that this felspar was introduced with the vein nor that the alteration was contemporaneous with the formation of the vein. It is more probable that the felspar was altered along a crack by aqueous solutions and that the pyroxene and amphibole were introduced by reaction and replacement at a later stage. The zone of reaction and replacement did not altogether coincide with the zone of alteration so that in some places there is a selvage of altered felspar to the vein and in other places the vein abuts against the unaltered rock (see plate XII, figs. 1 & 2).

The rock near the vein contains hornblende in place of biotite and also sphene which represents the titanium content of the biotite. The amphibole psuedomorphs the biotite and forms flakes which to the casual inspection are easily mistaken for biotite. Nearer the vein it forms bigger crystals which have their own crystal form. It is green with X = light greenish yellow, Y = green, Z = bluish green, X < Y < Z. There are pleochroic haloes around grains of allanite, zircon and sphene. One halo around an allanite grain had X = light greenish yellow (equal in intensity to the X direction in the amphibole) and Z = green (darker than the Z direction in the amphibole). The haloes around the sphene and zircon are much less conspicuous and only intensify slightly the colour of the amphibole. There is associated with the amphibole some granular epidote which is probably derived from the reaction. The sphene forms large wedge shaped crystals.

The rock was first altered along a crack by aqueous solutions and then injected by a vein of pyroxene. The pyroxene reacted with the biotite of the rock and formed an amphibole, and the titanium content of the biotite which did not pass into the amphibole went to form sphene.

No. 413 is a rather coarse granite gneiss in which bands of quartz and felspar alternate with thinner bands of black mica and hornblende. The foliation is not so perfect as in the previous rocks of this class. The felspar is slightly pink due to weathering.

The microscope structure is gneissose. The quartz and felspar grains are as a rule equidimensional but some are elongated parallel to the foliation and there are some quartz lenticles following the foliation. The biotite flakes also follow the foliation but have not the same rigid parallelism that is seen in No. 525 and similar rocks. The rock has an uneven grain size but the average lies between 0·2 and 0·5 mm.

The quartz is bent and fractured and has undulose extinction. It contains a few inclusions but is normally very clear.

The felspars comprise both microcline and plagioclase, plagioclase being the less abundant. Both felspars show the effects of crushing and have bent twin lamellae. The plagioclase has the composition of $Ab_{85}An_{15}$ and contains inclusions of quartz. The microcline does not show good twinning but has a few thin twin lamellae which fade out in the middle of the crystal.

The biotite is very dark in colour and has the pleochroism X = light golden yellow, Y = Z = very dark brown to opaque. It contains inclusions of sphene, apatite, and allanite, none of which produce pleochroic haloes.

Hornblende appears in this rock in appreciable quantity. It is usually intergrown with the biotite in such a manner as to suggest that it is derived from it. It is green in colour and much darker than the amphibole in No. 336. The pleochroism is X = light greenish yellow, Y = dark green, Z = dark greenish blue, $X < Y < Z$. The double refraction is fairly high but is masked by the absorption.

Sphene is rather common in this rock as large brown crystals and more usually as aggregates of smaller grains. Many of these aggregates have cores of magnetite or ilmenite. This has been ascribed to reaction between titanium in ilmenite and some supply of calcium and silica in the rock leaving a core of pure magnetite surrounded by a zone of granular sphene. This reaction is common in the rocks from Adelie Land and has been noted by Stillwell (1918, p. 78) and Glastonbury (1940, a). It is much more common in the basic types.

Allanite is also common and as usual is weathered to a yellow wax-like mass with a low birefringence. Some of the crystals which have been specially protected have a birefringence of over 0·02. Several of the crystals have an outer shell of pistacite around them. Pistacite is also present in the form of small grains.

Apatite the only other accessory forms clear white crystals with a moderate relief.

The minerals in order of abundance are microcline, plagioclase, quartz, biotite, hornblende, sphene, magnetite, allanite, epidote and apatite.

It is evident that the rock has been formed at a considerable grade of metamorphism. The failure to form garnet does not preclude its having reached the garnet grade and it is probable that it has done so as the formation of hornblende from the biotite needs a fairly high grade of metamorphism. That there has been notable stress is evidenced by the curving of the twin lamellae in the plagioclase.

The rock is a *granitic gneiss.*

No. 724 is a composite gneiss of a similar nature to No. 413. It differs in that it contains more hornblende and also in that it has a vein of hornblende traversing the rock. One portion of the rock is rather more massive and contains more hornblende while on the other side of the vein the rock is more perfectly schistose and contains more biotite. This latter portion is typical of the rock and the other portion is only a local variation.

The thin section of this less massive type is rather similar to that of No. 413, but contains more hornblende than No. 413. In the structure of the rock and in the proportions of the other minerals present it is quite similar. The microcline is nicely twinned and is quite fresh but the plagioclase is slightly weathered. The biotite has the same strong absorption. The hornblende is more abundant and is usually associated with the biotite. The pleochroism is X = light greenish yellow, Y = dark green, Z = dark blue green, $X < Y = Z$. The extinction $Z \wedge c = 23°$. Sphene is rather common as in No. 413 but in larger crystals. It has a light brown colour but a strong absorption and a notable pleochroism. Apatite forms clear crystals with a moderate relief.

The minerals present in order of abundance are microcline, plagioclase, quartz, hornblende, biotite, sphene, apatite, epidote, zircon and allanite.

The rock is a *hornblende felspar gneiss.*

No. 543 is another metamorphosed igneous rock but has been rendered more highly schistose than any of the other specimens. It has the appearance of a metamorphosed sedimentary rock and but for the presence of sphene and allanite which show its connection to the Granodiorite gneiss it would have been classified with the semi-calcareous argillaceous rocks. The rock is dark grey in colour and is of a fairly fine grain. The constituent minerals can be made out to be quartz, felspar, biotite and hornblende. It differs from the normal metamorphosed granodiorites in that the ferromagnesian is evenly scattered through the rock instead of being segregated into foliae.

The thin section shows the rock to have been thoroughly reconstituted. The grain-size is very even and averages 0·25 mm. The structure is typically gneissose in that the quartz and felspar are granoblastic and the biotite exhibits a parallel arrangement.

The quartz is not very abundant. It is not affected by strain and is reasonably free from inclusions of any nature.

The plagioclase has the composition of oligoclase $Ab_{80}An_{20}$. It is very fresh and unaltered and does not exhibit twinning in many of the grains. Orthoclase is also present, though in much less quantity than the plagioclase from which it can only be distinguished by its lower refractive index.

The biotite is a greenish variety in which X = light golden brown, Y = Z = dark greenish brown. It contains inclusions of zircon which induce pleochroic haloes.

The hornblende is green, X = greenish yellow, Y = bluish green, Z = greenish blue, $X < Y = Z$. The extinction is $Z \wedge c = 22°$.

Epidote is abundant and forms aggregates of grey crystals with a high relief and medium birefringence. Some with a yellow colour and low birefringence is allanite. The allanite is usually intergrown with the pistacite.

Sphene is rather common in the form of small xenoblastic crystals, the larger of which may contain ilmenite centres.

Apatite is fairly common and forms relatively large crystals.

The other accessories are zircon and ilmenite.

The mineral composition is as follows :—

Quartz	27·1%
Felspar	48·4%
Biotite	17·8%
Hornblende	1·5%
Epidote	2·4%
Sphene	1·4%
Apatite	0·8%
Ilmenite	0·3%
Allanite	0·3%
Zircon	p.

The composition of this rock is that of a granodiorite and it is more than probable that this rock is another of the granodiorite facies. The only other alternative is that it is a calcareous argillaceous arkose which would behave in a similar way. However, the presence of the allanite and sphene and the large excess of the felspar over the quartz strongly support the igneous origin. Apart from the hornblende the composition is very similar to that of No. 336 (q.v.).

The rock is a *felspar biotite gneiss*.

No. 156 is an metamorphosed igneous rock but differs from those described above in that it contains hypersthene. In this respect it is related to the Charnockites of Madigan Nunatak and Aurora Peak. Of the rocks described by Stillwell (1918) from these localities No. 754 from Aurora Peak (p. 139) most nearly resembles this specimen.

It is a dark massive rock when fresh but the partial weathering of felspar gives a lighter colour to the surface. There are some magnetite crystals on the surface and each has around it a zone in which the quartz is stained with haematite. There is an ill-defined foliation of the dark minerals.

The structure is granoblastic and the average grain-size is about 0·3 to 0·4 mm. The foliation of the darker constituents seen in the hand-specimen is not perceptible in the thin section.

The quartz forms large rounded grains which seem to have been segregated under the influence of pressure. It contains many trains of gas-liquid inclusions and shows undulose extinction.

Plagioclase is the dominant felspar. It has the composition of $Ab_{60}An_{40}$. The twin lamellae are often bent and the extinction position at one end of a crystal may differ by as much as 30° from the extinction position at the other end of the crystal. There is some little orthoclase present.

There are three ferromagnesian minerals present, biotite, hypersthene and hornblende. Hypersthene is apparently the primary mineral from which the biotite is derived. In section 0·02 mm. thick the pleochroism is scarcely noticeable but the colour can be seen to change from light pink to light green. The birefringence is considerably above that of quartz and indicates a moderate tenor of iron. The hypersthene has been affected by metamorphism and has broken down to form biotite although most traces of this reaction have been obliterated in the subsequent recrystallisation of the rock. There has been a later alteration of the hypersthene after the end of the metamorphism but this has resulted in the formation of granules of magnetite and of flakes of some indeterminate mineral along cracks in the hypersthene grains.

Hornblende is present in small quantity and is probably also primary. It has not been derived by any process of uralitisation of the pyroxene since the metamorphism of the rock. The pleochroism is X = light yellow, Y = yellowish green, Z = clear grass green, $X < Y < Z$.

The biotite is almost as abundant as the hypersthene. Its pleochroism is X = light yellow, Y = Z = dark brown. It contains a few grains of zircon with feeble haloes. Many of the flakes are bent indicating that the biotite was formed before the end of the metamorphic period.

There are two generations of magnetite crystals. The earlier crystals are porphyroblastic and are surrounded by a zone in which the cracks in the rock are filled with haematite, thus producing the red colouration seen in the hand specimen. The later crystals are derived from the breaking down of the hypersthene.

Apatite is the only other accessory.

The minerals in order of abundance are plagioclase, hypersthene, quartz, biotite, orthoclase, hornblende, magnetite and apatite.

This rock is unusual in that it represents an altered charnockite. The hypersthene in this case is obviously unstable and breaking down to biotite, although recrystallisation has blotted out most traces of the reaction.

The rock is a *charnockite gneiss.*

No. 662 is an erratic collected from Cape Hunter and is a light grey, fine-grained rock with a slight foliation. The minerals visible in hand specimen are quartz, felspar and biotite.

The thin section shows a rock in which the average grain-size is about 0·25 mm. The structure is very uneven as the grains of felspar have sutured edges one to the other and there is a considerable amount of fine material both quartz and felspar. The larger quartz grains are about 0·50 mm. across and are lenticular in section. They all have undulose extinction and contains strings of gas-liquid inclusions. The smaller grains are about 0·05 to 0·10 mm. in diameter and as they are entirely recrystallised are free from stress and undulose extinction. The microcline is mainly in the form of large grains (0·3 to 0·4 mm.) with very irregular edges and a well developed cross-hatching. These contain included grains of quartz and plagioclase. There are not many small grains of microcline as most of the recrystallised material is quartz but there are a few areas in which the microcline has been broken and recrystallised. The plagioclase is less common than the microcline. It is of the composition $Ab_{75}An_{25}$ and is usually cloudy due to incipient alteration. The biotite is reddish brown, pleochroic from X = light yellow to Y = Z = dark reddish brown. It forms flakes in two ranges of sizes. The larger range from 0·15 to 0·30 mm. There are also a great number of smaller flakes 0·10 mm. and smaller which together with the irregular structure of the quartz and felspar give a ragged appearance to the rock. There are a few flakes of muscovite intergrown with the biotite. The accessories are sphene, magnetite, pyrite, apatite, calcite, allanite and zircon. The sphene is in small grains which appear to have been derived from the breaking up of a larger grain and the scattering of the pieces along the direction of flow of the rock. The pyrite is in the form of large grains which invariably have an outer zone of magnetite formed, apparently, by the oxidation of the pyrite. Some larger grains of magnetite represent pyrite wholly changed and there are all stages between the slightly altered and the completely altered pyrite. The apatite is in clear grains included in the quartz and felspar. Zircon is not uncommon as small elongated grains of high relief and mostly included in the quartz. There are only two or three grains of very altered allanite. Calcite is present in small quantity and is apparently original or at least formed before the onset of metamorphism.

