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METAMORPHOSED LIMESTONES AND OTHER CALCAREOUS SEDIMENTS FROM THE MORAINES.

A FURTHER COLLECTION.

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

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PART 8.

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AND

OTHER CALCAREOUS SEDIMENTS

FROM

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BY

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THE METAMORPHIC LIMESTONES OF COMMONWEALTH BAY.

BY

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

I. INTRODUCTION.

A LARGE number of rocks of this nature from the moraines at Commonwealth Bay have been described by Dr. Tilley in his memoir in this series (Vol. III., Pt. 2). However, the rock collection of this Expedition from that area contains a number of specimens of metamorphic limestones additional to those dealt with by Tilley. It has been deemed advisable, for the sake of completeness, to put on record the characteristics of these supplementary examples:—

Tilley states that his study of some of these rocks has led him to conclude that:—

> "The carbonate rocks from which these rocks have been derived were characterised to a greater or less degree by the presence of detrital material, which in the process of metamorphism has reacted with the carbonate minerals."

The observations of the present worker confirm this finding and lead to the conclusion that not only siliceous detrital matter has been present, but frequently felspathic (particularly microcline) and micaceous matter have been present to a considerable degree. The conclusion that Tilley reached in connection with the effect of magmatic material, viz.:—

> "There is no example which suggests any extensive addition of material from magmatic sources, other than purely volatile constituents,"

is in accord with the observations made in the present work.

In connection with mineralogic content, the rocks can be divided into nine main classes, six of which coincide with those of Tilley, a seventh which approximates to one of his, and two of a different nature. The nine classes are the following:—

(1) Forsterite-marbles.
(2) Tremolite-marbles.
(3) Diopside-tremolite-marbles.
(4) Pyroxene-garnet-marbles.
(5) Pyroxene-epidote-marbles.
(6) Epidote-marbles.
(7) Carbonate-free calc-silicate rocks.
(8) Tremolite-epidote-marbles.
(9) Forsterite-mica-marbles.

Classes (1) to (6) are those which are certainly identical with those of Tilley. Class (7) seems to be a variation of his class (7). Class (8) is allied to class (6), but is distinguished from it by the presence of a very considerable amount of tremolite. Class (9) is entirely different from any of the other rock-classes.

II. PETROGRAPHY.

(1) Forsterite Marbles.

The rocks to be dealt with here, characterised by the presence of magnesian olivine, or serpentine developed from such olivine, are Nos. 301, 316, 402A, 704. The rock No. 741 contains considerable forsterite but because of the remarkable development of a pale brown pleochroic mica it has been placed in another class, viz., class (9).

In Nos. 301 and 402A the forsterite, although considerably serpentinised, is still present to a large degree, but in No. 316 the serpentinisation has proceeded almost to the entire replacement of the original olivine, and the rock is more properly named ophicalcite.

These rocks are very similar in nature to those described by Tilley under the same heading. In fact they belong to his group of forsterite marbles. They are light-coloured, and show greenish yellow pseudomorphs of serpentine after forsterite.

Mineralogically, they consist of dolomite, calcite, serpentine, forsterite, graphite, apatite, phlogopite, limonite, and chondrodite (?).

In addition to the three criteria Tilley has used for differentiating between dolomite and calcite, viz., dolomite twinning on the $02\bar{2}1$ plane, the greater degree of turbidity in calcite, and the Lemberg staining method, a fourth stated by Harker, viz., the higher position of dolomite in the crystalloblastic series, has been helpful in discriminating between the two.

Chondrodite, if present at all in these rocks, is present in a very minor amount and then in a somewhat different manner from the occurrence in Nos. 135 and 137 of this series. It may be present in one or two grains in No. 402A. If so, it occurs colourless and not in the pleochroic form of the other two occurrences.

The only other remark of a general nature concerns the phlogopite. This mineral is undergoing chloritisation to some extent.

Detailed Descriptions of Rocks.

Rock 301.

This is a light coloured marble in which yellow globules of serpentine represent earlier olivine. Blebs of black graphite are also present.

Under the microscope, the rock is seen to consist of grains of both dolomite and calcite. The former can be recognized by its cleaner appearance and its idioblastic nature when contrasted with xenoblastic characters of the calcite. There are also present notable amounts of serpentine. This mineral is quite colourless and its relation to pre-existing olivine is made apparent by occasional patches of unaltered forsterite in it. Other inclusions in the serpentine are calcite, which is then more or less scaly in character, and, in one place, at any rate, a colourless mineral which has one well defined cleavage, extinction on this about 35°, double refraction about 0·010, and is optically positive. Very possibly it is allied to the pyroxenic mineral fassaite.

