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1911-14
UNDER THE LEADERSHIP OF SIR DOUGLAS MAWSON, D.Sc., F.R.S.

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SERIES A.
VOL. III.

GEOLOGY.

PART VI.

PETROLOGICAL NOTES
ON
FURTHER ROCK SPECIMENS
COLLECTED FROM *IN SITU* OCCURRENCES
COMMONWEALTH BAY REGION.

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

WITH TWO PLATES.

PRICE: THREE SHILLINGS AND SIXPENCE.

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WITH TWO PLATES.

I. NOTES ON FURTHER* SPECIMENS FROM THE METAMORPHOSED DYKE SERIES OF CAPE DENISON.

1. Introduction.

" One band of amphibolite, outcropping near the centre of the Cape Denison area, is phenomenal in containing a large number of xenoliths. There are two distinct types of material among these meta-xenoliths, and they may be distinguished as—

(1) Saussuritic type;

(2) Gneissic type.

The saussuritic type includes pale green and pale pink masses which may be again subdivided into—

(*a*) Those composed wholly of saussurite—the individual type.

(*b*) Those composed of an aggregate of saussurite and hornblende—the composite type." (Stillwell: Series A, Vol. III, Pt. 1, p. 48.)

This statement of Stillwell's is given because the rocks to be discussed here (Nos. 142, 421, 432, 632, 633, 635A, 666 and 1240) are all members of the dark amphibolitic series found *in situ* at Cape Denison.

No. 421 is the coarsest of the set. As seen in the hand specimen it consists of handsome blades of black hornblende set in a base of coarsely crystalline opaque felspar. Its structure is gneissic.

Nos. 432, 666 and 1240 are examples of the amphibolite xenoliths containing porphyritic saussurite individuals. They are of " The individual type of meta-xenolith " variety according to Stillwell's classification.

No. 142 is another of the individual type of meta-xenolith, but owing to the few phenocrysts of saussurite and the definite schistosity it has taken up it seemed well to give it a further description.

*Dr. Stillwell's original report deals with outstanding examples of the dominant types of rocks met with *in situ*. Rocks described in this contribution are, in the main, closely similar to examples selected and described by Stillwell. The present descriptions are supplied in order to render more complete the microscopical examination of the whole of the rock collection. D.M.

Nos. 632, 633 and 635A are specimens of amphibolites from the metamorphosed dyke series of Cape Denison. These specimens are like Nos. 634, 634A and 635 described by Stillwell in this connection. They have developed schistosity to a considerable degree by a parallel arrangement of hornblende prisms. Both Nos. 632 and 633 are markedly fissile because of the perfection of this parallelism.

2. Mineralogical Characters of the Individual Xenoliths.

Under the microscope Nos. 142, 421, and 431 fall into one mineralogical division and Nos. 666 and 1240 in another. The differences are not so much in actual mineral content as in the nature of the crystal development. In the first three of these rocks the felspar, not only in the phenocrysts themselves, but throughout the whole rock-mass is turbid and highly saussuritised. The amphibole present is pale green in colour and is definitely actinolitic in character. The crystals are elongated but small. They have not the massive, compact appearance of typical hornblende. Their colour, as a matter of fact, tends to blue, suggesting that the glaucophane molecule has been concentrated in them to some extent. No. 666 serves as a transition stage. It is marked by the plagioclase intermingled with the amphibole crystals, as distinct from that in the saussurite phenocrysts, being pellucid. This shows that the felspar of these regions has completely recrystallised and either assumed again the matter rejected during saussuritisation or expelled it by diffusion to be taken up in the composition of the hornblende. The amphibole in this rock is not so actinolitic as in the first three, but it is by no means so compact and green as in rock No. 1240.

In this rock, No. 1240, the chief difference from the others mentioned above, is the intense green and brownish green colour of the amphibole, which now is quite definitely hornblende. Another striking difference is the almost entire absence of saussurite which is present in the nuclei of two large phenocrysts only.

Other mineralogical points of interest are first, the relationship of sphene and nuclear ilmenite. The development of this is shown quite well in these rocks. In No. 142 the border of the sphene is quite narrow, sometimes less than 0·005 mm., while in the other rocks there is a range of 0·05 mm., and perhaps even more. Secondly, a genetical relationship between the three minerals ilmenite, sphene and zoisite (or clino-zoisite, or epidote as the case may be) and felspar is shown by a similar serial arrangement.

Other reactions which involve sphene are best seen in Nos. 142 and 421. In these rocks a more fibrous biotite than usual, whose pleochroism is from Z a weak brown to X practically colourless, is found associated with grains of sphene, hornblende and nearly colourless chlorite (Plate XLV, fig. 1). The chlorite is derived from the biotite, its development being a possible explanation of the bleaching of the colour of the mica. The sphene seems to be forming chiefly at the expense of the hornblende which, as a result, is poikiloblastic in texture and studded with small inclusions of the sphene. But a similar relation exists, to a more limited extent, between the biotite and sphene.

This is more particularly noticeable where biotite and hornblende crystals interlock, that is, where it is more definite that the two minerals were formed by the same general alteration of the augite of the dolerite rocks. Epidote, too, is associated with this brown biotite, but is a rim-growth rather than an inclusion.

The minerals epidote, zoisite, clino-zoisite are usually found with white mica in the saussurite matrix. The lawsonite, however, is not so restricted as the others; it occurs (in addition to the above manner) as veins which penetrate the amphibole masses and in localised patches in the neighbourhood of the amphibole. Frequently zoisite is found as irregular scales which thread through the saussurite. Under crossed-nicols it is seen to form an ultra-blue background in which the other alteration minerals and relic felspar occur.

In Nos. 666 and 1240, there is practically no sphene, and no biotite or chlorite. This shows that when the more complex amphiboles are produced in the higher stages of metamorphism they have absorbed into their composition much of the matter of both sphene and biotite. The disappearance of white mica, epidote and zoisite, and the recrystallisation of the felspar in a more acidic form emphasise the increased complexity of the new amphibole molecule; and this variation in chemical content is reflected in the different appearance of the mineral.

3. Genesis of the Xenoliths.

This has been discussed by Stillwell on pp. 53–54 of his work. He immediately (pp. 54–5) proceeds adequately to discuss the significance of the meta-xenoliths. In view of this, nothing further will be given here on these matters.

4. The Amphibolites of the Metamorphosed Dyke Series.

This account is concerned with the mineral composition and the microscopical characters of the amphibolite rocks Nos. 632, 633 and 635A.

No. 632 differs from No. 633 under the microscope. Although it shows some tendency to linearity of amphibole crystal arrangement, yet, on the whole, it is advisable to call its texture granoblastic. In No. 633, however, there is a marked schistosity produced by the parallel orientation of its amphibole crystals. This schistosity is accentuated by the elongation of the crystal prisms whose average elongation factor (length : width) is about 3; this is exceeded somewhat in regions where smaller crystals are interwoven with felspar; it is fallen short of in the more massive parts of the rock. Again, in No. 632, there is a fairly even distribution of parts exclusively amphibolic and parts essentially composed of both amphibole and felspar. No. 633, on the other hand, has these mineral groups arranged in parallel alignment, producing a completely different aspect.

The minerals present in these two rocks are much alike. The dominant one is a pale blue-green actinolite. This is sometimes concentrated in zones free from other minerals, and sometimes associated with highly saussuritised felspar. The saussuritic mass contains epidote, zoisite and clino-zoisite. No. 632 contains an occasional lath of biotite, but this mica, as an unusually pale variety, is one of the determinative minerals of the finer-grained regions of No. 633. Each rock contains some granules of sphene, rare grains of ilmenite and crystals of apatite.