This rock has been metamorphosed under conditions of strong pressure and only moderate temperature. The temperature has not been high enough for complete recrystallisation nor has the pressure been strong enough to effect any notable degree of crushing. In the early stages of metamorphism the quartz recrystallised into large lenticular grains but later some of the quartz and felspar dissolved under pressure and formed small crystals around the larger grains. The sphene and the biotite both show signs of a crushing and shredding which has been partly obscured by recrystallisation.

The minerals in order of abundance are microcline, quartz, plagioclase, biotite, magnetite, pyrite, apatite, sphene, allanite and zircon.

The rock is a *granite gneiss*.

(4) Rocks Crushed and Invaded by Boron containing Vapours.

In this group are placed those rocks in which crushing of the rock has been followed by the invasion of boron vapours up through the crush zone. These vapours have altered the felspars in the crush zone to tourmaline and quartz and in the extreme case have attacked the whole rock till all that is left of the original rock are a few relic felspars in a quartz tourmaline rock. Rocks 899, 15, 1209 and 708 show in increasing order the reaction involved in this transformation.

No. 899 is a crushed granitic rock in which the introduction of tourmaline is merely incidental to the formation of the rock. It is light pink to colourless in hand specimen, and has a rough planar schistosity. Bands of crushed quartz and felspar alternate with bands in which the felspar is quite uncrushed.

Under the microscope the disparity in size between the crushed and the uncrushed grains is more evident. There are large microcline crystals up to 4 mm. in length set in ground-mass of crushed material with an average grain-size of about 0·07 mm. The larger relic crystals are all microcline but some of the smaller are plagioclase. The quartz is mostly in the ground-mass but there are some aggregates of larger crystals.

Some of the relic microcline crystals are rather perthitic, one in particular being strongly affected. The development of perthite is so marked as to preclude any idea of exsolution. That the perthite has been produced by replacement of microcline is shown by the fact that one portion of the crystal is practically free from albite. The albite forms flat lenticles elongated parallel to the trace of the microcline twinning and these, in the portion of the crystal richest in them, are crowded very closely together (see Plate XII, fig. 3). That this albitisation occurred before the crushing of the rock is seen from the fact that the zone richest in albite bears no relation to the edges of the crystal. Other crystals of microcline are free from perthite and show only incipient twinning. The microcline in the ground-mass has well developed twinning and is free from perthite. The plagioclase freed by the recrystallisation of this microcline has formed small crystals in the ground-mass. One medium sized crystal of microcline has a mantle of plagioclase formed probably as a late magmatic process.

Plagioclase occurs both as " relics " and in the ground-mass. Its composition is $Ab_{90}An_{10}$ and it is quite fresh and unaltered. The relic crystals have been fractured and have curved twin lamellae.

Quartz being more mobile has entirely recrystallised. It is seen both in crushed areas and as aggregates of larger crystals.

During the crushing sericite formed along the slipping planes as a result of the breaking down of some felspar. As the grade of metamorphism became higher it was recrystallised to muscovite and this in turn altered to form sillimanite. Some muscovite has not been changed and occurs as strings of crystals often bent as they follow the course of the slipping plane.

The sillimanite is in the form of small but distinct crystals which average about 0·015 mm. in cross section. They follow the lines of the original sericite and are confined to the crush areas.

Some little garnet has formed irregular pink crystals.

Tourmaline has been introduced by vapours ascending up the zone of crushing. Its late origin is shown by the fact that it forms large unbroken crystals in an area in which the rock has been severely crushed. It is pleochroic from light greenish pink to a dull olive green.

The rock was originally a granite or a pegmatite of a fairly coarse grain, in which late magmatic changes had resulted in the formation of perthite. After the rock was completely solidified it was subjected to dynamic metamorphism with the formation of a sericitic quartz felspar gneiss. Later a considerable rise in temperature raised the rock to the sillimanite zone. It was either just before or concurrently with this stage that the tourmaline was introduced.

The minerals in order of abundance are microcline, quartz, plagioclase, tourmaline, sillimanite, muscovite and garnet.

The rock is a *tourmaline sillimanite granitic gneiss.*

No. 15 has had a similar history to No. 899 but the granulation has not been so severe. In hand specimen it has the appearance of a tourmaline-garnet bearing aplite. Closer inspection shows a slight tendency to segregation and foliation in the quartz and the presence of micaceous films along planes which can be interpreted as slippage planes. The tourmaline and garnet form small crystals and the grain-size is that of a fine grained granite.

In thin section the larger relic felspars (5-8 mm. in length) are seen to be set in a crush mass of grain-size about 0·1 to 0·5 mm. It is to be noted that the grain-size of the recrystallised material is much greater than in No. 899.

The quartz appears both as large crystals which are fractured and show strain shadows under polarised light and as smaller grains which have been recrystallised and show no sign of stress.

The relic felspars are all plagioclase-antiperthite. The sodic phase has the composition of albite $Ab_{95}An_5$. The potassic phase is microcline scattered through the host as irregular blebs with a common orientation. The microcline is distinguished by its lower refractive index and by its typical twinning (see Plate XII, fig. 4).

There are several quite wide crush lines across the slide in which the quartz and felspar have been crushed and recrystallised. The recrystallised plagioclase is quite free from any antiperthite and the potash phase so released has produced a few microcline crystals. These show good twinning and are clear, free from perthite and quite unaltered.

Along the lines of greatest crushing there have been formed numerous flakes of muscovite. The flakes are bent and small and in some places seem torn as if there has been repeated movement during the line of weakness.

There is associated with the muscovite a small amount of biotite. It is green, X = light greenish yellow, Y = Z = brownish green.

Some pink garnet forms small subidioblastic crystals.

A few crystals of sillimanite have developed from some sericite but only in one instance. This points to the beginning of the sillimanite zone.

It is in the crush zones that the tourmaline has developed and here again it forms large unbroken crystals. It has a characteristic pleochroism O = dull olive green, E = greyish pink, O > E.

The rock has passed through a similar series of changes to No. 899 but the initial crushing was not so intense nor was sillimanite produced to the same extent as in No. 899.

The rock is a *tourmaline-bearing garnetiferous granite gneiss*.

No. 1209 shows another stage in progressive tourmalinisation. In the two rocks just described the tourmaline is in small amount and has not reacted with the felspar to any extent. In No. 1209 there is ample evidence that the tourmaline was not introduced as such but as boron vapours which have reacted with the felspar to form quartz and tourmaline.

The rock consists of large relic crystals of light pink felspar and some aggregates of quartz and felspar and shows wide crush zones up which the boron vapours have risen to react with the felspar and which are now represented as veins of quartz and tourmaline.

The thin section shows that here, as in previous rocks, there has been a notable amount of crushing during the early metamorphic history of the rock.

The felspar crystals which in this rock are microcline microperthite are of a large size—up to 10 mm. or more in length. The sodic phase is albite and is distributed through the microcline as irregular blebs with their c-axes parallel to the c-axis of the microcline. Some of the microcline crystals are bent at the edges and have curved twin lamellae.

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There are great areas of " crush " in which the grains have an average size of about 0·1 mm. In this the most prominent mineral is microcline which forms small crystals with a well developed cross-hatching. The albite released from the perthite has crystallised in the crushed area. There is little quartz in with the fine material. Some muscovite has recrystallised from the sericite which was developed during the crushing of the rock.

It is into these crushed areas that the boron vapours have come and altered the felspar into tourmaline and quartz. This quartz by reason of its having crystallised in the presence of abundant volatile has formed much bigger crystals than the microcline and has an average grain size of about 0·8 to 1·0 mm. These large uncrushed crystals of quartz can be seen enveloping patches of crushed microcline in a way that leaves no doubt as to the processes involved. The quartz shows undulose extinction but is not crushed, and encloses corroded patches of recrystallised microcline and forms stringers into the microcline microperthite along cracks in the solid crystals.

The tourmaline forms big crystals sometimes set amongst the crushed microcline but the more often surrounded by the quartz produced in the reaction. It is similar in colour to that in other rocks, E = light greenish pink O = dull olive green, O > E. Basal sections exhibit a zoning of the colour in which irregular patches are of a lighter, more blue colour than the rest of the mineral. Some of the crystals contain inclusions of quartz.

The minerals in order of abundance are microcline, quartz, plagioclase, tourmaline, muscovite. Of these microcline and quartz are about equal and together make up about 80% of the rock.

This rock is the half-way stage in the production of a quartz tourmaline rock by the action of boron vapours on the felspar. It is notable for the fact that in the areas in which there is no felspar there is nothing to distinguish the rock from a true quartz tourmaline pegmatite. The structure is shown in Plate XIII, fig. 1.

The rock is a *tourmalinised granitic gneiss.*

No. 708 has been affected by boron vapours to a greater extent than No. 1209 and has still less felspar. The rock contains about 20% of felspar in large pink " relic " crystals. The remainder of the rock consists of fine grained quartz and tourmaline which makes a striking contrast with the large felspar crystals.

The quartz tourmaline portion of the rock has a saccharoidal structure. The tourmaline crystals have an average size of 2·0 × 0·7 mm. and the quartz about 0·4 mm. There are some corroded " relic " crystals of felspar amongst the quartz which are not much bigger than the quartz. The larger crystals range up to a centimetre or more in length.

It is difficult to say whether there was any crushing before the introduction of the tourmaline as most of the pre-existing structures were destroyed by the reactions involved in the tourmalinisation, but it is probable that like the other rocks of this group it was crushed before the introduction of the boron vapours.

The quartz is free from inclusions of any nature but usually shows undulose extinction. The quartz grains have remarkably simple edges and many pairs of grains meet in simple curves or even at times in straight lines.

The tourmaline has E = light greenish pink O = dull olive green, O > E. Some crystals have a distinct basal parting.

The felspar shows the effects of the reaction with the boron. Most of the smaller grains seen have rounded and corroded borders and some have embayments in them similar to those in partially resorbed felspars of rhyolites. There are some very small and apparently crushed grains of felspar forming an aggregate surrounded by quartz and with corroded edges. The felspars comprise both microcline and plagioclase, the latter being less abundant. The plagioclase—antiperthite—contains numerous scattered grains of microcline with a parallel orientation. It has the composition of albite and is similar to that in No. 15. The microcline is slightly perthitic and has not developed a good twinning. Both felspars are weathered to some extent.

The minerals in order of abundance are quartz, tourmaline, microcline, and plagioclase.

This rock is of interest as it shows the last stages in the formation of a quartz tourmaline rock from a granite or a pegmatite. The earliest stage is the crushing of the rock and the introduction of a little boron along the crush lines. An increase in the amount of boron leads to the attack of the felspar on a large scale and the formation in crush areas of " veins " of quartz and tourmaline. The last stage seen in parts of this specimen, occurs when the boron vapours attack the uncrushed rock and finally results in a quartz tourmaline rock or luxullianite in which the quartz has a saccharoidal texture and in which there is no sign of the original rock (see Plate XIII, fig. 2).

The rock is a *luxullianite.*

The series of rocks Nos. 899, 15, 1209, 708 show the processes involved in progressive tourmalinisation. The first two rocks are representative of the first stage in which the boron vapours have risen up lines of weakness, in this case crush zones, and have altered the material in the crush zones. Nos. 1209 and 708 show successive stages in the tourmalinisation of the whole rock. Nos. 899 and 15 show different phases of the initial rock. In No. 899 the rock has been crushed and recrystallised to the stage of a mylonite gneiss before the introduction of the boron vapours. The formation of sillimanite in No. 899 is an incident connected with the general rise of the thermal gradients and the increase of volatile accompanying the tourmalinisation and is not connected with the earlier crushing of the rock. In No. 15 on the other hand, the crushing took place at a higher temperature and as a consequence the megascopic effects of crushing have almost obliterated and the rock has the appearance of a garnet tourmaline aplite. However the microscope by showing the large broken felspar crystals in a mass of finer recrystallised material reveals the true nature of the rock.

There are two rocks in which recrystallisation concurrent with the introduction of the tourmaline has gone a further stage and all but obliterated every evidence of the pneumatolytic origin of the tourmaline.

No. 194 is a fine grained light coloured rock in which small crystals of tourmaline 5 × 1 mm. are irregularly distributed through a white mass of felspar and quartz. There are crystals and aggregates of coarse felspar which may be regarded as relics.