Associated with the calcareous minerals is an appreciable quantity of graphite. It occurs mainly as streaks and blebs in the calcite, but sometimes as a border to the serpentine zones.

An unusual feature is the prominence of apatite in this rock. This mineral occurs too abundantly for its presence to be accounted for as part of the original substance of the rock, and as Harker says :—" We are led to the conclusion that there has been an introduction of phosphate, or rather of phosphorous in some volatile form. We may suppose this to react with water :—

$$P\ Cl_5 + 4\ H_2O \rightarrow 5\ H\ Cl + H_3\ PO_4,$$

the acids so produced then entering into reaction with some of the silicates present.

Rock 316.

This is a dense, greyish-yellow holocrystalline rock in which recognisable minerals are white calcite and deep yellow green serpentine. These crystals are formed both as porphyroblasts and granoblastic ground-mass. This rock is of the type known as ophicalcite.

The slide shows clear ovoid crystals of colourless serpentine and rectangular laths of colourless phlogopite set in a very cloudy and turbid calcite matrix. The cloudy nature of the calcite is particularly noticeable at the junctions with the serpentine and seems to be due to the liberation of graphite.

The serpentine is undoubtedly derived from earlier forsterite. There is one grain of this mineral set in a serpentine base. The phlogopite is the typical mica developed in this kind of rock. Here it is practically colourless unlike the pale brown varieties formed in other specimens of this suite. The polarisation colours indicate that chloritisation has proceeded to some extent. Apatite and limonite figure as accessory minerals.

Rock 402A.

This is a white to pale grey, coarsely crystalline rock in which carbonate minerals predominate. Rounded and irregular masses of yellow serpentine, derived from forsterite, are very common. Small black flecks of graphite are also visible to the naked eye.

This rock is very similar to No. 316, except that the development of phlogopite has not been so great. The main minerals are calcite and dolomite. The calcite is clouded with minute dust particles of graphite which has been concentrated in some parts of the rock into definite grains. The forsterite produced by dedolomitisation has not been serpentinised to such a degree as has that of No. 316.

The serpentine is usually colourless, but in places it has assumed a very pale yellow colour. Occasionally included in the serpentine is a colourless mineral which resembles olivine, but from which it differs in its lower D.R., fair cleavage, inclined extinction. It possibly is a colourless variety of chondrodite.

Rock 704.

May be regarded as a special subdivision of this section namely, forsterite-marble with zones of high silicic content.

The hand specimen of this rock consists of a band of pale green diopside which cuts off two other portions which are very similar to one another. They are highly calcitic and show a less prominent banding in which occur forsterite and phlogopite as well as calcite. These end portions of the rock show the result of weathering which has been differential in nature, as is shown by small green grains of forsterite standing out in relief. The pyroxenic portion of the rock does not show this structure.

This specimen shows the different lines of transformations in rock masses whose initial constitutions were different. The diopsidic portion of the rock represents a region of a dolomitic rock where more than enough silica was present for dedolomitisation purposes ; in the other parts of the rock the opposite has been the case.

For these reasons the rock may be regarded as a member of a special subdivision of class (1) ; the non-diopsidic portions belonging to that class itself.

(2) Tremolite-Marbles.

This class is represented by Nos. 1160 and 740. The first of these rocks is light coloured and schistose. The schistosity is due to the considerable development of parallel fibres of tremolite. The minerals present include calcite, graphite, edenite, tremolite, colourless spinel, phlogopite-biotite mica, magnetite, felspar (including microcline at least), chlorite and haematite. The characteristics of these minerals will be stated in the more detailed description which is given below.

Detailed Description of Rock.

Rock 1160.

There has been a segregation of material into carbonate areas and darkish green tremolite areas. This distribution is due in large part to the original chemical and mineralogical differences in the original sediment, the one part being more calcitiferous and the other more argillaceous. Evidence of secondary calcification is given by the presence of small white calcite crystals showing actual crystal form in parts of the rock. The vein-nature of these crystals is apparent from the way a film of this matter lies on the rest of the rock. The difference in the nature of this calcite from that of the original sediment is also shown by the very much darker grey colour of the mineral here. The tremolite is acicular, radiating. Symmetrical radiate masses from central nuclei are particularly well developed. An occasional grain of chalcopyrites is seen.