No. 635A is a rock in which the simpler pale-green actinolite has been recrystallised into more complex green amphibole. This recrystallisation of amphibole has been accompanied (or preceeded) by a recrystallisation of felspar. The hornblende crystals are small, but no longer exclusively elongated, as a matter of fact they are usually equi-dimensional. They do not exhibit such marked parallelism as do the crystals of amphibole in No. 633. Sphene has practically disappeared, the biotite has a much stronger reddish brown colour. These facts, together with the deeper green colour of the amphibole, again emphasise the way in which the amphibole (and the mica too) gain complexity in the higher grades of metamorphism by the absorption of the "rejection products" of saussuritisation and of minerals like sphene. Lawsonite and the suite of epidote minerals are practically absent.

The recrystallisation of the felspar has resulted in the formation of many grains of quartz. The new felspar is frequently twinned, both albite and pericline multiple twin lamellae being seen.

Some little iron ore (magnetite) and rods and needles of apatite are also present.

These three rock types can be summarised thus :—

No. 632—Chlorite-albite-epidote-amphibolite.

No. 633—Chlorite-albite-epidote-amphibolite-schist.

No. 635A—Amphibolite.

II. NOTES ON ADDITIONAL ROCK TYPES FROM STILLWELL ISLAND.

1. Introduction.

A discussion of some of the rock types found at Stillwell Island has already been given in these Scientific Reports (Stillwell, Vol. III, Pt. 1). A brief résumé of some of the points made there is necessary for an understanding of the sequel.

"Stillwell Island is one of the largest members of the Way Archipelago.

The most conspicuous rock is a massive granitoid gneiss, often carrying abundant dark aggregates of garnet and mica. Varieties of gneiss are also found without any garnet at all, and the higher part of the island is formed of an acid hypersthene gneiss.

In crossing the islet areas are found consisting of more strongly foliated gneisses, and the trend of the foliation is a little west and north. Irregular bands of black gneiss, with dyke form, exist here as at Cape Denison, and some are full of fine garnet." (pp. 145–6.)

Mention is then made of—

(*a*) Garnet gneisses (No. 917), p. 151;

(*b*) Acid hypersthene gneisses (Nos. 979, 947), p. 155;

(*c*) Metamorphosed basic dyke series (Nos. 951, 942, 935, 953, 952), p. 171.

The present contribution is devoted to a further description of these groups with mention of specimens not dealt with by Dr. Stillwell, but which show variations from the main types and important differences in detail.

The specimens dealt with are Nos. 59, 699, 972, 973, 974, 976, 977, 978, 980.

It is found that Nos. 699 and 980 fall in Group (*a*), the Garnet Gneisses, and Nos. 591, 972, 973, 974, 976, 977 and 978 are all members of the metamorphosed basic dyke series, Group (*c*).

2. Petrography.

(a) *The Garnet Gneisses.*

As mentioned above the additional members to this group of gneisses which occur both at Cape Pigeon Rocks and Stillwell Island are Nos. 699 and 980.

No. 699. Garnet-Felspar-Quartz-Gneiss.

This rock consists of alternate bands of biotite and quartz-felspar matter. Through the rock, but concentrated to a greater extent in the vicinity of the biotite, are clusters of deep red garnet crystals, some of which assume a high degree of crystalline form.

In some respects this rock resembles Nos. 777 and 917 described by Stillwell. The former was collected at Garnet Point and the latter at Stillwell Island. There are large porphyroblasts of garnet, and although they are to some extent penetrated by biotite, they are not skeletal like those of No. 777. The mica developed is of two kinds. One is biotite which is found as a greenish-yellow fibrous mass forming an aureole around the garnet, and as more compact masses pleochroic in dark and light browns. The other mica is sericite which has developed during the alteration of potassic felspar.

The areas not so immediately associated with the garnet consist of quartz, plagioclase, orthoclase, microcline, microcline-microperthite, sericite, calcite and accessory apatite.

The quartz is frequently undulose and contains inclusions of fluorite arranged in long parallel lines. The fact that the fluorite shows abnormal birefringence is evidence that the mineral has suffered internal tension. The quartz and orthoclase frequently occur in a myrmekitic intergrowth; other varieties of intergrowth occur, of which the commonest consists of blebs of quartz included in areas of orthoclase. The felspar, when plagioclase, is very highly saussuritised. Some lamellar twin forms, both albite and pericline, are present. The orthoclase and microcline are, in part at least, developments due to the concentration of the potassium from earlier plagioclase which must have been highly potassic. A further development has been the production of considerable sericite which is almost invariably associated with secondary calcite, the mineral which has been formed by the contemporaneous concentration of the lime molecule of the original felspar. The existence of quartz and calcite together is evidence of the dynamothermal metamorphism to which the rock has been subjected.

Zircon occurs as nuclei of intense pleochroic haloes in the biotite and also as isolated fragments in the orthoclase. Its brown colour is suggestive of monazite, but its positive uniaxial nature differentiates it from that mineral.

The structures developed are porphyroblastic, shown by the garnet, granoblastic shown by almost the whole of the remainder of the rock, and granulitic shown by the calcite.

No. 59. Garnet-Plagioclase-Pyroxene-Hornblende Gneiss.

A note with this specimen made at the time of collection (by Dr. Mawson) records that it forms a broad band about 20 feet wide with ill-defined borders where the boat was kellicked when a landing was made upon the island.

The rock itself is gneissic. It is composed of black pyroxene and amphibole crystals set in a mesh-work structure of brown matter, whose content is made up of pink garnet, felspar and a very little quartz.

The mineral content of the rock is pyroxene, hornblende, biotite, ilmenite, garnet, andesine, quartz and pyrites.

The pyroxene is non-pleochroic. It always shows some indication of alteration. There is exhibited a serial change in different parts of the rock. The simplest is the separation of ilmenite as fine dust particles which make the mineral very dark and patchy. There is usually, but not always, an accompanying development of green hornblende; particularly is this true in the peripheral areas where a border of hornblende round the pyroxene is quite common. This last development sometimes occurs with grains of quartz (or very acid felspar), thus showing that these two constituents have been formed contemporaneously by the mineralogical alteration of the pyroxene.

The rest of the mineralogical changes are of interest for they show the progressive stages in the formation of garnet by the interaction of felspar and hornblende—as a variation there is also seen the formation of garnet from the reaction between biotite and felspar. The usual arrangement of these minerals consists of a central core of skeletal ilmenite interwoven with brown biotite which gives way to a surrounding zone of hornblende—the ilmenitiferous content is much lower—and the hornblende, in turn, frequently terminates in phalanges which project into reaction areas of highly acidic felspar or quartz. These reaction areas are usually found as inner zones next to the zone of garnet. They show how the amphibole and the original basic felspar combine to form the garnet and to give rise to a separation of quartz. That this separation of quartz is an intermediate stage of the metamorphism and not the final one, is made evident where garnet and the green hornblende abut without an accompanying acidic reaction zone. The acidic material set free in the earlier reaction has been taken up completely in the final one and hornblende and garnet are, in consequence, in intimate juxtaposition.

Exactly similar relationships are seen to hold wherever the biotite region has been able to react with the original felspar. There are places where phalanges of biotite mingle with clear siliceous matter (or highly siliceous felspar), and there are other places where the biotite and garnet abut against one another. This is good evidence of the complementary nature of the biotite and the hornblende; the one being the more ilmenitic derivative of the original pyroxene and the other the component richer in iron and more especially magnesia. They show, too, how the original pyroxene has progressively altered, first, setting free a swarm of ilmenite grains; secondly, producing a granulitic pyroxenic aggregate; thirdly, the formation of green hornblende; fourthly, the subsidiary production of brown biotite by the concentration of ilmenite in the ferromagnesian, and lastly the reaction between the new ferromagnesian and the original basic felspar with the final production of a pink garnet but with the intermediate stage of silica liberation and later phase of absorption of this matter.