The thin section shows a rock in which recrystallisation has been responsible for the development of the present structures. The structure is that typical of so many of these older granites and is similar to that described in the metamorphic granites (cf. No. 709). The minerals present are quartz, plagioclase, microcline, and tourmaline. Of the felspars plagioclase is badly weathered probably by post-metamorphic agencies. The felspars in most instances appear not to have recrystallised but to have remained passive while the quartz recrystallised round it. It is certainly so with the plagioclase but the microcline shows signs of recrystallisation in that it has enveloped small crystals of plagioclase in a structure more typical of metamorphism than of primary igneous crystallisation. The quartz has all recrystallised and has since developed undulose extinction. It contains numerous strings of gas-liquid inclusions. The tourmaline is green and pleochroic from light pinkish grey to deep olive green. It contains quartz grains which are unstressed. There are some small crystals of colourless garnet. It is probably almandine. The accessories are apatite and zircon.

Amongst the metamorphic structures in which the average grain-size is between 0·6 and 0·8 mm. the tourmaline forms unbroken crystals which are all larger than 0·8 mm. and which reach lengths of 2 to 3 millimetres. The crystals are not fractured or cracked and contain inclusions and embayments of quartz and are in every way similar to those developed in Nos. 1209 and 708. It is suggested that the recrystallisation of the quartz and the felspar was much accelerated by the presence of so much volatile in the rock. It is typical of this rock that two slides cut from portions of the specimen only five centimetres apart should show different structures. In the one slide the quartz is in irregular and often elongated grains which merely fit in between the felspar grains. In the other not only is the grain-size somewhat larger (1·0 to 1·2 mm.) but the structure is equigranular and granoblastic. It is notable that this latter slide only contains a little tourmaline.

The minerals in order of abundance are quartz, plagioclase, microcline, tourmaline, garnet, apatite and zircon.

The rock is a *tourmalinised granite gneiss.*

No. 565 is a light coloured rock of medium to coarse grain. Tourmaline forms obvious crystals 2 to 6 mm. in diameter and from 5 to 15 mm. in length. There are many felspar crystals which measure 2 to 3 centimetres in their longest direction but some of the felspar is much smaller. The quartz is in small vitreous grains.

Under the microscope the rock shows many signs of crushing in certain areas and gives clear evidence of the pneumatolytic origin of the tourmaline. The rock consists essentially of quartz and felspar and exhibits many of the structures noted in granites which have been crushed after solidification. It differs from them in having several planes of discontinuity along which the quartz and felspar have been crushed to a fine powder. In other areas the felspars have withstood the crushing to a large extent and remain imbedded in a mass of fine grains of quartz and felspar. In the crushed areas the structure is not unlike that of No. 1243. Some of the tourmaline is in these crush areas and is then clearly of secondary origin. Other crystals although in the uncrushed felspar have a corona of quartz which appears to be formed as a by-product of the reaction.

The felspar is all microcline-microperthite and is unweathered. The crystals show strain and have not infrequently been bent and fractured. The quartz has strings of inclusions which preserve a constant orientation throughout the slide. The tourmaline is pleochroic from light pink to deep olive green. There is some sericite developed chiefly along the planes of slippage. In one instance a lenticle of sericite in contact with a big tourmaline crystal is rather well crystallised and it appears as if the boron vapours actually "catalysed" the recrystallisation. The accessories are zircon and haematite. The zircon is in small dark grains. One has been fractured by the crushing of the rock and has not recrystallised. The haematite is in dendritic aggregates of small plates and is probably a product of late metamorphic changes.

The rock is a *tourmalinised granite gneiss.*

(5) Rocks formed by the intrusion of Magma during the actual period of Metamorphism.

This group comprises the rocks formed by the intrusion of magma during the actual period of metamorphism. There is a great diversity of types, the variations being dependent on the intensity of metamorphism at the time of intrusion. In some of the extreme cases the viscous and still semi-liquid rock has been squeezed and the liquid portion strained off from the mesh of solid crystals. In less stressed rocks the only effect has been the production of a foliated granite. In these gneissic rocks it is impossible, in the absence of field relations, to decide whether the foliation has been impressed on an already solid rock, or whether it is due to piezo-crystallisation. For this reason several rocks which have all the characters of gneissic granites and which could quite easily have been formed by piezo-crystallisation have been described as having been produced by the deformation of solid rocks. There are, however, several rocks in which the metamorphism seems to have been most active while the rock was still in semi-liquid state and these will be described below.

No. 352 is a gneissic granite in which occasional large felspar crystals cutting across the foliation suggest that the foliation was imposed by stresses acting on the still viscous magma. The stress has produced a foliation which is linear rather than planar, in that although the ferromagnesians have a common orientation, the foliae are stretched out in pipes with an oval-shaped cross-section.

The microscope structure is very uneven due in a large measure to the large felspar crystals. The quartz and the smaller felspar grains have an average size of 0·2 mm. but the poeciloblastic felspars attain lengths of several millimetres in thin section. The biotite and hornblende are of a larger size than the quartz and have a mean diameter of about 0·4 mm.

Of the felspars both plagioclase and microcline are present the latter being the more abundant. The plagioclase, which has the composition of oligoclase, is rather considerably weathered. It is made cloudy by a flaky mass in which the individual crystals cannot be determined. It is suggested that this is sericite and represents the small amount of potash originally in solid solution in the plagioclase. The microcline on the other hand is quite fresh. Although it is perthitic the plagioclase streaks are not altered as is the other plagioclase of the rock.

Quartz is not very abundant and constitutes less than 10% of the rock. It contains strings of inclusions and exhibits undulose extinction.

Of the ferro-magnesian minerals biotite is more common. It is brown in colour with X = light golden yellow, Y = Z = dark reddish brown to opaque. The crystals are often bent and in places are fractured across the cleavages. There is some magnetite developed around the edges and in the cracks of the crystals.

The hornblende is not much less abundant than the biotite. It is green with X = light greenish yellow, Y = yellowish green, Z = grass green, $X < Y < Z$. It contains some inclusions of allanite crystals which induce pleochroic haloes in which Y_h = yellowish green, Z_h = yellowish green, $Y < Y_h = Z_h > Z$. There is usually some biotite intergrown with the hornblende.

There are some few grains of apatite which are usually associated with the ferro-magnesians. Magnetite is confined to the biotite and appears to be the result of weathering of the biotite.

The association of magnetite with the biotite is taken as an indication that the biotite is decomposing to form hornblende.

The minerals in order of abundance are microcline, plagioclase, quartz, biotite, hornblende, magnetite, apatite and allanite.

The rock is a *gneissic granite.*

No. 279 is another granitic rock in which stress has been applied while the rock was still crystallising. The rock in hand specimen shows little sign of gneissic structure. It is light grey in colour and consists of white felspar with a little quartz and a fair amount of biotite. There are large pink garnet crystals up to 2 or 3 cm. in diameter. The microcline tends to porphyroblastic development and is especially noticeable as it forms large white crystals in the finer grained rock. The biotites have a parallel arrangement and bend around the microcline.

The structure in thin section is dominated by the microcline crystals which may attain a size of 10 mm. The other minerals and some more microcline fill the spaces between the porphyroblasts and average about a millimetre in diameter. The biotite shows little trace of the parallel arrangement seen in the hand specimen.

The microcline is perfectly fresh and so clear that a cleavage piece 5 mm. thick is quite translucent. When exposed to ultra violet light from a mercury vapour lamp for 10 minutes it shows a purple fluorescence. It does not exhibit the normal cross-hatching but has only a few ghost twins starting from cracks and inclusions of quartz and plagioclase. It comprises about 70% of the rock.

The plagioclase is much less abundant than the microcline and forms small crystals many of which are included poecilitically in the microcline. They are often slightly weathered and have the composition of $Ab_{65}An_{35}$. There are some micrographic intergrowths of plagioclase and microcline in which the plagioclase is the more abundant.

The quartz is not abundant and shows a tendency to segregation. It has strain shadows and some of the grains have broken down to several optically discontinuous pieces. It contains few inclusions.

Biotite forms about 5% of the rock and is rather unevenly distributed. It has X = light yellowish brown, $Y = Z$ = deep greenish brown. A few scattered zircon crystals induce pleochroic haloes.

The garnet forms ragged crystals which contain inclusions of quartz and biotite. It is pink and isotropic and has a refractive index above 1·79. It is probably almandine.

Apatite is rather abundant. It forms relatively large prismatic crystals with a moderate relief. It is not evenly distributed through the rock but has segregated in with the biotite clumps.

The rock is an ortho-gneiss, an igneous rock which has been injected during the metamorphic period and which subsequently, while still in a viscous condition, has acquired foliation by the action of one-sided pressure. There is no granulation such as would have occurred if the rock has been completely solid before metamorphism. It is possible that some quartz has been removed during the metamorphism, leaving the rock richer in the less mobile felspar and biotite.

The rock is a *garnetiferous microcline gneiss.*

No. 263 is of a similar nature to No. 279 but lacks the garnet. It is a light grey rock of a medium grain size and consists of microcline, quartz and biotite. The microcline is blastoporphyritic and is usually elongated in a common direction though some large crystals may break across this foliation. Quartz is rather more abundant than in No. 279 and occurs in small grains uniformly distributed through the rock. The micro-structure is again dominated by the large blastopoecilitic microcline crystals, which attain a size 3 to 5 mm. They are not so abundant as in No. 279 but make up 40% of the rock. Both the large crystals and the smaller grains in the ground-mass have a well developed twinning. There is little perthite but the microcline contains round inclusions of both plagioclase and quartz. The microcline in the ground-mass has a grain-size of about 0·2 mm.

Plagioclase does not amount to more than 5% of the rock. It is slightly weathered and has the composition of basic oligoclase. It forms rounded crystals included in the microcline and in the interstices between the grains.

Biotite is a brownish variety with X = light golden yellow, Y = Z = very dark brown. The flakes have a more or less common orientation and form foliae which give the suggestion of parallel structure in the hand specimen. There are a few rather intense pleochroic haloes round small crystals of zircon. There are some granules of epidote associated with the biotite.

The metamorphic origin of this rock is shown by the fact that muscovite is constantly idioblastic against the biotite, whereas in normal igneous rocks biotite is idiomorphic against muscovite.

Apatite is uncommon and no garnet could be detected.

Quartz is more common than in No. 279 and forms as much as 20% of the rock. It forms big irregular grains with undulose extinction and shows a tendency to segregation into the foliae. There are small grains of quartz included in the microcline.

The minerals in order of abundance are microcline, quartz, plagioclase, biotite, muscovite and apatite.

The rock has had a similar history to No. 279 but differs in that it contains more quartz and in that it has a more distinct foliation.

It is a *granite gneiss.*

No. 802 represents a phase in which the gneissic structure is more pronounced in hand specimen. This is largely due to greater degree of parallelism in the elongated felspars but is made more obvious by the mica flakes which themselves are also parallel. It has the appearance of a gneissic granite.

Under the microscope the finer grained minerals in the groundmass are seen to be more common than in the two previous rocks. The large blastopoecilitic microcline crystals are not so abundant as they were in No. 279 but do not lack the size of those of the previous rocks. Smaller crystals of microcline are more common than the larger and average about 0·5 to 1·0 mm.

The microcline is clear and fresh and shows a well developed twinning pattern It contains a few round grains of quartz and plagioclase but these are not so common as in No. 279. In one or two instances a crystal of microcline has grown between and around quite large crystals of plagioclase and still remained in perfect optical continuity.

Plagioclase is a little more abundant than in No. 263 but is not nearly so abundant as the microcline. It is usually altered and may contain as a product of alteration epidote and sericite.

The quartz is usually segregated into foliae and individual crystals are elongated parallel to the foliation. That it suffered from stress is evidenced by the undulose extinction and occasional granulation. It contains many strings of gas-liquid inclusions.

The biotite is a dark variety X = light greenish yellow, Y = Z = dark greenish brown to opaque. It is frequently bent and in places fractured. Intergrown with it are some epidote and a few large flakes of muscovite. This muscovite is typical high temperature muscovite and is constantly idioblastic against the biotite. The epidote is colourless but has a moderate tenor of iron indicated by its high polarisation colours.

The minerals in order of abundance are microcline, quartz, plagioclase, biotite, muscovite, epidote, apatite and zircon.

This rock has been metamorphosed while in the last stages of crystallisation and stress conditions have prevailed after crystallisation was completed. This is shown by the undulose extinction and the slight but significant granulation in the quartz.

The rock is a *granite gneiss.*

Nos. 234, 244 and 822 are similar to those described above but have one point of difference in common in that they contain large porphyroblasts of felspar up to several centimetres in length set in a ground mass in which the constituent minerals have an average grain-size of below 0·5 mm.

No. 822 is the most striking example as in it large tabular microcline crystals up to 3 cms. in length are set in a ground mass which is almost fine enough to be called aphanitic. The felspars are a light pink in colour and are commonly twinned on the Carlsbad Law. The ground-mass consists of quartz, felspar and biotite and has a dark colour due to the presence of finely divided biotite.