The most striking features of the rock when it is observed microscopically are the extremely dirty nature of the calcite and the very irregular distribution of the tremolite. Graphite and pale brown mica are also noticeable.

The calcite is fairly well crystallized, but except in scattered and somewhat isolated patches, this is obscured by the unusually large development (for this set of rocks) of graphite. Not only is this mineral present as graphite dust, but the coalescence of fine particles of this material has proceeded to a much greater degree than in the other rocks, producing quite an abundance of black blebs and streaks. The tremolite is practically colourless in prismatic sections, but it is pale yellow-green in sections normal to the *c*-axis. It seems probable that both edenite and tremolite are present. Occasional pleochroic haloes with nuclei of zircon are found in these minerals. The prismatic forms are frequently poikiloblastic, including clear calcite.

The mica is pale brownish green. The green is stronger in the periphery of the laths which are particularly fibrous at the ends, and shows that chloritization is progressing towards the centre. There is a very minor development of colourless zoisite.

Rock 740.

This is a low-grade member of the tremolite marbles. The rock is dense, dark, fine-grained. The only minerals identifiable by the naked eye are calcite and small cubes of pyrites.

Under the microscope the rock is seen to be a granular aggregate of small calcite and microcline crystals. Accompanying these are numerous grains of epidote and laths of fibrous tremolite.

The rock is a very low grade member of the metamorphic rocks derived from calcitic sediments which have a certain amount of argillaceous, siliceous and felspathic impurities.

All the calcite is crystalline, but the metamorphic process has not proceeded far enough for large crystal masses to have developed. The epidote and tremolite are not detrital, as is the felspar, but show that metamorphism has proceeded far enough for their production. A little sphene and some graphite are also present.

(3) Diopside-Tremolite-Rocks.

(a) *Diopside Tremolite Marbles.*

Only two representatives of this group are to be described here, viz., Nos. 877, 225.

The first rock is seen in the hand specimen to be a diopside-tremolite rock carrying a little sphene. Small amounts of carbonate matter allies it in some respects to Group (7). The chief minerals present include diopside, tremolite, calcite.

No. 225 is light coloured and schistose due to the development of considerable tremolite in parallel orientation.

Detailed Description of Rocks.

Rock 877.

This rock is pale green in colour, dense, and considerably weathered superficially. The obvious mineral content is pale green diopside in compact crystals, darker green acicular tremolite, and occasional grains of very clear calcite.

The microscope shows generally the same group of minerals, but a few lozenge shaped grains of sphene are also seen in the slide. The great bulk of the rock consists of diopside, which is seen in colourless prisms or grains. Frequently it exhibits a poikiloblastic texture, including calcite, tremolite and sphene crystals. The peripheral regions are usually considerably granulated, and sometimes the cataclastic effects are seen to penetrate the crystal to a higher degree. Multiple twinning of the diopside is by no means uncommon.

Tremolite is present in subordinate quantity. It, too, is colourless, prismatic, and of moderate birefringence. Its more fibrous nature (tending to needles of asbestos in places) and smaller extinction angle serve as discriminating criteria.

The calcite is clear. It is frequently multiply twinned.

The sphene is developed sporadically, it being a minor constituent of the rock.

Rock 225.

In the hand specimen the rock has a light green colour. It consists of an aggregate of light green prismatic crystals of edenite and somewhat deeper green acicular crystals of actinolite and dense compact light green diopside. The whole rock is penetrated by an irregular veining of calcite.

Microscopically the rock is resolved into very dirty-looking calcareous matter and colourless amphiboles which alternate with bands of diopside. The calcite has probably assumed this appearance by the segregation of carbon granules in the form of minute particles of graphite. In places there has been a slight concentration of the carbonaceous matter with the consequent production of identifiable graphite. Throughout the calcite, which is usually highly twinned, are flakes of biotite which has been almost entirely converted into pale greenish-brown chlorite, and infillings of pale yellow serpentine.

The amphibolic areas are composed of edenite and tremolite. The two minerals occur in different manners. The edenite is found in larger masses where schistosity is not noticeable as it is in the smaller tremolite crystals. Both minerals are colourless and are present in prismatic crystals, but they can be distinguished by the difference in extinction ($Z \wedge C$ is 24° for the edenite and 16° for the tremolite) and by the fact that the edenite is optically positive.

The diopside microscopically is pale green in colour and shows pyroxene cleavages very well. Along parallel lines in this pyroxene are found veins of calcite which is scaly in places and quite granular in others. More massive grains of earlier calcite and flakes of tremolite are poikiloblastically set in the diopside.