Some indication of the structure of the rock has been given by what has been said above. But the general arrangement of the mineral masses is that these more or less circular masses are set somewhat regularly in a felspathic base. In places two or more ferromagnesian alteration zones have coalesced and then the same internal structures are seen to be preserved but there is now no separation region of felspar. The circular nature of the pyroxene and its derivative minerals sometimes gives place to an elongated formation—probably due to the effects of non-hydrostatic stresses—where the length and breadth of the masses are roughly in the ratio 2 : 1. Where the pyroxene is not much altered the average grain-size is about 0·55 mm. This size is preserved remarkably consistently throughout all the metamorphic stages, and finally there has been produced a core of ilmenite, biotite, and hornblende about 0·5 mm. across with a surrounding aureole of garnet from 0·05 mm. to 0·10 mm. wide. The distance between the adjacent nuclei of these masses is about 0·8 mm., leaving an average space of 0·10 mm. to 0·15 mm. occupied by the felspar.

No. 980. A coarse Garnet-Plagioclase-Cordierite-Biotite Gneiss.

A coarse-grained garnetiferous rock was collected from the summit of Stillwell Island. The perfectly developed garnet crystals are set in a matrix of dense greyish felspar. A contact region is present in the specimen examined, where a considerable quantity of biotite comes into the rock and where the grain-size is much reduced.

Regional metamorphism has been the chief determinative factor in the constitution of this rock. The high temperature-pressure conditions which prevailed were followed by thermal metamorphism where pressure no longer was one of the dominant factors operating. This throws new light on the metamorphic transformations which have taken place in the rocks of the island.

The large garnet crystals which dominate the slide have been formed under the first set of conditions mentioned above; but the masses of strongly coloured brown biotite and little accompanying flaky chlorite scattered throughout their whole mass are more likely products of the second set of circumstances. As is true in the case of the red garnets of the Scottish Highlands (Harker, p. 324), so here the formation of biotite which has assumed a decussate arrangement in some places and rosette forms in others has from the garnet liberated ilmenite, which is seen in skeletal crystals, and some interstitial cordierite which, though clear, is usually intensely crushed. The cordierite is recognised by the presence of intensely pleochroic yellow haloes and its biaxial nature (2V large, approximately 80°). The alteration of the chemical nature of the minerals of the rock has proceeded, *pari passu*, with the disintegration of the crystal form. Smaller, more or less skeletal, masses of garnet are separated from one another by the products of alteration, ilmenite, cordierite and biotite.

The pleochroism of the biotite (apparently titania-rich) is intense, the colours being Z deep red-brown, and X very pale brown. The absorption as usual is $Z > X$. Other features of the biotite are the presence of numerous pleochroic haloes with zircon nuclei and the bent nature of the laminae. The bending shows that a shear stress has been operative to a perceptible degree.

In the coarser parts of the rock the acidic plagioclase present occurs in large grains which, however, have been considerably crushed, but more especially is this noticeable in the neighbourhood of the biotite and the garnet. The plagioclase is not so clear in this rock as in most rocks from this area, nevertheless it shows albite and pericline twins very well developed. Bends in the twin lamellae are further evidence that shear has occurred in the history of the rock. Quartz grains are associated with the plagioclase, particularly in the parts where granulitisation has been most intense.

In the finer parts of the rock practically no garnet is seen at all. In its stead is a granulitic aggregate of cordierite and clear acid felspar shot through with flakes of brown biotite and scales of very green chlorite. The disintegration which is noticeable in the very large garnet crystals of the coarser part of the rock has been able completely to change the nature of the smaller garnets and this mass of cordierite, acid plagioclase, biotite and chlorite, maintaining the position and size of the earlier garnet, is paramorphous after the garnet. The granular nature of the aggregates is realised more clearly under crossed nicols, for then the heterogeneously oriented granules of cordierite form a definite mosaic.

Except for an inevitable difference in size the plagioclase of the finer parts of the rock is much the same as that found in the coarser.

(b) The Acid Hypersthene Gneisses.

This division recorded by Stillwell is unrepresented among the present series of specimens.

(c) The Metamorphosed Dyke Series.

Sir Douglas Mawson recorded in his diary (p. 171 of present series), "irregular bands of black rock exist as at Cape Denison: some are not much altered, and others are full of fine garnet."

Dr. Stillwell then continues to note that some of the rocks exhibit "remarkable stages of incipient alteration." An alternative hypothesis seems to be suggested by the more recent work of Harker and Wiseman in connection with the so-called epidiorites of the Scottish Highlands: that these rocks are high grade metamorphic types, where hornblende is giving place to two pyroxenes, garnet is developing and granulitic texture is characteristic.

No. 972. Hornblende-Plagioclase-Pyroxene Gneiss.

This is a dense, fine-grained rock. Its apparent uniformity is resolved on close inspection into dark masses of relatively coarser material and dark spots whose grain-size is considerably smaller. An ill-defined band where biotite and quartz are megascopically visible also tends to relieve the uniform nature of the rock.

The biotite and hornblende are not without signs of alteration. The grains of these minerals are arranged in the typical decussate manner, but particularly in the case of the hornblende, instead of being compact they are definitely poikiloblastic due to a development of quartz. Associated with the biotite and hornblende, but more particularly with the biotite, are diablastic and myrmekitic intergrowths of quartz and orthoclase. The biotite prisms are still oriented in the manner referred to above, but owing to the nature of their development unchanged pyroxene granules remain as inclusions. The relationship between these intergrowths and the biotite (and hornblende) is revealed by the bays and bights in the ends of the prisms and frequently by their presence in the more crystalloblastically powerful sides of the prisms.

The granulitic areas are composed of small rounded grains of pyroxene set in a matrix of plagioclase, probably labradorite, which has been formed by recrystallisation.

An imperfectly formed vein of quartz traversing the rock suggests that there has been a possible acquisition from without of silica which may have been effective in supplying this material to the amphiboles which are usually below the meta-silicate stage in rocks of this kind.

The existence of considerable hydrostatic pressure is evidenced by the presence of garnet crystals, and, this pressure, no doubt, has played a considerable part in the recrystallisation of the pyroxene.

A thin vein of chlorite, and some flakes of calcite suggest that in the very late history of the rock it has been subjected to a very slight metamorphism of a retrograde nature.

The rock is a little higher grade than No. 974. The hornblende-biotite masses are more coherent, and the granules of pyroxene are much more numerously developed. The greater abundance of pink garnet and the presence of some sphene indicate the greater degree of metamorphism the rock has undergone.

No. 973. Plagioclase Amphibolite.

This is another of the amphibolites which were found in the dykes which cross the gneiss on Stillwell Island. It is a little more schistose than is usual with this suite of rocks, but preserves the main characteristics, medium-grain size, black, dense, and hard.

The rock differs completely from those described by Stillwell from this source, but is much like certain plagioclase amphibolites from the moraines at Cape Denison which have come under notice, described by the present writer.

The ferromagnesians present are almost entirely confined to green compact hornblende whose pleochroism is strong and which has been described before in the place referred to above. The grains are nearly equi-dimensional, they are arranged in the decussate manner, usually they show the two amphibole cleavages quite well but where prismatic sections are seen only one cleavage is, of course, to be perceived.