In thin section the disparity in grain sizes is made more evident. The ground-mass consists of grains about 0·03 mm. in diameter with a few strained crystals of quartz ranging up to 0·15 mm. The porphyroblasts of felspar vary in size from 3mm. to 30 mm. with an average of about 10 mm. There is a distinct foliation marked out by the flakes of biotite but the larger felspars disturb the foliation.

Most of the felspar is microcline which does not always show its characteristic twinning. The microcline is perthitic. The other felspar is an acid plagioclase and is confined to the ground-mass. Both felspars are fresh and unweathered.

Quartz is abundant but is at times difficult to distinguish from the clear untwinned felspar. It usually has undulose extinction and shows a tendency toward elongation parallel to the foliation.

The biotite is greenish but how much this is original and how much due to partial alteration to chlorite is difficult to decide. The flakes which have a high birefringence show X = light golden yellow, Y = Z = dark brownish green. In other flakes, however, X = golden yellow, Y = Z = bright green, and the polarisation colour is a light bluish grey which is masked by the absorption of the mineral. This latter, no doubt, represents partial alteration to chlorite.

There are a few grains of hornblende intergrown with the biotite. The pleochroism is X = yellow, Y = green, Z = greenish blue, and the extinction $Z \wedge c = 21°$.

Sphene is too common to be called an accessory. It forms porphyroblastic crystals 0·1 to 0·3 mm. in diameter with a typical brown colour and absorption. The crystals are xenoblastic and contain inclusions of quartz and biotite. Several of the grains show a fair cleavage. One in particular shows two very good cleavages (110) at an angle of about 130°. It also shows multiple twinning but the oreintation could not be determined.

There are a few crystals of garnet. They have been fractured and pulled apart and have at a later period been recrystallised. It is light pink to colourless and is quite isotropic.

Epidote with a moderate relief and a moderate birefringence is scattered through the slide. Tourmaline is present but is not common. It is pleochroic from light pink to a dark green. Apatite and zircon are present in their usual modes. Magnetite is not common and is altering to haematite.

The structure is that of an igneous rock which has been metamorphosed during crystallisation. The metamorphism has had the effect of reducing the grain-size of the crystallising minerals while because of the lack of resistance to stress the felspars which had already crystallised were not crushed to any extent. The size and shape of the felspar rules out any suggestion that they can be augen left after crushing of the rock and it is far from likely that they would grow to such a size if they had recrystallised from an evenly crushed rock. There are some signs of crushing in the later stages of the cooling of the rock reflected in the fracturing of the garnets and the breaking across of one or two of the large felspars.

The rock is a *granite gneiss.*

No. 234 is of a similar nature to No. 822 but is more coarse grained. It contains large pink felspars set in a fine-grained matrix and has the appearance of a porphyritic granite. These felspars are all aligned to follow the foliation which is marked out by the parallelism of the biotite. The porphyroblasts average about 10 mm. in length and are usually twinned on the Carlsbad Law. They comprise both microcline and plagioclase but the microcline is far more abundant. The mass of the rock has a very uneven grain-size and varies from 0·15 to 0·70 mm. In addition there are plagioclase crystals which are intermediate in size between the ground-mass and the porphyroblasts, and vary from 1 to 3 mm. in length.

The plagioclase is twinned on the Albite, Carlsbad and Pericline laws, and has the composition of oligoclase $Ab_{85}An_{15}$. It frequently shows signs of strain indicated by the curving of twin lamellae.

The microcline porphyroblasts are all twinned on the Carlsbad Law but show only a patchy microcline twinning. They are perthitic and contain in addition round inclusions of quartz and plagioclase.

The quartz is strained and recrystallised. It has undulose extinction and some grains are slightly biaxial due to strain. The grains are segregated into foliae in which individual grains are elongated parallel to the foliation.

The biotite is brown with X = light yellow, Y = Z = dark reddish brown to opaque. It contains few inclusions but occasional grains of zircon induce pleochroic haloes. There is intergrown with it a small amount of muscovite.

Garnet forms large ragged crystals which have as inclusions grains of quartz and biotite. It is pink and isotropic and is probably almandine.

Apatite is not uncommon in the form of hexagonal prisms and is usually associated with the biotite. Magnetite and zircon are also present in small amounts.

The minerals in order of abundance are microcline, plagioclase, quartz, biotite, garnet, apatite, magnetite, and zircon.

The rock is a *granite gneiss.*

No. 244 is a similar rock to No. 234 but under the microscope it shows the effects of crushing after solidification. The porphyroblasts are again for the most part microcline with only an occasional larger crystal of plagioclase.

The microcline is slightly perthitic and is twinned on the Carlsbad Law and imperfectly on the Microcline and Albite Laws. The porphyroblastic microcline crystals contain as inclusions round grains of plagioclase and quartz. The plagioclase has the composition of acid oligoclase. It is often weathered and many grains have been rendered cloudy by the alteration products.

The larger grains of quartz have all been elongated parallel to the foliation, but the smaller grains resulting from the breaking down of these are equidimensional. The larger grains contain strings of dust and fluid inclusions, the latter each with its included gas bubble.

The biotite has X = light yellow, Y = Z = very dark reddish brown. Some of it has been broken and shredded by movements in the rock during the late stages in the metamorphic history of the rock. There is now associated with it some magnetite especially in the vicinity of the fractured flakes. The magnetite appears to have been derived from the breaking down of the biotite.

Apatite is fairly abundant and is usually included in the biotite and associated with the biotite clots. Zircon is present but is not common.

The rock is a *blastoporphyritic granite gneiss.*

There is in No. 244 ample evidence of crushing after the solidification of the rock but the foliation seems to have been impressed while the rock was still in the plastic state. As in the other two rocks of this class it is almost certain that the felspar porphyroblasts originated in a rock that was still in a semi-molten state and that they have been preserved because during the period of maximum stress the rock was still plastic enough to yield by flowage without imposing any undue strain on the felspars. The finer material in the ground-mass of the rock actually crystallised during the period of maximum stress and because of the stress conditions crystallised rapidly about a great number of nuclei and so formed many small grains. In No. 244 the felspars are more rounded than in the other rocks but there is very little of the mortar structure that would be present if there had been crushing around the felspar porphyroblasts. There are, however, some zones in which there is strong mortar structure and shredding of the biotite but these zones are clearly formed after the solidification of the rock and have no relation to the structure of the rock. In the other rocks (Nos. 822 and 234) there is little or no sign of this post-metamorphic crushing. In none of these rocks does the recrystallised felspar reach a size comparable with that of the porphyroblasts. Thus these porphyroblastic felspars are really phenocrysts which played a passive part in the foliation of the rock by piezo-crystallisation. In most cases they have been turned with their " b " faces parallel to the foliation.

No. 702A is composed essentially of large round crystals of plagioclase and much biotite filling the interstices between the grains. Garnet is distributed through the rock in large pink grains. Apatite can be clearly seen as long green needles often as much as 10 mm. long and less than 1 mm. in diameter. The plagioclase is white and very clear. It forms crystals about 15 mm. in diameter. The biotite flakes are 2 to 3 mm. in length.

The structure cannot be well seen in thin section as the felspar crystals are too large to allow of more than one in a standard size section. They seem to have a rounded outline, but this is not nearly so conspicuous as in the hand specimen. The plagioclase is perfectly clear and shows no signs of alteration. It has good multiple twins on both the albite and pericline laws. In many of the larger crystals the twin lamellae are bent at the edges of the crystal and one of the crystals has been broken across the lamellae and the two pieces displaced relatively to one another. There are smaller grains filling the interstices between the larger grains of plagioclase. These are about 0·3 to 0·6 mm. in diameter and show no sign of fracturing or crushing. Both the large and small grains have the same composition $Ab_{55}An_{45}$. No orthoclase could be detected.

The biotite together with the smaller grains of plagioclase fills in the interstices between the large round grains. It forms flakes from 0·5 mm. to 1·5 mm. in length with a ratio of elongation = 4 to 1. It has X = very light straw yellow, Y = Z = dark greenish brown. It is biaxial negative with a very small optic axial angle. Zircon with its pleochroic haloes is almost entirely absent but some xenotime crystals which are intergrown with the biotite flakes induce dark pleochroic haloes in the portions of the grains in contact with them.

Garnet, pink and isotropic, forms large crystals 5 to 15 mm. in diameter. It has developed in the areas between the plagioclase crystals.

Apatite is rather abundant and forms large crystals usually in aggregates associated with the clots of biotite although as can be seen in the hand-specimen it is also distributed through the felspar. It is colourless and clear and has a high relief.

There are also a few relatively large crystals of xenotime intergrown with biotite. The xenotime is uniaxial positive and differs from zircon in its lower relief and its greyish brown colour. It forms large irregular grains 0·15 to 0·3 mm. in diameter. It has a distinct cleavage parallel to the elongation of the crystals.

There is only a little quartz in the rock. It is associated with the smaller grains of plagioclase in the interstices between the larger plagioclase grains.

This rock has many points of similarity with an oligoclase biotite gneiss described by Barrow from near Glen Doll in the Southern Highlands of Scotland (Barrow, 1892, pp. 64-5 ; 1912, pp. 67-9). For this rock Barrow postulated that after most of the plagioclase and some of the biotite had crystallised the rock was subjected to powerful stresses which strained off the still liquid portions of the magma and left the mesh of crystallised felspar and biotite. Further stress ground the plagioclase crystals together and rounded off the corners and at the same time crushed and bent the biotite flakes and forced them between and around the plagioclase grains. The plagioclase that was broken and dissolved off the larger plagioclase grains recrystallised in the interstices. Much of the biotite was also recrystallised at the same time, and consequently does not show much sign of shredding and crushing. The plagioclase is rather basic but it is probable that had the rock been allowed to follow its normal course of crystallisation it would have reacted with the residual liquid containing the orthoclase, albite and quartz which was strained off and probably injected as a pegmatitic vein in some other place. The original magma probably had the composition of basic granodiorite.

The rock is a *plagioclase biotite gneiss.*

No. 112 is an even more unusual type and in the absence of field relations it is impossible to be quite certain of its exact origin. It is a fine-grained dark coloured rock in which biotite, felspar and garnet are the only minerals visible to the naked eye. The garnet forms large crystals 5 to 10 mm. in diameter sporadically distributed through the rock, but the other constituents are of a smaller size. It is more massive than schistose but has a rude cleavage due to a parallel arrangement of the biotite.

In thin section the rock is seen to consist essentially of plagioclase and biotite with some quartz and garnet. The plagioclase forms grains about 0·5 mm. in diameter and the biotite, quartz and some more plagioclase fill in the interstices between the larger grains.

The plagioclase has a maximum extinction in the symmetrical zone of 48° which corresponds to a composition of about $Ab_{20}An_{80}$. Its refractive index is so high as to give the mineral a notable relief in thin section. It is commonly twinned on both the albite and the pericline laws. It is unweathered but has undergone some alteration to muscovite during metamorphism. The crystals contain inclusions of quartz and biotite. There is some felspar which is untwinned and which by reason of its lower relief was identified as orthoclase.

Quartz comprises about 5 to 10% of the rock, and occurs both as grains comparable in size with the plagioclase and as smaller recrystallised grains which with the biotite form a matrix for the plagioclase. The larger grains have undulose extinction.

The biotite forms small flakes which are often bent round the plagioclase crystals It is crushed and there are some places where a larger flake of biotite is seen to have been replaced by smaller shredded flakes. The pleochroism is X = very light yellow, Y = Z = greenish brown. It contains a few inclusions of epidote and zircon both of which minerals induce pleochroic haloes. There is intergrown and often interlaminated with the biotite a mineral which has the properties of lawsonite. It does not appear to have been derived from the biotite by any process of weathering.

Muscovite and zoisite are formed as the result of the breaking down of plagioclase and may sometimes be seen in the peripheral zone of an otherwise quite unaltered plagioclase crystal. This appears to have taken place during the last stages of metamorphism as in a few instances the muscovite so formed has grown in optical continuity with already formed biotite flakes.

Garnet forms large pink isotropic crystals many of which have been fractured by later movements in the rock. Where this has occurred the space between the pieces drawn away from the rest of the crystal has been filled with recrystallised plagioclase and quartz.

There has been some little sillimanite developed in the crush areas between two plagioclase crystals and it appears to have been formed from the sericite which would be expected to have been produced in such a place. It is not at all common and is only in its incipient stages.

The minerals in order of abundance are plagioclase 50%, biotite, quartz, orthoclase, muscovite, epidote, lawsonite and sillimanite.