(b) *Diopside-Actinolite-Felspar Injection Gneisses.*

Specimens 618, 716, 964, 1153, 1154, 1162, 1222 are allied rocks.

Each is a diopside rock, and very probably each is portion of a diopside-actinolite rock, although some specimens are so small that none of the diopside is present. Each rock is an injection gneiss where the injected matter consists of granular pink material which is largely composed of highly saussuritised felspar, sericite and lawsonite. Most of the specimens do not show definite banding because such structure is too coarse to appear in rocks the size of those in this collection. Nos. 716 and 1153, however, are believed to be representative of the main mass of the rock. No. 716 is decidedly banded, being, indeed, a true injection-gneiss whose bands are alternately earlier diopside-actinolite matter and later purplish felspathic intrusion matter. The banding of No. 1153 is much coarser, this specimen doubtless occurring further from the intruding acidic magma.

The earlier diopside-actinolite rock was a high grade metamorphic derivative of an original calc-silicate rock. The metamorphism had proceeded so far that none of the original carbonate remained as such.

The rock was then intruded by an acidic magma with the consequent intensification of the above process and the assimilation of some of the lime and magnesia (and possibly alumina) by the magma itself. This consolidated magma is for the most part highly saussuritised felspar, but in some specimens, notably No. 1153, a considerable quantity of quartz appears. This quartz shows very plainly the effects of strain, produced, no doubt, as the magma squeezed in between the original fibrous masses. The effects of strain most readily observed are pronounced undulose extinction which shows the quartz to have acquired a definite elongation during the period of stress, and pronounced mortar structure. The granulation of the peripheral portions of the quartz grains has frequently produced a border of very small particles which are entirely surrounding the larger and less affected centre.

The calcic minerals produced by assimilation are not uniformly the same. In No. 964 this process has given rise to the formation of considerable lawsonite, a mineral which is sparingly developed in No. 1153. Its place seems there to have been taken by an extremely dirty-looking variety of zoisite. Chemically, these minerals are not unrelated, lawsonite $H_4CaAl_2Si_2O_{10}$ and zoisite $HCa_2Al_3Si_3O_{13}$ (Winchell), they differ in the greater proportions of hydrogen in the former and of calcium and aluminium in the latter. That there are considerable quantities of these three elements in No. 964 is shown by the chemical analysis of this portion of the rock given below.

Each of these rocks shows a considerable development of sericite, derived mainly from the potash of the felspar in the introduced magma.

Minor minerals found in the rocks include allanite, sphene, zircon and interstitial calcite.

The following chemical analysis of the purplish pink matter of No. 964 was made by J. H. C. Mingaye, F.I.C., Mines Dept., Sydney.

SiO_2	42·28
Al_2O_3	32·86
FeO	0·90
Fe_2O_3	0·00
CaO	10·36
MgO	0·13
BaO	0·07
K_2O	6·42
Na_2O	0·21
Li_2O	present
TiO_2	abs.
H_2O	4·36
CO_2	2·28
MnO	0·23
P_2O_5	trace
Total	100·10

The norm calculated from this analysis is approximately :—

Or.	37·81
Ab.	1·57
An.	37·25
Co.	11·83
Fs.	2·11
Hy., En.	3·00
Calcite	5·18
Total	98·75

The SiO_2 is deficient by about 0·01% to satisfy the norm as given above.

The points of interest in connection with this chemical composition are the high alumina and potash contents and the equality of orthoclase anorthite in the norm. The alumina is taken up by the following minerals in the mode : felspar, lawsonite (or zoisite) and sericite. The potash appears in the felspar (to some extent) and in the sericite (a large percentage of which is possibly primary muscovite). Most of the water of the rock appears as hydroxyl in the sericite and the lawsonite (or zoisite). The carbon dioxide is taken up in the secondary calcite which has been introduced subsequent to the intrusion of the calc-silicate rock by the acidic magma.

(4) Pyroxene-Garnet-Rocks.

(a) *Pyroxene-Garnet-Marbles.*

The rocks to be referred to this class are Nos. 619 and 830.

These two rocks are the darkest coloured of the set which is being described in this work. In some points their mineralogic contents are alike but in some other respects the two show wide differences. In No. 619 the garnet is present in large crystal masses whereas in No. 830 it is not visible to the naked eye. In No. 619 highly sericitized felspar and scapolite are present but in No. 830 these minerals are almost entirely absent and microcline is developed to a very considerable extent.