Some brown biotite, passing into chlorite is present. There is also some green somewhat fibrous biotite, but here the alteration to chlorite is not quite so strongly developed. The only other dark mineral component is magnetite which occurs in fairly well-formed crystals, but irregular outlines are presented by some grains where neighbouring particles have coalesced to make a larger individual. Occasional skeletal crystals of this mineral occur.

The felspar which is the mineral second in abundance is andesine with Ab_{65} An_{35}. It is quite clear and usually gives sharp extinction. There is no doubt of its secondary nature. Its pellucid nature and the absence of every trace of original structure are conclusive evidence of this. It exhibits both albite and pericline multiple twinning, the latter sometimes appearing in very delicately defined lines which are unusually well-developed. A little quartz is associated with the plagioclase, but its amount is remarkably small.

Apatite occurs quite freely in small well-shaped rectangles, hexagonal basal sections, and prism sections. It is also found in the felspar as acicular rods which suggest that they have been able to resist the changed conditions which have so considerably affected the rest of the rock.

The presence of some few scales of calcite afford evidence that dynamic effects have been more potent in the alteration of the rock than heat, though, of course, the part played by the latter factor has been by no means inconsiderable.

No. 974. Hornblende-Plagioclase-Pyroxene Gneiss.

This rock, like No. 942, which was described by Stillwell, occurs in dyke-like bands up to 10 feet wide crossing the garnet gneiss. The rock is dark, dense, and fine-grained, although the granular nature is differential, in that there are fine-grained portions surrounded by more coarsely crystalline rock. One face of the hand specimen shows a remarkable development of pale brass-yellow sulphide ore, probably pyrrhotite. Of the faces which were exposed to weathering, one has the typically indurated appearance common to the rocks of this area, and another has been coloured yellow by the formation of some limonite by oxidation and hydration.

The rock may have been formed in the manner Stillwell suggests for No. 942, but the presence of an occasional crystal of pink garnet shows that the metamorphism suffered by the rock has been a little more intense, or that there has been a slight variation in the composition of the rock.

The rock, like No. 972, contains some hypersthene as well as monoclinic pyroxene, calcite, well formed grains of magnetite and some crystals of apatite. An occasional pleochroic halo, with zircon as nucleus, is found in the biotite.

No. 977. Garnet-Plagioclase Amphibolite.

This is a moderately medium-grained, massive rock in which the most prominent minerals are red garnet and biotite. Hornblende is quite abundant and felspathic areas are readily observable.

The most striking feature of the rock is the presence of remarkable skeletal crystals of ilmenite whose peripheries are composed of many curved hooks or fingers which come from the main mass. Their relationships with the green hornblende of the rock is made manifest by the reaction zones which exist between the two. These reaction zones consist of a dactylitic intergrowth of felspar and pyroxene—called diablastic by Stillwell, but the term used here is preferable as it emphasises the finger-like nature of the components which enter into the intergrowth. The ilmenite is the nuclear region where concentration of iron (and titanium) from the hornblende is occurring: the dactylitic region shows where the actual diffusion of matter can be regarded as occurring. The source and the goal of the transfer are at once made evident.

Occasionally crystals of garnet are set in a rim of clear felspar which separates it from hornblende. In the felspar are to be seen very minute, but well shaped, rectangles of pale green amphibole which seem, in part, at least, to play a similar part to the pyroxene fingers in the transfer of material mentioned in the previous paragraph. These rims of felspar, with hornblende and sometimes biotite, are the reaction zones between the hornblende and the garnet nucleus. The possibility of felspar being potential hornblende to some degree at least is thus emphasised, and an indication is given that the relationship is reversible under suitable conditions.

Such masses of ilmenite, as previously referred to, are as frequently found associated with garnet as they are with hornblende. The fingers of the dactylitic intergrowth are still alternate bands of felspar and green pyroxene, but this time there is evidence that the pyroxene is a diffusion path of titanium as well as lime. It is quite usual to have the following serial relationships, hornblende connected to ilmenite nucleus by dactylitic felspar and pyroxene in a narrow rim, and then, the ilmenite nucleus connected to the garnet crystal by another such dactylitic rim, but this time, wider.

The garnet crystals have not assumed their perfect crystal outline, an indication that they are still undergoing the process of formation. They are remarkably embayed, and contain a large number of inclusions which include quartz, ilmenite, hornblende and biotite which produce the unusual effect of poikiloblastic garnets.

The other main minerals developed are hornblende, biotite, andesine and quartz. Accessory minerals include sphene, zircon in minute crystals, and apatite.

Rock No. 976 is merely a duplicate of this (No. 977).

No. 978. Garnet-Plagioclase-Amphibolite.

This rock, which was collected near the boat moorings, looks very much like No. 977, except that together with an increased micaceous content there has developed a more pronounced schistosity. This feature, however, has not been developed to such a degree as would warrant calling the rock a schist—it is still a gneiss. Another factor which favours a reduction in the gneissic nature of the rock is the smaller amount of garnet present, but, even so, garnet is still one of the most important minerals in the rock. Other minerals which can be recognised by the naked eye are hornblende and felspar.

Weathering has converted the biotite of the superficial layers into a golden coloured mica and has set free considerable quantities of oxidised iron compounds with the result that the exposed surfaces have assumed a deep yellow-brown colour.

The microscopic examination confirms the conclusions formed from the study of the hand specimen. Except for a slight increase in the amount of biotite present the rock differs in no material respect from No. 977. There is the same green, compact hornblende, garnet, ilmenite and hornblende in the same relations as before, and leucocratic areas of quartz and plagioclase.

III. ADDITIONAL PETROGRAPHIC NOTES ON ROCKS FROM MADIGAN NUNATAK.

1. Introduction.

A brief summary of Stillwell's description of the locality and the kinds of rocks found on the Nunatak is necessary.

He says (p. 128), "the Madigan Nunatak is situated in Lat. 67° 8½′ and Long. 143° 20′, about 30 miles distant from Cape Denison . . . , and 18½ miles from Cape Gray."

He gives photographic views of the Nunatak (Plate XXIV, figs. 1 and 2).

He further states, "it is composed of gneissic rocks whose foliation strikes approximately north and south"; and "two rock types are found in this area. One is a black massive plagioclase-pyroxene-gneiss" which "seemed to form a band whose trend cuts at right angles across the foliation. The second type is the more abundant acid gneiss, containing blue quartz and hypersthene. In the neighbourhood of the anticline it has a banded character, but in other parts the gneissic character, though evident is less prominent."

2. The Plagioclase-Pyroxene-Gneiss.

(a) *Modal Composition of Rocks.*

Stillwell has taken specimen No. 794 as the standard of this type of rock. Four other specimens were collected by Stillwell's sledging party in the summer, 1912–13. He has not given a description of any of these specimens, viz., Nos. 775, 783, 788, 792. They are readily seen to be akin to the standard but differences are none-the-less readily observed.

In the hand specimens the rocks are black, dense and fine-grained. They resemble very fine-grained dolerites when viewed macroscopically. The minerals seen in the hand specimens are pyroxene and felspar. As in the case of No. 794 the weathered surfaces of these specimens are discoloured by a brown iron stain.

The textures of the rocks shown by the microscope are granoblastic, "with subsequent modification by cataclastic effects." The average grain-size is about 0·25 mm., although No. 783 is somewhat finer, its average grain-size being approximately 0·17 mm.

The modal mineralogical contents of the rocks (determined by use of the Leitz Integration Table) are shown in the following table where they are compared with that of the reference specimen, No. 794 (determined by Dr. Stillwell).