The rock by reason of its peculiar composition presents a problem whether it is igneous or sedimentary. It is difficult to conceive of a sedimentary rock which could consist of 50% of a felspar as basic as $Ab_{20}An_{80}$ and for that reason the sedimentary origin has been ruled out. This leaves two alternatives. The first that the rock is a crushed anorthosite has been abandoned because there is not the amount of crushed felspar that would have been formed in the process of crushing of such a rock nor does the felspar appear to have recrystallised in any quantity. On the other hand anology with No. 702 suggests that it too might have formed by the metamorphism of a mass of plagioclase crystals which were segregated by one of the many processes of differentiation or contamination and subsequently squeezed free from the still liquid residuum. However, in the absence of any evidence as to field relations it is impossible to do more than theorise about its origin.

The rock is a *bytownite biotite gneiss.*

IV. ROCKS OF DOUBTFUL ORIGIN, INCLUDING GARNET ROCKS.

(1) Garnet Rocks.

No. 441A is the most interesting of these rocks. It has been so highly metamorphosed that it has lost all traces of its original structure. From the point of mineral composition it could be either a highly metamorphosed sediment or the metamorphosed equivalent of a basic igneous rock.

It consists of garnet, biotite and quartz with occasional segregations of felspar. The general appearance is striking as the bulk of the rock is made up of red garnet with lustrous flakes of black biotite filling in the interstices. The quartz is subordinate and is not seen till the rock is closely examined.

The microscope appearance is even more striking. The garnet which is a light pink in thin section forms large crystals over a centimetre in diameter, and encloses large crystals of quartz and biotite. Its refractive index is above 1·79 and as the mineral is completely isotropic it is most probably almandine.

The biotite is a vivid green and has X = light brownish yellow, Y = Z = deep emerald green. It is biaxial negative and has 2E approximately 15°. It is noticeable for the beauty and abundance of the pleochroic haloes developed in it (Plate XIII, fig. 3). The included grains are both zircon and xenotime. The haloes have X = yellow (more intense than the rest of the biotite), Y = Z = very dark brown. There is some muscovite intergrown with the biotite.

Sillimanite is developed extensively and forms rod-like crystals up to 0·02 mm. in diameter. It has formed both from biotite and muscovite. From the coarse crystals of sillimanite present it was judged that the rock was well within the sillimanite zone.

The quartz forms large irregular grains which are not fractured and do not show undulose extinction. There are many strings of inclusions both of dust and of gas-liquid types.

The only accessories are the zircon and xenotime which induce the pleochroic haloes in the biotite.

The estimated mineral composition is garnet 57%, biotite 30%, quartz 10%, and sillimanite 3%.

The rock is a *sillimanite-bearing garnet biotite gneiss.*

No. 711A is less rich in garnet than No. 441A but contains more garnet than the typical garnetiferous granites. It consists of white plagioclase and biotite and large crystals of pink garnet. The biotite flakes do not show any parallel orientation but there are bands in which the mica is less common than in others.

The plagioclase is of the composition $Ab_{70}An_{30}$, and is slightly weathered. It is commonly twinned on the albite law and to a lesser extent on the pericline law. There is no orthoclase to be seen in the rock.

The biotite is pleochroic from X = very light brown to Y = Z = brown. It is not highly coloured and is probably rich in the magnesian molecule. It contains many inclusions of zircon.

The garnet is pink and isotropic and has a refractive index above 1·79. The crystals are large and well-formed though somewhat rounded and are quite free from any of the usual inclusions. It is noticeable that these primary garnets in the igneous rocks contain few inclusions in contrast to those that have been developed in the solid rock. These latter contain as inclusions full-sized grains of quartz and biotite (cf. No. 526A and Plate IX, fig. 4).

Apatite forms large grains 0·3 to 0·5 mm. in diameter and is so common that it can hardly be called an accessory. It does not exhibit its crystal form but occurs as irregular grains elongated parallel to the vertical axis.

Zircon, the other accessory, is rather abundant. Two of the largest crystals are 0·24 × 0·08 mm. and exhibit zoning under crossed nicols.

The minerals in order of abundance are plagioclase, biotite, garnet, quartz, apatite, zircon and haematite.

The rock is a *garnet felspar gneiss*.

No. 560 is more rich in garnet than the previous rock. In hand specimen it has the appearance of a metamorphosed sedimentary rock, and consists of pink garnet and a little biotite set in a mass of quartz grains.

The thin section shows the rock to consist of quartz and garnet with subordinate biotite and felspar. The quartz forms irregular grains which have sutured edges toward one another and all of which show undulose extinction. It contains a few strings of inclusions and some small mineral grains. The quartz grains are very uneven in size and vary from large grains 0·8 mm. across down to small grains 0·05 mm. in diameter. These smaller grains appear to be derived from the breaking of larger grains and in some instances the granular aggregate resulting from the breaking down of some larger grain has been elongated in the direction of least pressure. There is some little felspar in the quartz ground-mass.

The biotite is brown and pleochroic from X = light yellow to Y = Z = dark brown. It is psuedo-uniaxial and negative. It contains a few inclusions mostly of apatite. It is not uniformly distributed through the rock but is practically confined to a few narrow bands in the rock.

The garnet is pink and isotropic and has a refractive index above 1·79. It forms rounded grains which have inclusions of biotite and quartz. It is probably almandine.

The accessories are apatite, zircon and magnetite. The zircon forms small rounded grains included in the quartz and garnet and in one instance in a crystal of apatite. The apatite is distributed through the rock in fairly large grains about 0·1 mm. in diameter. The only magnetite present is found included in the crystals of garnet.

The estimated mineral composition is quartz 50%, garnet 30%, biotite 15% and felspar 5%.

The rock is a *quartz garnet gneiss.*

Nos. 80 and 81 are two specimens which are rather similar in appearance and in composition. Both are pegmatites containing large garnet crystals up to 4 cm. in diameter and both contain a considerable amount of apatite. No. 80 shows the intrusive nature of the rock as there is a narrow selvedge of the wall rock attached to each side of the vein. The vein is 8 to 10 cms. wide and consists of quartz, felspar and garnet. The intruded rock has the appearance of a quartz biotite gneiss similar to No. 161 (q.v.). It is not noticeably garnetiferous except at the contact with the vein where large garnets have been developed.

The quartz and felspar form rather large grains and are irregularly distributed as is usual in rocks of this class. The garnet forms large red crystals which are very conspicuous in the light coloured rock. It has a refractive index of about 1·79 and is probably almandine. It is altered in places to a green chlorite which is psuedo-uniaxial and negative and has a weak birefringence. Apatite can be seen in the hand specimen as light green elongated crystals. The only biotite in the rock is near the edges of the vein and appears to be due to reaction with the wall rock.

No. 81 is rather similar to No. 80 but contains more apatite and slightly less garnet. The thin section shows a considerable amount of apatite in a rock composed of plagioclase with subordinate amounts of microcline and quartz. The apatite is by far the most notable mineral in the rock and forms large xenoblastic crystals many of which are 0·5 to 1·0 mm. in diameter. It has all the properties of normal apatite except that it gives a biaxial interference figure. The birefringence is weak and the refractive index is 1·635 ± 0·002. Apatite has been reported as biaxial according to Winchell (1927, p. 129). The interference figure was difficult to obtain and the most common, found in sections which are almost isotropic, gives the biaxial optic axis figure of a single isogyr which rotates about the centre of the field. The isogyr is almost straight thus indicating an optic axial angle of approximately 90° and for this reason the sign was indeterminate. Micro-chemical tests confirmed the presence of phosphorous.

The plagioclase is of the composition $Ab_{75}An_{25}$, and is usually weathered. There is a little microcline which in contrast to the plagioclase is not weathered. There are a few scattered flakes of biotite and muscovite.

The garnet is pink and isotropic and is quite similar to that in No. 80.

The accessories are zircon and xenotime. The zircon forms small grains with dark borders and high interference colours. The xenotime lacks the distinctive relief of the zircon and is a greyish brown in colour in contrast to the water-clear grains of zircon. The xenotime grains have a border of a brown opaque mineral which is yellowish brown in reflected light. A few of the xenotime grains are included in the apatite.

The rock is a *garnet-apatite bearing pegmatite.*

No. 711 is another of these garnet rocks and is not remarkable except for the retrograde metamorphism that has altered the garnets to biotite and has produced large ragged muscovite crystals in the felspar. The rock is seen in hand specimen to consist of pink microcline in which is set large crystals of garnet. At first sight the garnet appears to have been entirely altered but this effect is seen to be due to the fact that the alteration has gone around the edges of the crystals and has also penetrated all the cracks. There is some little quartz and the rock seems to have been a pegmatite in which the garnet formed as a primary crystallisation as in No. 80 above. In this case the apatite so abundant in the previous rocks is virtually absent.

The thin section shows the rock to have been drastically altered by retrograde metamorphism. The rock consists essentially of microcline and garnet and it is the alteration products of these minerals which are interesting. It must be emphasised that these alterations products are not such as would be formed by weathering however drastic or long continued, but are minerals which can only be formed at a considerable grade of metamorphism.

The microcline is in crystals 3 to 4 mm. across, and even larger. It is slightly perthitic, the sodic phase being distributed irregularly through its host. In places this plagioclase forms small square crystals arranged in lines running through the microcline. In other places it forms veins as if it had replaced the microcline along cracks. It is along these lines that the felspar is particularly liable to alteration to muscovite. In several places a large irregular patch 1 to 2 mm. across has been replaced by a plexus of muscovite crystals. These crystals are well crystallised but have ragged edges and are totally unlike the idioblastic crystals formed in the normal metamorphic rocks. There are also irregular veinlets and patches of calcite stained with haematite scattered through the microcline. The alteration of the microcline to muscovite is also to be seen round the edges of the garnet crystals.

The garnet is pink and isotropic and has a refractive index above 1·79. The alteration has taken place around the edges and along cracks through the crystals and has produced green biotite (Plate XIII, fig. 4). The biotite has X = light greenish yellow, Y = Z = bright green. It is biaxial negative with 2E = approximately 15°. There are also some crystals of biotite which were included in the garnet at the time of crystallisation. These have X = light brownish yellow, Y = Z = dark brown. In several places a vein of green biotite has crossed a crystal of the brown biotite and has altered the outside of the crystal to green biotite which is in optical continuity with the brown biotite in the centre. The garnet also contains inclusions of quartz, apatite and xenotime.

There is some quartz in the rock mostly enclosed in the larger grains of microcline.

Ignoring the alteration the structure of the rock is that of a coarse grained granite or pegmatite. Where the microcline has been altered to muscovite the structure can best be described as chaotic.

The rock is a *microcline garnet gneiss.*

No. 641 is composed mainly of garnet with subordinate amounts of felspar and quartz. The garnet forms rounded grains which are set so close that individual grains touch. The result of this is that in the hand specimen the rock has the appearance of being nearly all garnet. There is also a small amount of biotite.

The felspar is micro-perthite, in which the sodic phase has the composition of oligoclase. It is usually slightly weathered. Quartz is not abundant. It shows undulose extinction and contains many lines of inclusions.

The garnet is pink and isotropic and is probably almandine. It forms large crystals which have grown together and enclosed areas of the base of the rock. It also has inclusions of quartz, biotite and magnetite.

The biotite is brown with X = light straw yellow, Y = Z = dark reddish brown. There is biotite of the same colour enclosed in the garnet.

The only accessories are zircon and magnetite and both are almost entirely present as inclusions in the garnet. Magnetite is abundant (about 1% of the rock) but zircon is much less common.

The rock is of a peculiar nature and it is difficult without a chemical analysis to decide what was its ultimate origin but the presence of a strongly perthitic felspar points to an igneous origin and suggest that it was a pegmatite and that the garnet was a primary crystallisation.

The rock is a *garnet gneiss.*

No. 349 is of a similar nature to No. 641 but contains less garnet. It is a white felspathic rock in which are studded small garnets about 2 to 3 mm. in diameter and 4 to 5 mm. apart. The garnet crystals are rounded but show a suggestion of crystal form. There is about 5% of quartz and a very little biotite. The thin section has very little additional information to reveal. The structure is that of the xenoblastic felspar of an average grain-size 1·3 mm. with slightly larger crystals of garnet 2·0 mm. in diameter breaking up the normal structure of the felspar.

The felspar is a microcline with a well developed twin pattern. It has as inclusions a few small grains of plagioclase. The microcline is weathered to a slight extent and the plagioclase to a greater extent. The quartz of the rock is stressed and shows undulose extinction. It contains many strings of dust and gas-liquid inclusions. The garnet forms round crystals of a regular shape but contains included quartz grains. It is pink and isotropic. There is a little biotite now entirely changed to chlorite. The accessories are apatite and zircon.