(a) *Detailed Description of Rocks.*

Rock 619.

This rock is much darker and coarser grained than the other numbers of the suite. It is definitely gneissic in character, bands of yellow-green epidote and darker green pyroxene are studded with large reddish-brown crystals of garnet (up to 2·0 to 2·5 cm. across) and smaller grains of milky quartz. In one part of the rock the garnet has been streaked out to such an extent that it forms a garnet band in parallel alignment with the epidote and pyroxene.

The metamorphic nature of the rock is even more evident under the microscope than in the hand specimen. It is seen to be granoblastic for the most part, but the zoisite present sometimes assumes radial and plumose forms, the scapolite and sericite tend to be elongated and the garnet and epidote are usually poikiloblastic. The felspar present is highly sericitised. The calcite exists both in more or less equi-dimensional forms and in elongated streaks or veins which are suggestive of deposition from hot solution.

A more critical investigation gives rise to the following observations about the mineral content of the rock.

There is some differentiation into felspar-quartz areas and epidote-tremolite-pyroxene-garnet areas. That is, the gneissic nature of the rock is apparent microscopically.

The felspar, as mentioned above, is greatly sericitised. Nowhere can twins be detected, but suggestions of pre-existing twin lamellae are given by the streaks of sericite and scapolite along parallel lines. These two minerals are both replacing the felspar—which most likely was potassic—and each requires an addition of volatile material, the source of which was, no doubt, from the magma which produced the metamorphism of the rock.

The quartz occurs in large clear masses. It is recognised by its uniaxial positive character and the exhibition of the other characters it ordinarily assumes.

The epidote family is well represented. Ordinary epidote in large, poikiloblastic, pleochroic masses is the commonest ; this is frequently seen in association with non-pleochroic zoisite which gives typical ultra-blues under crossed nicols. The third member of the group is allanite, which occurs as nuclei of ordinary epidote crystals in a number of instances. The cerium required in its composition doubtless came with the other volatile constituents which have been taken into the composition of the scapolite and sericite.

The zoisite is usually light coloured, and here shows a somewhat lower birefringence than usual. Its radial nature has been commented on above.

The pyroxene present is light green in colour, its extinction ($Z \wedge C$) is about 44°, and the optical axial angle ($+2V$) is about 60°. These data suggest that it is a member of the diopside-hedenbergite series in which the relative weights of CaO, FeO and MgO are in the ratio 63 : 50 : 20 (roughly).

The garnet is a light brown colour. It is always poikiloblastic in nature, among the inclusions being calcite, pyroxene, epidote, quartz and sphene. The genetic connection between the calcite, pyroxene and garnet is seen by the presence within the garnet mass of the two.

The sphene in the rock frequently resembles the garnet very closely in parallel light, but the isotropic nature of the latter renders them easily distinguishable under crossed nicols.

Rock 830.

This is a medium-grained rock consisting essentially of pink and white crystals of calcite, greenish yellow grains of epidote which are in sub-parallel arrangement and minute black grains of actinolite with here and there an accumulation of this material into large masses of black fibrous amphibole.

Unlike 619 this rock is very fresh looking. This statement is particularly true of the calcite whose clearness is in marked contrast to the more turbid appearance it has in the other rock.

The minerals developed include calcite, epidote, green pyroxene, sphene, garnet, microcline, quartz, apatite, graphite and haematite.

A noticeable feature is that there is little difference in crystalloblastic force shown by these minerals with the exception of apatite and sphene, which are readily seen to be much higher in the crystalloblastic series than the others.

Except that the graphite dust has been almost cleared from the calcite and concentrated in streaks and blebs at the edges of this mineral there is no need for comment about the calcite.

The epidote, green pyroxene, and garnet have some textural properties in common. The most obvious is the definitely poikiloblastic nature of these minerals. This is of especial interest in connection with the garnet, a mineral whose force of crystallisation is usually strong enough to form crystals which reveal the actual crystallographic form of the mineral. Among the minerals enclosed by the porphyroblasts of these three minerals are sphene, calcite, microcline, apatite. Another feature of texture in connection with the epidote is the symplektic intergrowth between it and microcline. Genetic relationships are shown by the intimate intergrowths of epidote, green pyroxene and calcite.

More specific mineralogical properties of these minerals of interest are the intense and highly pleochroic yellow colour of the epidote, the diopside-hedenbergite character of the pyroxene, and close superficial resemblance of the garnet and sphene.