Mineral.	No. 775.	No. 783.	No. 788.	No. 792.	No. 794.
Felspar	55·0	46·9	53·3	36·3	42·5
Pyroxene	32·4	32·4	38·1	36·6	45·5
Hornblende	1·1	...	2·2	21·8	3·3
Biotite	5·4	13·9	Present.	2·4	0·3
Iron Ore	6·1	6·8	6·4	2·9	8·4
Total	100·0	100·0	100·0	100·0	100·0

It will be seen that the general tenor of the rocks is the same, yet, notwithstanding this, notable variations occur. The felspar ranges from a minimum of 36·3 per cent. in No. 792 to a maximum of 55·0 per cent. in No. 775. The pyroxene of No. 775 is least, viz., 32·4 per cent. (the same amount as in No. 783) and that of No. 974 is most, viz., 45·5 per cent. A remarkable variation in the amount of hornblende is shown by the table. It is practically absent from No. 783 and yet in No. 792 it forms over one-fifth of the rock. A correlation between the inverse of felspar and hornblende can be drawn. Considerable variation is also shown in the biotite content, it reaches 13·9 per cent. in No. 783 and practically disappears in Nos. 788 and 794. The iron ore content is nearly uniform, although No. 792 differs somewhat from the rest.

A triangular graph (Fig. 16) showing percentages of felspar, F, pyroxene, P, and metamorphic matter, M (viz., hornblende + biotite + iron ores) is given. A serial relationship from C to E to A to B to D is seen. This shows the progression from minimum metamorphic matter in C to the maximum in D. (The letters A, B, C, D, E refer respectively to rock specimens Nos. 775, 783, 788, 792, 794.)

The diagram suggests that part of both the original felspar and pyroxene is taken up in the formation of these metamorphic products (hornblende, biotite and iron ore); but this aspect of the matter will be treated more fully in part (*c*) below.

(b) *A Discussion of the Mineral Characters of the Rocks.*

As the Rosiwal analysis shows there are five main minerals present, felspar, pyroxene, amphibole, biotite, and iron ore. Accessory minerals include apatite and zircon.

The felspar present in all four rocks is plagioclase, although a little antiperthite is found in them all.

The natures of the various plagioclases present have been determined by refractive index methods and by the maximum extinction angles in the symmetrical zone.

Two of the rocks, viz., Nos. 783, 792, are like No. 794 of Stillwell in that they have two plagioclases present. In No. 783 there is a very small quantity of plagioclase which has $n_\alpha = 1{\cdot}538$ (approx.). Accordingly its chemical composition is oligoclase with $Ab_{80}\ An_{20}$. Most of the plagioclase in this rock gives a maximum symmetrical extinction ($X' \wedge 010$) of 20°, showing it to be andesine with $Ab_{63}\ An_{37}$. In No. 792 some of the plagioclase has n_α 1·535 and n_γ 1·545. This determines its composition as oligoclase with $Ab_{85}\ An_{15}$; but here again, most of the plagioclase is more basic. The extinction ($X' \wedge 010$) is 28°, corresponding to labradorite, $Ab_{48}\ An_{52}$.

The other two rocks, viz., Nos. 775, 788, carry only the more basic plagioclase, labradorite, whose composition is approximately $Ab_{50}\ An_{50}$.

The felspar in each of the four rocks shows both albite and pericline multiple twin lamellae. In every case the twinning is indistinct and tends to be discontinuous along the length of the laths. No. 792 has the least indefinite twin forms found in this suite of rocks, but even so there is a tendency towards the elimination of twinning in the central portions of the plagioclase grains. In No. 775 the concentric circular nature of the pericline twin lines is an indication of the deformations produced in this mineral by stresses.

Other stress effects are evidenced by the undulose extinction and the mortar structure associated with the peripheral granulation of the felspar.

None of the rocks shows saussuritised felspar, but every one contains felspar which holds inclusions of several kinds. No. 775 has abundant inclusions of magnetite dust, indiscriminately arranged flakes of biotite and green shreds of hornblende, and some crystals of zircon. No. 783 is much the same. The felspar of No. 788 is much cleaner, being practically free from hornblende and biotite inclusions, although it still has some magnetite and shows a new complication, viz., the presence of granulated pyroxene inclusions. There is a recurrence of the biotite flakes in No. 792, but here they tend to be arranged as tongue-like forms along cracks and cleavage lines rather than indiscriminate distributions through the grains as in No. 775. Magnetite dust is present in this specimen and also small granules of pyroxene (cf. No. 788), which are concentrated in the vicinity of larger grains.

These four rocks, like No. 794, contain both monoclinic and orthorhombic pyroxenes, the latter always being in considerable excess.

The orthorhombic pyroxene in No. 775 has $n_\beta = 1{\cdot}710$ (approx.), D.R. = 0·014. Its elongation is positive, its optic sign negative, 2V is large. These characteristics* are those of the hypersthene member of the enstatite-hypersthene series which carries a molecular percentage of 30 of $FeSiO_3$. In No. 783 n_α is slightly less than 1·680, which shows that the ratio $MgSiO_3 : FeSiO_3$ is greater, there only being 20 per cent. $FeSiO_3$ present. The mineral is still hypersthene.

* Winchell, 1927, Vol. II, p. 177.

In all four rocks the hypersthene is pleochroic in light tones of green and pink; Z is always pale green and X light pink. The absorption is not strong, the formula is $Z \geq X$.

The monoclinic pyroxene in all four cases is a pale green to colourless augite. It is optically positive, 2V large, the extinction ($Z \wedge c$) is about 45°, the D.R., 0·024.

In No. 792 occasional simple twins on 011 occur among the pyroxenes.

The pyroxenes are usually clear, but the augite of No. 792 exhibits good schiller structure, and not infrequently holds inclusions of magnetite (both as abundant dust and larger grains), flakes of biotite, felspar (and possibly a little quartz—the augite is here poikiloblastic), and hornblende.

Granulation, usually peripheral, of the pyroxene is evident in all four rocks, but more especially in No. 792.

Certain genetic relationships between the pyroxene and other minerals hold, but these will be discussed below.

The hornblende of No. 792 has as limits for its refractive indices $n_\alpha = 1·66$, $n_\beta = 1·67$, $n_\gamma = 1·69$. The extinction ($Z \wedge c$) is 15°. These data, according to Winchell (*op. cit.*, fig. 139, p. 224), correspond to that member of the pargasite-hornblende series whose chemical composition is approximately :—

	Per cent.
$NaFeSi_2O_6 + Fe_2O_3$	16
$CaMgSi_2O_6 + MgSiO_3$	42
$CaFeSi_2O_6 + FeSiO_3$	42

That is to say, it is a true hornblende. It is pleochroic, with Z brown-green, Y green-yellow, and X pale straw-yellow. The absorption is strong. The formula is the usual one, $Z > Y > X$.

In the other two rocks in which hornblende occurs to any appreciable amount (it is almost absent entirely from No. 783, see Rosiwal analysis above) it has the same characteristics as those given for No. 972. This rock was used as the standard of reference because of the greater abundance of hornblende in it.

The texture of the amphibole is usually granoblastic, although in places it is found in flakes and shreds. It holds frequent inclusions of magnetite (ilmenite). Its border is usually granulitic, in which respect it resembles the pyroxene.

The biotite of the rocks is deep reddish-brown in colour. It is pleochroic in lighter and darker shades, and has very strong absorption, $Z > Y > X$.

This biotite is associated with pyroxene, felspar, and ilmenite, frequently, but not always, with hornblende, and in No. 775 at least, with scaly calcite: it is intimately associated genetically with these associates, but see below, part (c).

It is always secondary (also see part (c)). In places, particularly in Nos. 783, 792, there are crystals whose curved outlines with sweeping bends suggest change of direction during growth produced by the variation of the prevailing stress-direction.