The rock is a *garnet microcline gneiss.*

No. 289 is a pegmatite vein which was injected during a period of great hydrostatic pressure. There is slatey wall rock on both sides of the vein which is about 10 centimetres wide. The vein consists of quartz and felspar but down the middle there is a row of big black garnet crystals 1 to 2 centimetres in diameter.

The felspar is practically all microcline with a beautiful fine cross-hatching. It is in large unweathered crystals which show no signs of strain or crushing. The quartz is in large grains which show marked undulose extinction. It is in places broken down into a granular mosaic. It contains a considerable number of gas-liquid inclusions in planes and strings through the quartz. The garnet is light pink in colour and is perfectly isotropic. It is probably almandine. It is somewhat altered along cracks and around the edges to green chloritic mica.

The rock is a *gneissic garnet pegmatite.*

(2) Miscellaneous Rocks.

No. 586 is a lit-par-lit gneiss in which a granitic or pegmatitic liquid has interleaved and all but assimilated a mica schist. The argillaceous portion is now represented by narrow bands of biotite separating the different "lit" of igneous material. These "lit" are about 2 to 5 mm. across with an occasional band 10 mm. or more across. Crystals of garnet are not uncommon and occasional larger crystals break across the banding.

The grain-size is very irregular. In the granitic bands the grains lie between 0·6 and 1·0 mm. The wider bands of argillaceous material are marked by the finer crystallisation of the quartz and felspar (about 0·4 mm.) and by flakes of brown biotite. The structure of the granitic bands is allotriomorphic granular and that of the argillaceous bands differs only in the parallel arrangement of the biotite crystals.

The quartz is abundant. It has undulose extinction and contains many strings of gas-liquid inclusions. The more common felspar is perthitic microcline. The albite forms small parallel streaks and is not at all closely spaced. Plagioclase is much less abundant than the microcline and has a composition of $Ab_{80}An_{20}$. In places there is myrmekitic intergrowth between the two felspars. Biotite is reddish brown with X = light straw yellow, $Y = Z$ = reddish brown. It contains pleochroic haloes around inclusions of zircon and xenotime. There is a small amount of muscovite also present. Garnet forms round pink grains and contains very few inclusions. The accessories are zircon, apatite, magnetite and xenotime. The apatite forms small hexagonal and elongated grains. Zircon is in small elongated grains with a high relief. Xenotime has a relief noticeable lower then the zircon and occurs in larger grains.

The minerals in order of abundance are orthoclase, quartz, plagioclase, biotite, garnet, muscovite, apatite, xenotime, magnetite and zircon.

The rock is a *lit-par-lit garnetiferous felspar gneiss.*

No. 943 is unusual in that in addition to biotite it contains an orthorhombic pyroxene. It is a dark coloured rock of rather fine grain and appears to consist essentially of garnet, biotite, quartz and felspar. The quartz and felspar are subordinate and are rather obscured by the darker constituents of the rock. The pyroxene is not distinguishable in the hand specimen.

In thin section the gneissic properties are made more apparent. The rock is fine to medium in grain-size without any distinct foliation. It consists of garnet, biotite, hypersthene, quartz and a very basic plagioclase. This assemblage is remarkable in that it corresponds to no common rock either igneous or sedimentary.

The plagioclase is perfectly fresh and unweathered. The maximum extinction in the symmetrical zone is 50° which corresponds to a composition of $Ab_{20}An_{80}$*. This basic composition is reflected in relief so high as to attract notice. It is twinned on the albite and less commonly on the pericline laws.

The biotite is brown, X = light golden yellow, Y = Z = very dark brown, and is the type normal to the higher grades of metamorphism. It contains a few inclusions of zircon with the usual pleochroic haloes. It shows no signs of any alteration either of a retrograde or a progressive nature.

The pyroxene although not so abundant as the biotite is the most notable mineral in the rock. It is pleochroic from light pink (X′) to light green (Z′). The birefringence is moderate 0·014 and corresponds to hypersthene with about 35% of the iron molecule. It forms large crystals associated with the biotite but shows no reaction relation with it.

Garnet is rather abundant in this slide and is segregated into areas in which it makes up about 60% of the rock. Associated with it is quartz and a small amount of biotite. It is difficult to decide whether the garnet is in the form of big poeciloblastic crystals or whether it is merely an aggregate of many smaller crystals which have grown together. In addition to these enclosed crystals of quartz and biotite the garnet grains include small grains of magnetite. It is noticeable that the garnet aggregates contain no felspar whereas the rest of the rock contains about 40% felspar.

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*In this determination and all others in this work the curves for extinction angles in felspars constructed by Chudoba (1933) have been used. They differ from those previously published in the standard text books.

In parts of the rock where there is no garnet the structure is that of a normal gneiss. The biotite and the hypersthene are intergrown but there is no suggestion that one is derived from the other. The biotite is constantly idioblastic against the hypersthene and it is probable that the hypersthene is merely an expression of the peculiar composition of the rock. In the presence of hypersthene this rock shows a point of similarity with some rocks from the area embracing Aurora Peak and Stillwell Island. For these rocks Stillwell (1918, p. 158) suggests a reaction between a calcic garnet and orthoclase to produce biotite and anorthite. Substituting a less calcic garnet in Stillwell's equation would produce hypersthene in place of some of the anorthite. By some such reaction as this it is possible to explain both the hypersthene and the calcic plagioclase. The areas of garnet left in the rock represent areas in which there was no orthoclase to react with the garnet. For rocks of a similar mineralogical composition from Cape Gray area Stillwell suggests a sedimentary origin and it is probable that this rock too is a metamorphosed sediment.

The rock is a *garnet hypersthene biotite plagioclase gneiss*.

No. 725 is a rock of very striking appearance. It is composed almost entirely of dead white microcline and bluish grey scapolite, the latter in crystals 1 to 2 centimetres across and 5 or 6 centimetres in length. The scapolite is in the forms of prismatic crystals which have many fine striations parallel to the " c " axis.

In thin section the microcline is seen to be in large crystals and one such crystal fills half of the slide. It has a well developed cross-hatching, remarkable both for the fineness of the twinning and its regularity. It contains a number of inclusions which under high power are seen to be liquid. It is slightly weathered.

The scapolite is clear and colourless and has but an imperfect cleavage. It is uniaxial and negative and has $N_e = 1{\cdot}548$, $N_o = 1{\cdot}573$. These properties correspond to scapolite of the composition $Ma_{50}Me_{50}$. It forms big crystals but in places what appears in hand specimen to be one large crystal is seen in thin section to be broken up into separate parts with areas of crushed material between.

The only other minerals present are muscovite, biotite and calcite, none of which exceed a few fractions of a per cent in quantity. The biotite is light brown in colour and is not highly pleochroic. Muscovite is only developed in one place where it fills a small vein in the scapolite.

The rock has been crushed and in places brecciated by late or post-metamorphic movements. One section of the rock shows little or no brecciation and is composed almost entirely of two single crystals of microcline and scapolite. Another section, however, shows that what appears to be one crystal of scapolite in the hand specimen is broken up by cracks and crush areas into grains 1 to 10 mm. across. In between the separate grains is crushed and recrystallised scapolite.

There is no hint in the structure of the rock as to its origin or to the processes involved in its present mineral composition, and, in the absence of field evidence, it is impossible even to guess at its probable mode of origin.

The rock is a *scapolite microcline gneiss*.

No. 360 is composed of alternating bands of black and red ferruginous quartz. There are no minerals visible to the naked eye. Under the microscope the red bands are seen to consist of a granular mosaic of quartz and haematite. The average size of the quartz grains is about 0·02 mm. and of the haematite about 0·005 mm. The quartz is clear and free from all inclusions except grains of haematite. The haematite is opaque under normal conditions of lighting and can only be made feebly translucent by greatly increasing the illumination. It is light brick red in reflected light. The high power objective shows the haematite to be in small idioblastic crystals with glistening crystal faces. In the black bands the iron is in the form of magnetite and is more abundant than in the red bands. The magnetite grains have grown together and formed a mesh in which the quartz grains are enclosed. There is a little chlorite and calcite associated with the magnetite. There are running through the rock several fractured veins containing quartz, chlorite and calcite. They are obviously post-metamorphic in their origin. The chlorite is in radiating clumps and is apparently original.

The rock is a *jaspilite.*

No. 39 is a rock with a granitic composition but it has been so altered that it is impossible to decide what it was before metamorphism. It is a white rock consisting of quartz, felspar and a little hornblende. The felspar is in small grains and is dead white in colour. The quartz is vitreous and stands out as large grains or aggregates of grains.

The thin section shows a remarkable structure. The quartz is in aggregates which measure 3 to 4 mm. across and in which the component grains are 0·4 to 0·5 mm. in diameter. These are set in a matrix of granular quartz and felspar. Almost all of the felspar is in small grains which have a rude decussate structure and which have a grain-size of from 0·15 to 0·20 mm. This granular felspar is fresh and for the most part untwinned. A few grains are seen by their twinning to be plagioclase and the rest is assumed to be orthoclase. There are a few large crystals of plagioclase in the slide which measure 1 to 2 mm. across. These are all weathered and clouded by decomposition products, and the composition could not be determined. The composition of the granular unweathered plagioclase is $Ab_{90}An_{10}$. The quartz in the aggregates is in irregular grains which have sutured edges. It contains strings and planes of gas-liquid inclusions and some areas are particularly rich in them. The amphibole is green with X = light greenish yellow, Y = green, Z = greenish blue, $X < Y < Z$. The extinction angle $Z \wedge c = 24°$. It is in isolated crystals and groups of crystals. There is a little biotite now entirely changed to chlorite. From its reactions with the hornblende it appears to have been changing to hornblende.

The rock is of interest because of the presence of some thin veins containing prehnite. These veins are confined to a zone several millimetres wide and traversing the whole of one side of the specimen. In this zone there are five or six thin and inconstant veins which run together and open out again. They vary from 0·1 to 0·6 mm. wide and contain only prehnite. The prehnite is in small grains which grow out from the edge of the veins. The elongation parallel to the cleavage is negative ; the birefringence is about 0·027 and the refractive index is fairly high. It is biaxial negative with 2V between 55° and 60°. It differs from lawsonite in its higher birefringence and its smaller optic angle.

The minerals in order of abundance are quartz, orthoclase, plagioclase, hornblende, epidote, prehnite and magnetite.

The origin of the rock is obscure but it is not unlikely that it is a metamorphosed quartz porphyry. The quartz phenocrysts of the original rock have simply recrystallised to a granular mosaic while still preserving their original shape. The large weathered felspar crystals represent the original felspar phenocrysts. The stony ground-mass containing potential quartz and felspar has crystallised to a granular mass of crystals in which the grain-size although less than the quartz of the aggregates is still considerably greater than it would have had the rock devitrified without the metamorphism. However in the absence of field relations this is no more than a hypothesis which can neither be proved nor disproved. In composition and in external appearance it closely simulates a granite and it can be called a *granitoid gneiss*.

V. SUMMARY AND CONCLUSIONS.

The rocks described in the preceding pages comprise both ortho and para gneisses. There were prior to metamorphism two series, one sedimentary and the other igneous, and into these a later series of igneous rocks was intruded during the actual period of metamorphism. The whole complex has been subjected to regional metamorphism that has in places reached the intensity of the sillimanite grade. The relative abundance of these sillimanite rocks amongst the metamorphosed argillaceous rocks in the collections from the moraines may be due to some irregularity in the collecting but it is more likely that it is real and points to the existence of a considerable area of highly altered rocks. There are associated with these highly altered sedimentaries some granitic gneisses such as Nos. 899, 270 and 709, all of which contain secondary sillimanite developed in crushed areas in the rock. The majority of igneous rocks, however, have not been subjected to such a high grade of metamorphism and appear to have reached an intensity equal to that of the metamorphism at Aurora Peak. They have formed simple gneisses both by deformation of solid rocks and by the piezo-crystallisation of still fluid but highly viscous magmas. There is only one instance of the formation of a "lit-par-lit" gneiss in this acid group but there are several other examples amongst the basic igneous types (see Glastonbury, 1940 a). There is also evidence that in places there has been accompanying the metamorphism the introduction of more or less volatile particularly boron and water vapour. In the sedimentary rocks Nos. 256 and 162A the boron has been introduced with the water vapour and has permeated the whole rock but in the igneous rocks the vapours have risen up crush lines through the rock. In these latter types all gradations can be traced from a crushed granite containing a few crystals of tourmaline to a rock in which the felspar has practically all been replaced by tourmaline and quartz. There are no rocks in the collections that can be looked upon as the primary source of this tourmaline with the exception of a rather doubtful pegmatite. There are also in the series some crushed and mylonitised rocks and it is of interest to note that rocks of this nature have been observed *in situ* at Madigan Nunatak. While many of the partly crushed rocks have been raised to a high grade of metamorphism in which the effects of crushing have been blurred and in some instances obliterated by the recrystallisation proper to this advanced stage of metamorphism, those rocks which have been crushed to the extent of forming mylonites still retain relic structures that reveal that the felspar has not recrystallised and that the quartz although recrystallised is still of a very fine grain. Thus it seems to be that in the areas in which the cataclasis was most marked the grade of metamorphism was not high, and it is probable that the more perfectly crushed mylonites originated along lines of strong crushing and shearing. This correlation between mylonitisation and shearing has been observed and commented upon in the type areas (Lapworth, 1885; Quensel, 1915; Tyrrell, 1924).