Isolated areas of highly altered plagioclase are present. Microcline which is somewhat perthitic in places is also developed to some considerable degree. The other minerals present call for no further discussion.

(b) *Pyroxene-Epidote-Garnet-Marble.*

Rock 1169.

This is a gneissic rock in which bands of green granular epidote, white felspar and quartz, brownish calcite and dark red-brown garnet occur. Larger isolated crystals of garnet are seen sporadically to occur throughout the rock.

The close relationship of this rock to the members of class (4) is seen from the above description. It is placed in a subdivision of this class in virtue of the large epidote content which it has ; this content being considerably greater than that of No. 619.

From the description already given and the following list of minerals found in the rock ; calcite, yellow pleochroic epidote, quartz, microcline, sphene, allanite and apatite, it will be seen that the rock is very similar to No. 619. In view of this it is unnecessary to add to the present description.

(5) Pyroxene-Epidote-Marbles.

The rocks in this class are Nos. 667, 624, 713, 1269.

Superficially the rocks do not look very much alike. Yet the mineralogical contents of the rocks and the mode of development of these minerals show the rocks to be essentially of the same nature.

Detailed Descriptions of the Rocks.

Rock 667.

This is a medium-grained granoblastic rock in which there is a preponderance of saccharoidal calcite which contains a fair amount of black pyroxene and yellow-green epidote, the former in small granules, the latter in somewhat larger crystals. The cemented material has been removed to a slight extent with the consequent production of a gritty surface on those parts which have been exposed to this action.

The texture of the rock is granoblastic, but flakes and shreds of serpentine and calcite give the rock a characteristic appearance. Granulation has taken place in some minerals, particularly the peripheral regions of some of the epidote grains, and the extremities of the more elongated laths of scapolite. Myrmekitic intergrowths of quartz and felspar are not uncommon.

Many of the minerals present have been alluded to in the previous paragraph, but further discussion is necessary.

Calcite occurs most abundantly. Epidote is present in large pleochroic grains of a yellow colour. Intensification zones of this colouration are noticed, sometimes of irregular outline and sometimes more definitely concentrated in small regions which then very closely resemble allanite. Zoisite is also present. It is distinguished by its comparative lack of colour and its ultra blue interference colours.

The pyroxene which is a member of the diopside-hedenbergite series appears to have been unstable under the conditions of formation of this rock. It is giving place to serpentine and epidote. The former is, no doubt, pseudomorphous after forsterite, which is one of the common derivatives of pyroxene in such rocks as this when they are subjected to pressures which produce the highest grades of metamorphism.

The felspars represented are microcline and microcline-microperthite. They are mostly clear, but cloudy zones are present. Inclusions of calcite and quartz are present. The myrmekitic intergrowths with this last mineral has been mentioned above.

Scapolite is present in some fairly large crystals which show one cleavage quite well. Sphene, graphite, apatite, zircon, magnetite, and possibly monazite occur as minor constituents.

Rock 713.

This rock is much more coarsely grained than No. 667. There is also a pronounced difference in colour, for the present rock has a predominant pink colour where calcite is found and which in parts gives place to light and darker greens where granular epidote and augite are respectively developed.

The rock is seen to be granoblastic under the microscope. The crystalloblastic order is sphene, diopsidic-hedenbergite, calcite, epidote, felspars and quartz. The calcite is seen to be higher than the epidote by its development of well defined hexagonal outlines whenever it is present as a nucleus in the epidote.

The minerals have the characteristics normal to them in these rocks and only the more interesting points will be mentioned.

There is a variety of felspars present, orthoclase, microcline, and highly sodic plagioclase (near albite). Sericitization has taken place to a large extent ; more particularly in crystals of felspar which are very cloudy indeed. The mode of production of the potassic and sodic felspars is seen by the occurrence of quartz, felspar, calcite and epidote. Frequently there is a zoning of minerals which run from outside to centre in the following order : calcite, epidote, felspar, quartz. The epidote has taken up lime not only from the calcite but from the felspar as well. The result has been that there has been a concomitant separation of silica which appears as the nucleus of the whole series. A variant is the replacement of clear felspar and quartz by cloudy felspar and sericite. Such nuclei are as common as the former.

Quartz also occurs as large xeno-blasts which frequently carry numerous small liquid inclusions, each holding a small bubble of gas. Kleeman has observed the same phenomenon in other metamorphic rocks from this area. The light green pyroxene is frequently surrounded by a corona of quartz which separates it from the main calcite mass. Usually the pyroxene is compact, but when poikiloblastic it has as inclusions calcite and plagioclase. The sphene is found irregularly distributed through the rock, but not to any very great extent.