The magnetite (ilmenite) present in all these rocks has often been referred to above. Its mode of formation and other relationships to the remaining minerals will be treated below, see part (c).

(c) *Critical Analysis of Genetics of the Gneiss.*

We can assume that the original rock was a felspar-pyroxene one. If we suppose that the metamorphic products, M, represent both original felspar and augite, and that all the iron ores came from the augite (some, of course, may have been original), and the amphibole and mica came equally (the simplest assumption, though, necessarily, unsubstantiated) from the original minerals, the modal compositions of the parent rocks are as follows:—

Minerals.	No. 775.	No. 783.	No. 788.	No. 792.	No. 794.	Av. Comp.
Felspar	58·3	53·9	54·4	48·4	44·4	51·9
Pyroxene ...	41·7	46·1	45·6	51·6	55·6	48·1

We can justifiably assume that the original plagioclase was basic, a labradorite. It is not so easy to tell if the orthorhombic pyroxene is original, although Hatch (*op. cit.*, p. 415) suggests that hypersthene-gabbro, hypersthene-diorite and hypersthene-granite may possibly be formed by differentiation, which implies the original character of the hypersthene. If it is true as has been suggested (Tyrrell, 1930, p. 139) that one of the distinguishing features of the charnockite series—rocks from norite to pyroxene-granite—is the poverty of water-formed or water-rich minerals such as biotite and hornblende, then an accession of water must be postulated to account for the presence of these minerals in the present rocks.

3. The Hypersthene-Alkali-Felspar-Gneiss.

(a) *Macroscopic Features.*

Stillwell (p. 133, *et seq.*) has dealt with Specimens Nos. 795, 797 of this series. There remain Specimens Nos. 778, 779, 787, 790, 791, 793, 798, 1226, 1227, 1254 to be described.

These members of the second type of gneiss at the Madigan Nunatak are coarse-grained rocks in which the gneissic structure can be detected (cf., Stillwell, p. 133). This gneissic structure is much more prominent in some specimens than in others. For instance, very definite leucocratic and melanocratic bands are visible in Nos. 779, 787, but the texture of Nos. 798, 1226, 1227 is granulitic, and that of Nos. 778, 790, 791, 793, 1254, is best described as intermediate. The colours of the rocks taken as a whole also form a series from light to dark with an intermediate group where neither colour predominates. In the leucocratic group are Nos. 778, 790 and 1254, the intermediate group consists of Nos. 779, 791, 793, 798, 1226, 1227, and in the melanocratic group is No. 787. The macroscopically visible minerals are quartz (which is often blue, but sometimes brown), felspar and hypersthene. Weathering of these minerals has produced normally a brownish-red colouration, but more complete hydration has sometimes resulted in the production of a remarkable mustard-yellow coating which is particularly noticeable in No. 778. There is a considerable variation in the grain-size of these minerals. Not only is this noticeable in the case of the hypersthene (cf., Stillwell) but in the felspar and quartz as well.

(b) *Mineralogical Characters.*

These rocks consist of quartz, orthoclase and plagioclase as their most abundant constituents, but always with important hypersthene, biotite and ilmenite. Accessories are apatite, pyrites and zircon (or monazite).

Most of the felspar is orthoclase, which is highly perthitic. The small inclusions of plagioclase have a higher R.I. than their host. They are usually linearly arranged in a great number of parallel lines which preserve their parallelism extraordinarily well. The regularity of the size and spacing of the intergrowths is remarkable. No crystal of orthoclase has been observed which is not perthitic. These intergrowths, as a matter of fact, frequently follow a rectangular pattern, where, again, the regularity of size, arrangement and orientation is remarkable. In rocks where the orthoclase overwhelmingly preponderates (*e.g.*, No. 790) there is occasionally some multiply twinned acid plagioclase (albiclase, $Ab_{90}An_{10}$) which has perthitic inclusions in the sense used by Chudoba (Chudoba, translated by Kennedy, 1933, p. 18), that is, where the host has a lower refringence than its inclusions. In other rocks, *e.g.*, No. 1227, where more plagioclase is present, large areas of antiperthite are frequently found. Where the plagioclase is more abundant it shows multiple twinning badly defined, and has the other properties of a little more basic variety, viz., oligoclase, with $Ab_{80}An_{20}$ (approx.). These differences in the composition of the felspar units through a single individual give a distinctive appearance to the rock even when the nicols are parallel, but more so when they are crossed. This appearance is enhanced by the effects produced by the extreme cataclasis which the rock has suffered.

The quartz of the rock shows equally well the cataclastic effects. Often there has been produced in the rock a crude schistosity by the parallel elongation of the crushed portions (cf. Stillwell, p. 134). These effects are rendered more obvious under crossed nicols when the undulose extinction of the alternate bands differentiates one streak from the next.

Where quartz and felspar are contiguous the crushing has produced new effects. Myrmekitic intergrowths of the two minerals appear, usually in contact with a mosaic of equi-dimensional quartz particles on the side adjacent to this mineral and a well-developed mortar structure on the side abutting the felspar.

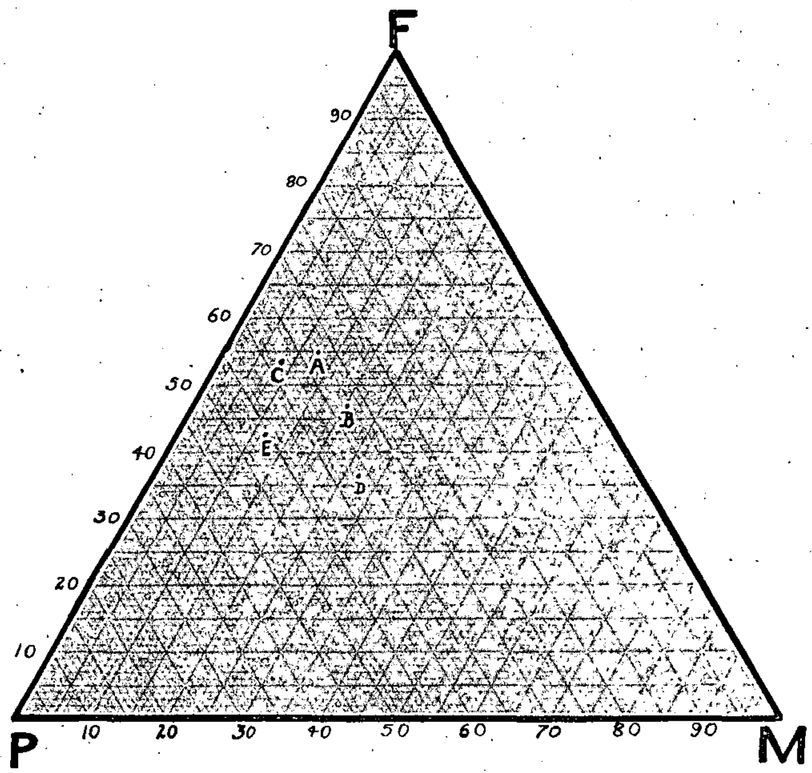

Fig. 16.

The pyroxene present is all hypersthene, which shows distinct pleochroism in pinks and greens, with Z green and X pink. The absorption is marked, the formula is $Z > X$. The appearance of the pyroxene is determined by the degree of cataclasis it has suffered and the extent to which it has undergone metamorphism. The second of these factors determines, to some extent, the amount of hypersthene present in the rock, but it is not the only influencing factor. The amount of original pyroxene is, of course, of importance. This is seen to vary from small quantities, as in Nos. 778, 790, 1227, 1254, to considerable amounts as in Nos. 779, 791, 1226. The degree of granulation appears to affect the readiness with which the pyroxene changes to ilmenite and biotite. The textural effects produced are the lenticular appearance of the larger grains (*e.g.*, No. 787), elongation of the grains (*e.g.*, No. 790), a parallel linearity of the grains (*e.g.*, No. 779) and streaked rows of minute granules (*e.g.*, No. 798).