In many of the rocks of this collection the biotite has been altered to chlorite and the felspar clouded by decomposition products by the action of either retrograde metamorphism or simple weathering. It is difficult in these erratic specimens to decide which of the two has been responsible for the alteration of any one particular specimen.

Several of the specimens (e.g. No. 813) have on one side of them a weathered zone up to several millimetres wide and in these cases it is obvious that simple weathering has been the cause. In others (Nos. 458, 391, 737, etc.), the alteration has been complete and it is not impossible that they have been affected by retrograde metamorphism. It is significant that the rocks that have been entirely altered in respect to the biotite are all fine grained and have never been raised to any high grade of metamorphism and it may be that they had been in a zone of country that had been more particularly affected by retrograde changes. It is most certainly retrograde metamorphism that has been responsible for the alteration of No. 711 and it is not unlikely that it has produced the alteration seen in other specimens. If as is suspected some of the partly altered rocks have been altered by weathering the problem next arises of how and when. That the weathering could have taken place since the rock was left on the moraine is ruled out for two reasons. Firstly the rock *in situ* is not weathered except by the mechanical agents of disintegration and then only to a slight extent, and secondly chunks of rock found on the moraine are smoothed by mechanical weathering on all faces but are seen to be chemically weathered on only one face. It is then manifest that the rock has been weathered *in situ* before it was plucked up by the ice. This is borne out by the fact that the rocks seen *in situ* at Madigan Nunatak, which show no signs of having been submerged by the ice and hence might well represent the original pre-glacial surface of the land, have been weathered to a considerable degree and to a depth of two or three centimetres. It is therefore certain that all of the altered specimens from the moraine have been altered *in situ*. It is also probable that some at least of the more thoroughly altered specimens have been altered by retrograde metamorphism and that the rest represent the original weathering of the pre-glacial land surface. There yet remains the possibility that the less altered rocks may have been altered at a distance below the surface of the ground by surface waters percolating down fissures and cracks.

Throughout this paper all measurements of grain-size represent average apparent grain-size as measured in thin section. This value is approximately half of the true grain-size of the rock. All mineral percentages are given in Volume Percentages. Where they have been tabulated they have been measured on a Leitz Integration Table : where they have been placed in the text they have been estimated by inspection.

The whole of this work has been done in the laboratories of the University of Adelaide and the writer is indebted to the University for the facilities of the laboratories and also for a grant that enabled him to carry on the work. He is also indebted to Sir Douglas Mawson for entrusting him with the work and for much helpful advice.

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VII. DESCRIPTION OF PLATES.

Plate IX.

Fig. 1. Garnetiferous Two-mica-Quartz-Schist, No. 53, showing the general appearance of the rock under the microscope. The poeciloblastic crystals of biotite are conspicuous. The perfect parallel arrangement of the micas which produces the cleavage of the rock can also be observed. × 33.

Fig. 2. Quartz-Felspar-Mica-Schist, No. 236. This figure shows the structure typical of the rock and of Nos. 161 and 238. The schistosity is not nearly so perfect as in No. 53. There can be observed a slight elongation of the quartz and felspar grains. × 33.

Fig. 3. Garnet-Biotite-Gneiss, No. 526A. This figure shows a quartz grain that has been bent into an S-shape by the deformation of the rock. Under crossed nicols the grain could be seen to have recrystallised into a mosaic of equidimensional grains. There are large biotite flakes cushioned by the mass of shredded flakes. × 27.

Fig. 4. The same rock as in fig. 3 but showing portions of two large unbroken garnet crystals which contain large included flakes of biotite. There are numerous pleochroic haloes in the biotite. The biotite not included in the garnet has been shredded between the garnet crystals. × 27.

Plate X.

Fig. 1. Sillimanite-Quartz-Biotite-Gneiss, No. 238. Biotite is breaking down to form sillimanite. The area here figured is one of the few isolated areas in the rock and shows the first stage in the breaking down of the mica. × 80.

Fig. 2. Sillimanite-Quartz-Mica-Gneiss, No. 521. In this rock the sillimanite is aggregated into knots which contain quartz and very little mica. The figure shows such a knot. × 80.

Fig. 3. Sillimanite-Quartz-Biotite-Gneiss, No. 1233, showing the coarser development of the sillimanite and its characteristicly shaped cross sections. The magnetite is derived from the breaking down of the biotite. × 80.

Fig. 4. Zoisite-Biotite-Amphibole-Schist, No. 1211. A portion of a "feather" crystal of amphibole in the fine grained groundmass of the rock. All of the pieces of amphibole seen in the figure are in optical continuity and there is no doubt that they are all parts of the same crystal although the connecting pieces are not in the plane of the slide. × 33.

Plate XI.

Fig. 1. Epidote-Biotite-Schist, No. 1257. The banding of the epidote is due to differences in composition of the laminae of the sediment and can be seen parallel to the length of the figure. The parallel growth of the biotite was controlled by the direction of pressure during metamorphism and makes an angle of 70° with the composition banding of the epidote. × 80.

Fig. 2. Metamorphosed Garnet Sandstone, No. 1255, showing the abundance of small garnets and their arrangement in certain bands. The foliation of the biotite is roughly parallel to this sedimentary banding. The felspar is cloudy due to incipient alteration. × 33.

Fig. 3. Mylonite, No. 199, showing an area in which the crushing has not been as intense as in the rest of the rock. Some of the felspar crystals have been preserved as augen but the quartz has all been recrystallised. The dark areas are dark (under crossed nicols) because of this slide (0·02 mm. thick) there are so many grains of quartz or felspar one above the other that the light is entirely cut out. × 38, crossed nicols.

Fig. 4. The same rock as fig. 3 but showing a portion in which the mylonitisation has been more perfect. A few felspar augen are still preserved but most of the rock has been rolled out. The dark bands are all composed of very finely crushed quartz and felspar. × 38, crossed nicols.

Plate XII.

Fig. 1. Contact of Pyroxene vein with Granite Gneiss, No. 336. The pyroxene can be seen at the bottom of the picture and between it and the unaltered rock above is the zone of amphibole. Almost in the middle of the figure are two allanite crystals which have induced pleochroic haloes in the amphibole and just above it is a crystal of sphene. The colourless minerals are felspar and quartz, the former distinguished by slight cloudiness due to alteration. × 35.

Fig. 2. Same rock as in fig. 1 but showing the zone of altered felspar adjacent to the vein. The degree of alteration increases as the vein is approached. Sphene is abundant in this contact zone. × 35.

Fig. 3. Tourmalinised-Sillimanite-Granite-Gneiss, No. 899, showing portion of a large crystal of perthite. The host is microcline and is dark in this picture. The albite is in flat lenticles arranged parallel to the trace of the microcline twinning. The proportion of albite to microcline increases from top to bottom of the picture. × 44, crossed nicols.

Fig. 4. Tourmalinised-Garnetiferous-Granite-Gneiss, No. 15, showing antiperthite. The microcline is scattered through the albite host as irregular blebs with a common orientation. There is one grain of quartz in the picture. × 44, crossed nicols.

PLATE XIII.

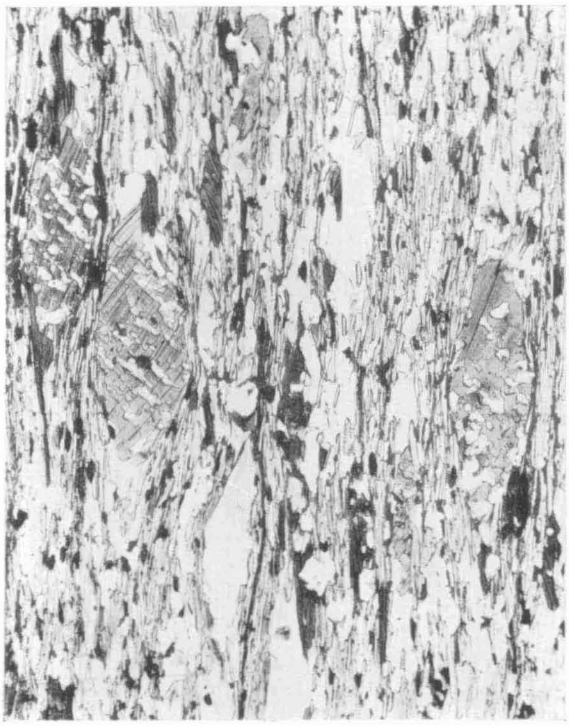
Fig. 1. Tourmalinised-Granite-Gneiss, No. 1209. This picture shows the crushing of the rock and the manner in which the tourmaline has developed in the crush areas. The tourmaline is the dark crystal at the top of the picture and to the left is the quartz formed as a by-product of the reaction between the microcline and the boron vapours. Below is part of an uncrushed crystal of microperthite. × 27, crossed nicols.

Fig. 2. Luxullianite, No. 708. In this rock the felspar has all been destroyed except a few crystals such as the one in the centre of the picture between the two tourmaline grains. The quartz has a saccharoidal structure. × 27, crossed nicols.

Fig. 3. Sillimanite-bearing-Garnet-Biotite-Gneiss, No. 441A. Pleochroic haloes surrounding zircon inclusions in biotite. The largest halo is about 0·14 mm. across. × 125.

Fig. 4. Garnet-Microcline-Gneiss, No. 711. The photograph shows the garnet which is in large crystals and is altered to green biotite along a series of parallel cracks. × 27.

Sydney: Thomas Henry Tennant, Government Printer—1940.



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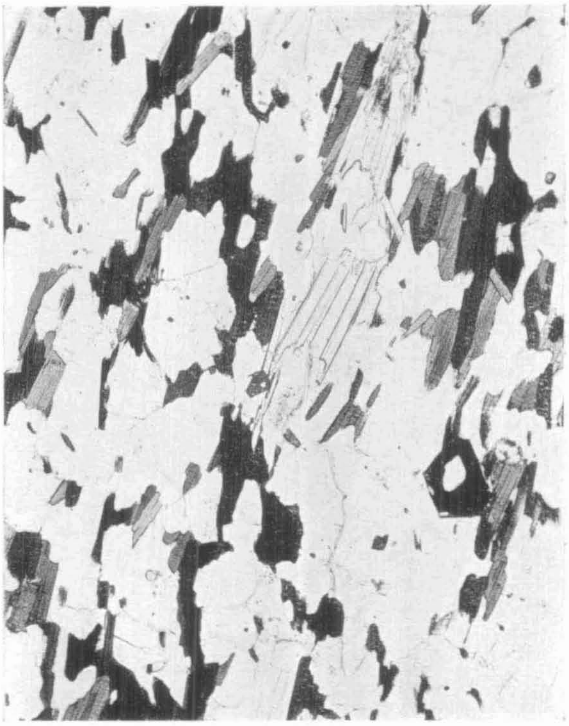

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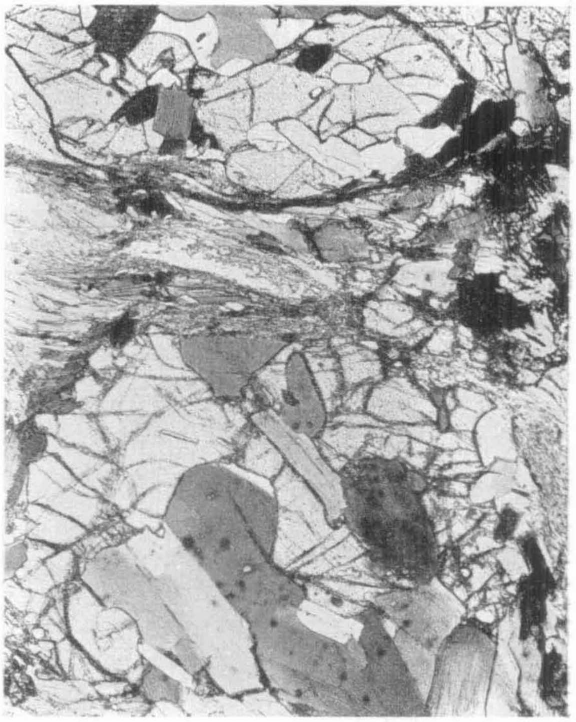