Rock 624.

This is a light-coloured rock composed mainly of calcite, small black grains of diopside and dark green grains of epidote. Large grains of detrital pink felspar and some quartz (possibly vein) make up the rest of the rock. Differential weathering has produced a honey-combed appearance on the exposed surface the removal of the calcareous cement has left rounded grains of quartz and felspar prominently exposed.

The microscopic examination of the rock shows the same general mineralogical composition which, however, is extended to include sphene, apatite, actinolite, zoisite and a little detrital tourmaline. The felspar is found to be microcline.

Textural features are shown more clearly. The crushed nature of the calcite is more obvious. The poikiloblastic epidote grains are a characteristic feature of the rock. The development of sphene and the vein-like nature of the quartz are also points of interest which the microscope reveals.

Rock 1269.

This rock, though definitely gneissic, is most certainly a member of the pyroxene-epidote-marbles. This character is clearly revealed by a microscopic examination of the rock.

Microscopically the rock is seen to consist of bands of white and pinkish quartz and felspar alternating with bands of green epidote and diopside. Veins of quartz (with felspar) and epidote cross the rock. Differential weathering has left bands of the harder green material in relief.

The calcite, which is not very obvious in the hand specimen, is found microscopically, to be the commonest mineral in the rock. It shows to a very marked degree the effects which stress can produce in this very mobile mineral when circumstances are favourable. The cleavage lines are wavy and often the mineral appears quite fibrous. Elsewhere it has even been highly granulated.

The felspar, once more, is microcline. Some sphene, magnetite and apatite are present.

(6) Epidote Marbles.

Included in this group are Rocks 305A, 486, 1165, 551 and 966.

No. 305A is definitely gneissic, whereas No. 486 is considerably more coarse-grained and has relatively less non-carbonate matter.

The mineralogical content includes calcite, epidote, microcline, apatite, granular quartz, scapolite, zircon, muscovite, pale-green actinolite, sphene, tremolite, green biotite, phlogopite and plagioclase. It will be seen that this list is more comprehensive than that of Tilley's group (6). The most important of the additional minerals is scapolite and the others are tremolite and phlogopite.

Detailed Description of Rocks.

Rock 305A.

This is a gneissic rock in which contortion is visible in the hand specimen. It consists essentially of green epidote with white and pink bands of calcite. Black flecks of magnetite are scattered throughout the rock: some others are composed of amphibole.

The rock is granoblastic, consisting of coarse crystals of calcite, and much smaller crystals of idioblastic epidote, sphene, and xenoblastic microcline, plagioclase, quartz, amphibole and phlogopite.

The calcite crystals are usually polysynthetically twinned, and the flexures in the twin lamellae are evidence of the stresses to which the rock has been subjected. The epidote occurs in faintly pleochroic yellows in slightly elongated laths and more equi-dimensional forms. It is idioblastic towards all the other minerals present, except sphene. The microcline is found in clear xenoblastic grains which have a low R.I. and which exhibit the typical cross-hatching under crossed nicols.

The plagioclase is clear, but the twins developed are usually poorly defined. From extinction angle measurements on 010 the plagioclase is determined as $Ab_{65}An_{35}$. Quartz occurs in scattered grains. Small, brown, lozenge-shaped crystals of sphene are among the minor minerals of the rock. The phlogopite is pale brown to colourless, and, in places, shows plications which are the result of stress conditions.

The amphibole present is a pale green tremolite. It shows weak absorption and faint pleochroism in blue-greens and pale yellow-greens. It is usually poikiloblastic, including crystals of olivine, quartz, sphene and magnetite. The magnetite occurs as discrete grains, frequently associated with epidote or sphene.

Rock 486.

This is a coarse-grained holocrystalline rock consisting of light pink to white crystals of calcite in which are set small greenish black crystals of actinolite with an occasional concentration area of greater size. In one place a concentration of brownish green micaceous matter has developed.

Stress effects are clearly seen in the slide. The large calcite crystals have not been able to adjust themselves to the stress conditions as is usually the case and, in consequence, their twin lamellae are bent and the borders of the crystals are much granulated.