The oblique extinction of some of the hypersthene suggested that the mineral might be monoclinic pyroxene. The low refractive index and the negative optic character of the mineral differentiated it from augite, and the parallel extinction of cleavage flakes established its orthorhombic nature. Merwin* observed the same phenomenon, and accounted for the oblique extinction by saying that the parting or cleavage developed was parallel to b (010). Doubtless the same explanation holds in this similar instance.

(c) *The Metamorphism of these Rocks.*

The biotite, ilmenite and hornblende of these rocks are the products of the metamorphism of the pyroxene (usually with some inter-action with felspar). Where the granulation of the pyroxene has gone to the stage of the streaking-out into fine granules the production of biotite has been most easily accomplished; but some of the biotite is associated with the larger masses of pyroxene. It will be remembered that inter-action with felspar has been mentioned above as a necessary part of the formation of the final biotite product from the pyroxene. That this is so is shown by at least two remarkable features of these rocks. The first is the presence of biotite streaks along nearly every crack and cleavage line of some of the felspar grains, and the second is the presence of row upon row of parallel lines of minute dark rectangular and rhombic grains which represent the ultimate effect of the crushing of the original pyroxene. The alternation of regions where these rows are concentrated with bands where the felspathic matter is free from them has developed a microscopic gneissose structure comparable in its essential features with those of macroscopic dimensions. Frequently there is seen a development of biotite associated with these very fine grains. The other streaks of biotite in the felspar where the very fine pyroxene grains are absent represent the conditions which exist when all the content of the pyroxene has been altered (*e.g.*, No. 793). Another feature showing the genetic relationship that exists between the felspar and the biotite is the usual radiating growth of small biotite crystals from a central core of ilmenite. Each of the small biotite crystals penetrates into felspathic material. The effect produced is singular. From the arrangement of these three minerals there can be no doubt that the growths represents a reaction between them.

4. Summary.

From this treatment of the pyroxene-plagioclase-gneisses and the hypersthene-alkali-felspar-gneisses it will be seen that the acidity of the rock is the factor which determines whether the metamorphic derivative of the pyroxene shall be biotite or hornblende. In those rocks where the acid-felspar content is relatively low (*e.g.*, No. 792) the hornblende-content is great, but where the quartz-felspar-content is great (*e.g.*, No. 778, analysis below) hornblende is absent and the metamorphic derivative is biotite.

* "The Charnockite Series of Igneous Rocks": H. S. Washington, Am. Jour. Sci., XLI (1916), p. 331.

The usual occurrence of pyroxene in rocks whose nature is definitely not acidic obscures this two-fold mode of its alteration. It is only in this so-called "Charnockite Series" that much pyroxene is found in definitely acidic rocks. It is, then, possible to find the metamorphic derivatives of pyroxene in acid surroundings in this suite only. Even so, the usual slight metamorphism which rocks of this suite from other regions have suffered has permitted Washington (*op. cit.*, p. 335), after citing the occurrence of the charnockite rocks from Norway, Ellesmere Land, New York and West Africa, to say that "biotite is rare or accessory and quite absent in most of the types." That this is not necessarily so in the metamorphic representatives of the suite is seen from the Rosiwal analyses of the "Intermediate Charnockites" Nos. 775, 783, where 5·4 per cent. and 13·9 per cent. of biotite is present. The amount of pyroxene in each of these rocks is 32·4 per cent. The same reaction is shown more powerfully by the following table where the volumetric compositions of two metamorphic derivatives (Nos. 778, 787) of "hypersthene granites" are given :—

	I	II	III
Quartz + Felspar	90·4	82·7	94
Hypersthene	6·7	6·0	3
Biotite	1·6	11·3	1
Ores	1·3	p.	2

I.—Rock No. 778.

II.—Rock No. 787.

III.—Specimen (9·658) of the Indian Survey. Occurs in central part of Magazine Hill, St. Thomas Mount, eight miles south of Madras. (Washington, *op. cit.*)

It will be seen that in each of these three rocks no hornblende has developed, but there is an appreciable quantity of biotite, especially when referred to the hypersthene—in No. 787 it is nearly twice as abundant.

It can be concluded then that amphibolization of the pyroxene is the characteristic alteration of this mineral in basic (and related) rocks, but that the formation of biotite is the characteristic metamorphic process in rocks which have original pyroxene and yet are acidic. Such rocks are the so-called hypersthene-granites and diorites and it must be among the comparatively rare metamorphic derivatives of these rocks that we must look to see the effects which have been suggested above. The rocks here described from Madigan Nunatak seem to be among the most interesting from this point of view.

DESCRIPTION OF PLATES.

Plate XLIV.

Fig. 1. Cordierite-Garnet-Plagioclase-Biotite-Gneiss, Stillwell Island (No. 980).

The micro-photograph shows a mass of cordierite and biotite derived from the alteration of an earlier garnet crystal. Mag. 80 diams.

2. Hypersthene-Alkali-Felspar-Gneiss, Madigan Nunatak (No. 1227). The micro-photograph shows small biotite crystals proceeding from a large ilmenite grain and projecting into felspar. Mag. 44 diams.

3. Hypersthene-Alkali-Felspar-Gneiss, Madigan Nunatak (No. 778). The micro-photograph shows a synneutic aggregate of hypersthene in a matrix of felspar. Reaction between the hypersthene and the felspar has liberated ilmenite which has in places formed nuclei for biotite growths which project into the felspar. Mag. 35 diams.

4. The same rock as in Fig. 3.

A portion of the field of the previous photograph has been considerably enlarged to show more clearly the relation between the ilmenite, biotite and felspar. Mag. 170 diams.

Plate XLV.

Fig. 1. Amphibolite occurring *in situ* near the Magnetograph Hut at Cape Denison (No. 421).

Crystals of sphene with nuclear ilmenite are shown together with biotite, felspar and a little hornblende. Mag. 35 diams.

2. Garnet-Plagioclase-Amphibolite, *in situ*, Cape Denison (No. 977). The micro-photograph shows a reaction zone where dactylitic growths of hornblende are the medium of transference of material from ilmenite to garnet via felspar. Massive hornblende is also seen in the field of view. Mag. 125 diams.

3. Hornblende-Plagioclase-Pyroxene-Gneiss, *in situ*, Cape Denison (No. 972).

The micro-photograph shows a circular region where earlier garnet has given place to a granulitic mass of pyroxene and felspar. Some remnants of the original garnet crystal remain. Mag. 44 diams.

Sydney: Thomas Henry Tennant, Government Printer—1940.

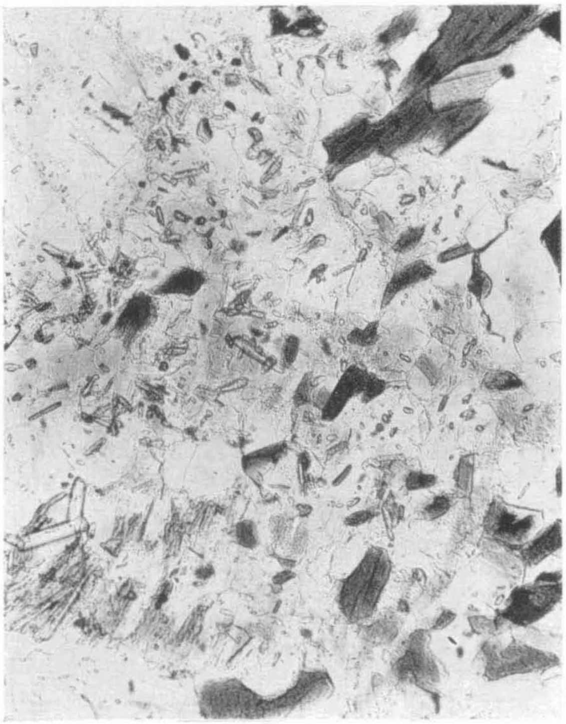

Fig. 1.