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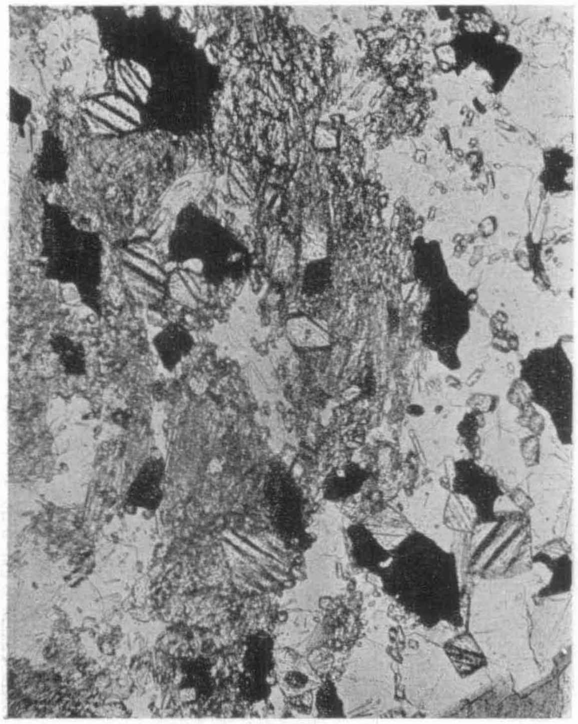

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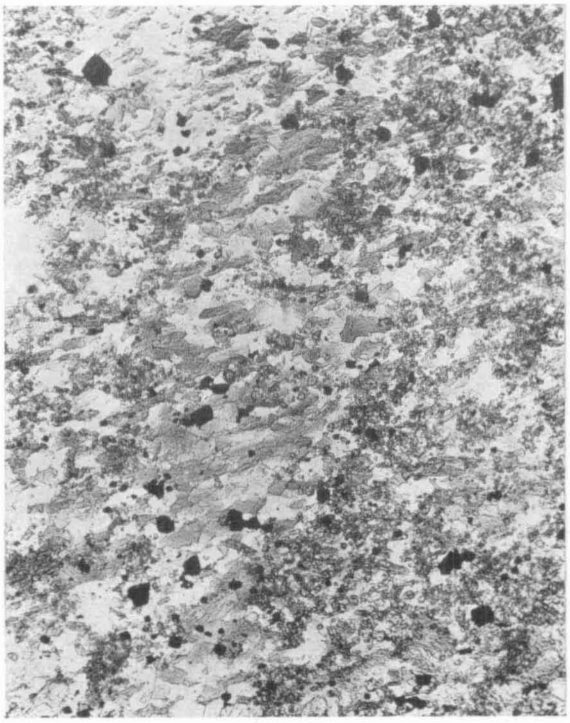

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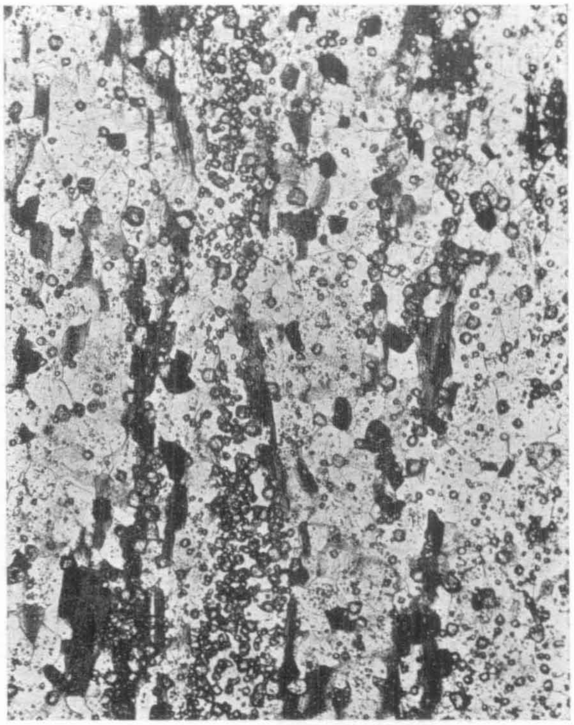

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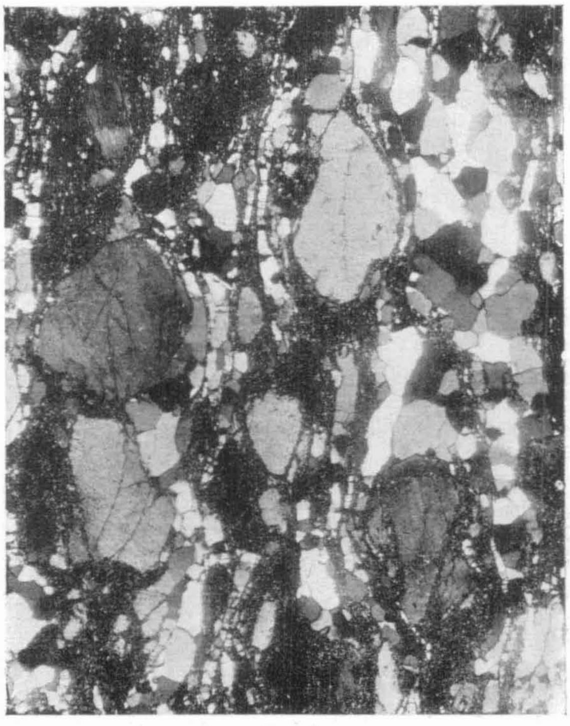

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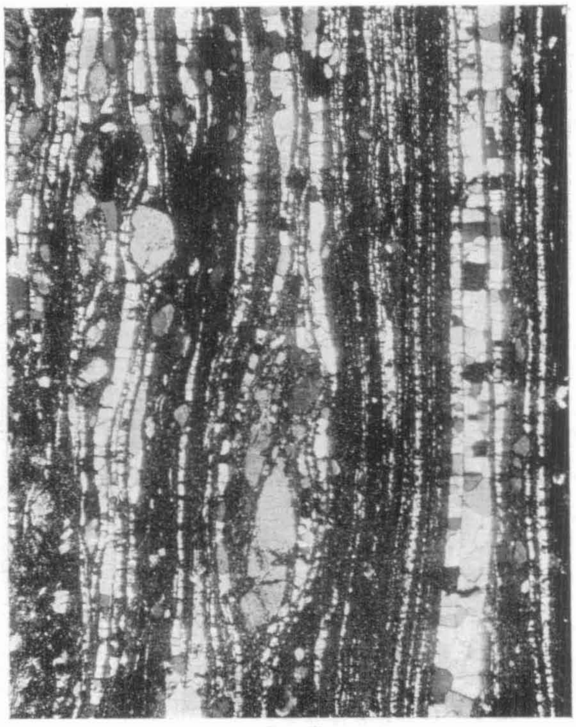

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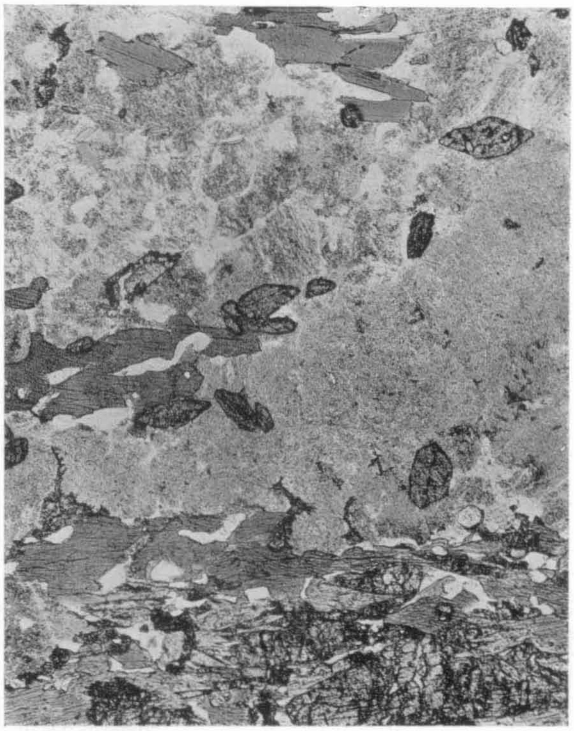

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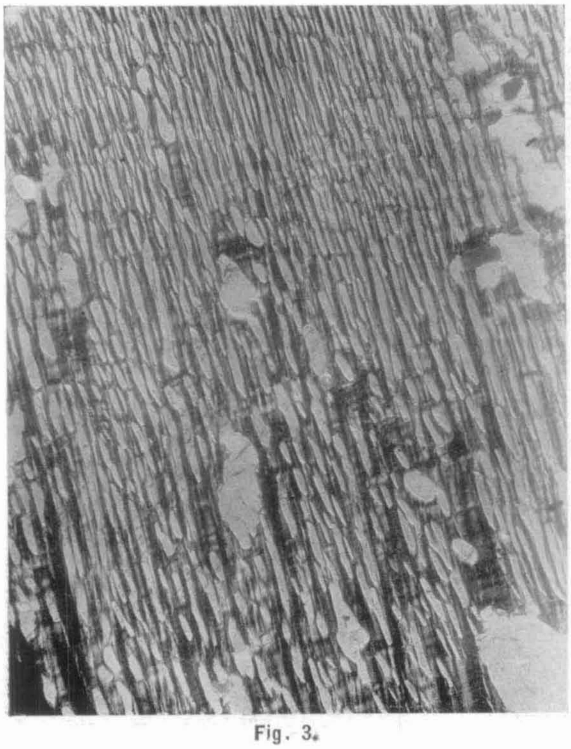

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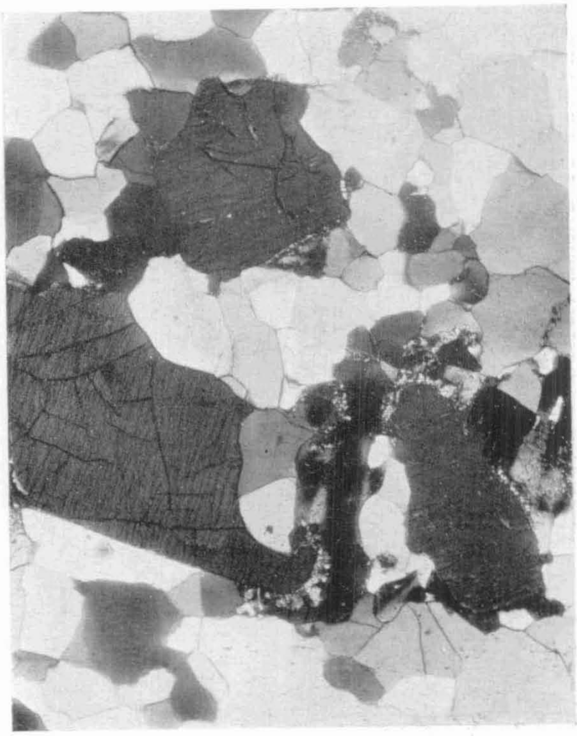

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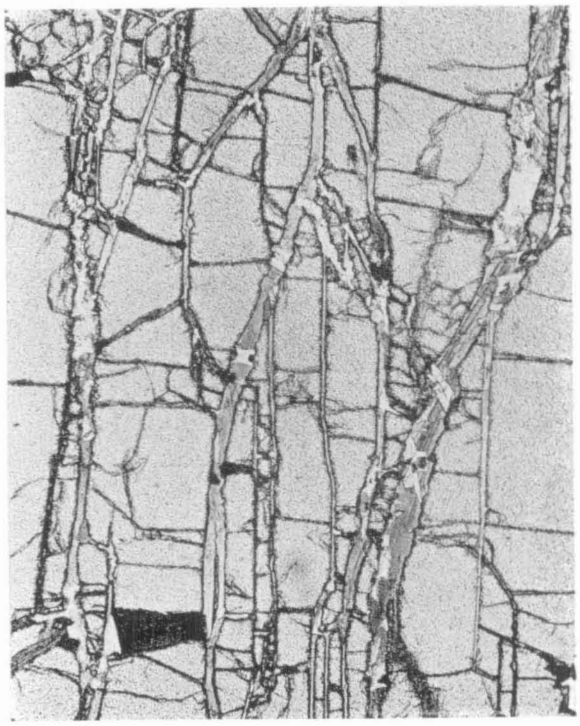

Fig. 4.

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