Fig. 2.

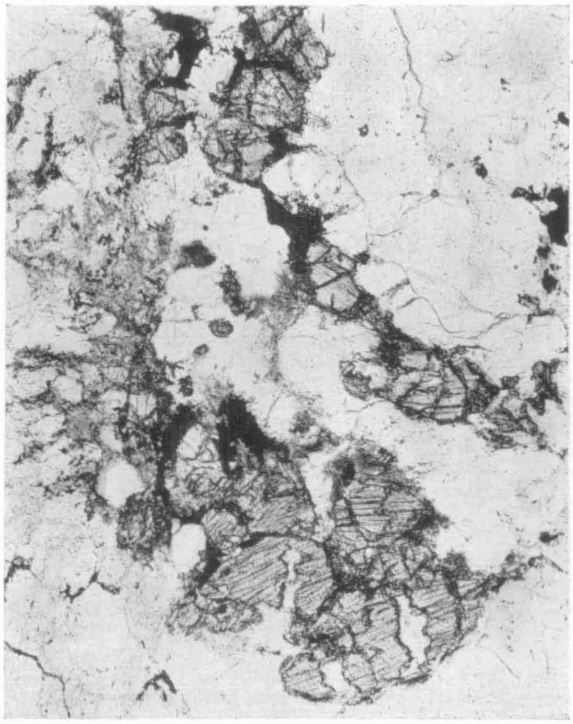

Fig. 3.

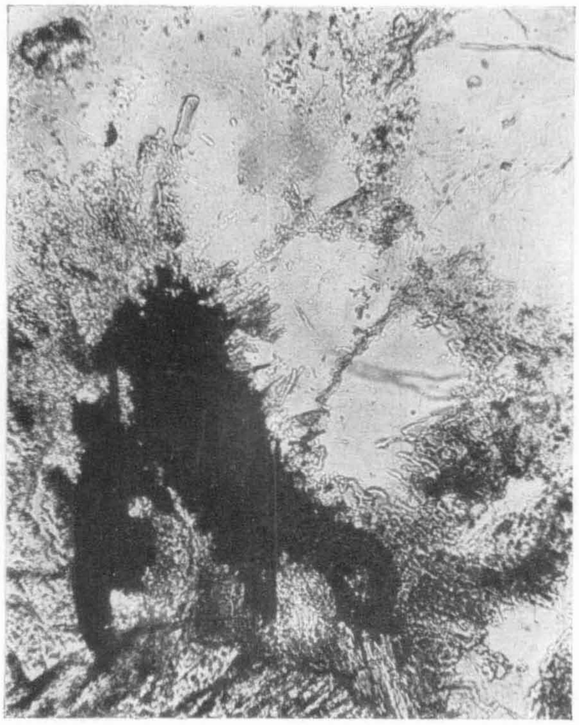

Fig. 4.

* 62830—D

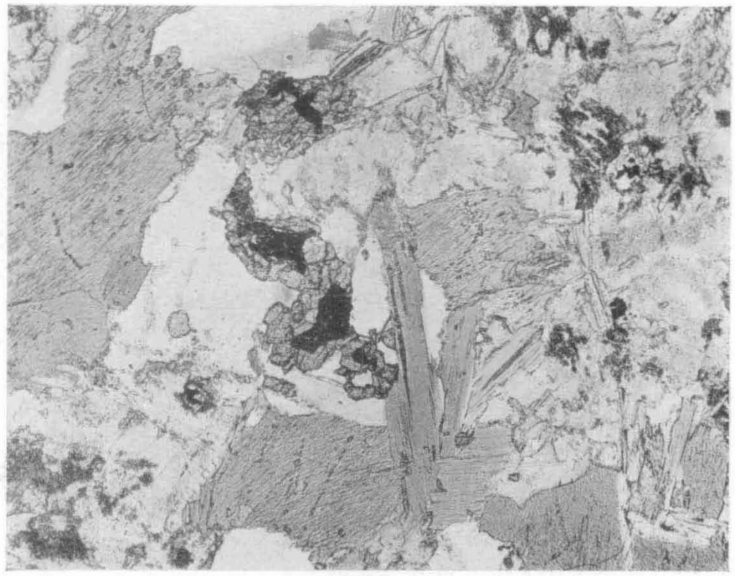

Fig. 1.

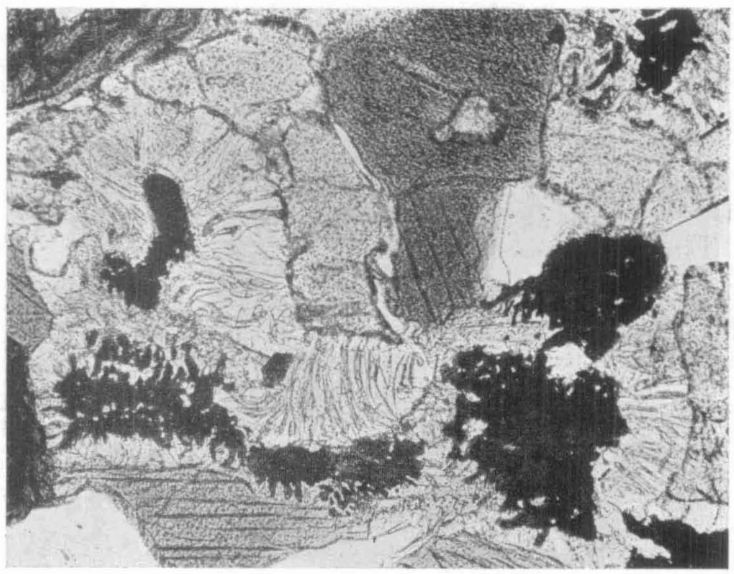

Fig. 2.

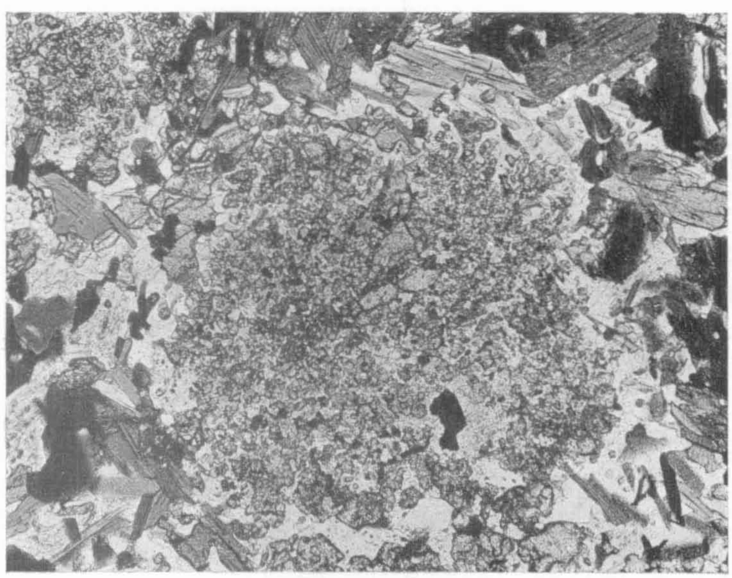

Fig. 3.

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