The quartz grains present show the same granulation ; the granoblastic quartz particles exhibit very greatly sutured edges. The actinolite is pale green in colour. It is poikiloblastic, enclosing grains of calcite, threads of quartz, and laths of colourless phlogopite or muscovite, as well as granules of sphene and apatite. Pale green to pale yellow brown laths of biotite are present. Other minerals contained in the rock are epidote, plagioclase, microcline, sphene, scapolite and sericite.

The epidote occurs in large honey-yellow idioblastic or subidioblastic crystals. There is some indication of the granulation of this mineral.

The plagioclase is much altered. The metamorphic derivatives are sericite on the one hand and scapolite on the other. One crystal of plagioclase is seen being converted into both these minerals. The difference in the product can be determined by difference in birefringence and optical elongation. Another distinguishing criterion is the elongation ratio, length : width. In the sericite the ratio may reach 6 : 1 but with the scapolite it rarely exceeds 5 : 2.

The microcline occurs in large, clear masses. It is recognised by its low refringence and by occasional suggestions of cross-hatching twin effects.

Apatite is present in its typical form. The sphene assumes its usual colour and lozenge shape. Its genetical relation to calcite is shown by one large crystal having a partially unaltered calcite grain as nucleus.

Other genetic relations are shown by the symplektic intergrowth of quartz and actinolite, the myrmekitic intergrowth of plagioclase and quartz, and the separation of minute rectangular masses of higher R.I. in the felspar, and the progression from a radial and plumose aggregation of zoisite to calcite and then to a thin shell of epidote.

Rock 1165.

This is a gneissic rock in which the bands consist of pinkish red felspar, dull green epidote, and a lighter coloured felspathic mass penetrated by thin veins of epidote.

The calcite present in this rock is certainly a deposition from solution. It is found in very minute crystals in veins throughout both the felspathic and epidotic regions of the rock. These veins are the more prominent in the felspar where a veritable mesh-work arrangement of them has been formed by infiltration of liquid along the lines of weakness. In the epidote, the veins are by no means so numerous, nor so haphazard in direction. The calcite is localized in a few somewhat wider parallel cracks.

The felspar of the red bands is microcline-microperthite. Apart from the veins of calcite, its cracked nature, and its relative freedom from inclusions, save for a little flaky green chlorite, there is no need for comment.

The epidote (including zoisite) of this rock is much granulated, and where its colour is not obscured by dirty masses of kaolin inclusions (from felspar) it is seen to have a pleochroic yellow colour. The interstices between the epidote grains are filled by granulitic felspar, which too is microcline-microperthite, and possibly a little quartz. Some haematite and shreds of chlorite are also present.

Rock 551.

This rock is coarse-grained and consists of white calcite and green epidote with some pink crystals of detrital felspar. Very subordinate dark green pyroxene is also present.

Under the microscope the mineralogical content is seen also to have some sphene, fibrous pale green pleochroic actinolite and apatite. The felspar is found to be microcline. In other respects, as well as those listed here, the rock is like the other members of this class.

Rock 966.

This is a modified epidote-marble. It is traversed by a vein of quartz and felspar.

This rock is composed almost entirely of reddish brown coarsely crystalline calcite. well-formed crystals of pistachio green epidote are also present. Some quartz and felspar occur as vein-material in one part of the rock. The thin section examined was cut from this part of the rock.

Microscopically calcite is found to be the commonest mineral.

The felspar is saussuritised acidic plagioclase. In one place long thin laths of zoisite have developed along cleavage lines in the felspar.

The epidote presents the usual characteristics: granular, yellow, pleochroic, etc.

A little dark green diopside is present.

Pale green, fibrous, pleochroic actinolite is present. Occasionally it includes zircon with an attendant pleochroic halo.

Apatite, sphene and rare pleochroic detrital tourmaline are present.

(7) Tremolite Rocks.

These rocks are not quite the same as Tilley's group (7) to which he gives the name Carbonate-free Calc Silicate Rocks. Each of the members of the present group (7) (Nos. 860, 856 and 1221) has a small carbonate content. There is reason for believing that some of their calcite is secondary and, in consequence of this, the rocks may be more properly grouped under the heading given by Tilley.

Detailed Descriptions of Rocks.

Rock 856.

This rock consists of pale green acicular tremolite grouped in radial and plumose forms. The arrangement suggests that the interlocking of fibres would make the rock extremely hard and tough. A band of white quartz has been deposited in the tremolite, with the consequent production of a gneissic appearance for the rock.

The same features are revealed in the slide which was cut from the tremolite portion of the rock. The long bladed laths of the amphibole have the same arrangements as mentioned in the description of the hand specimens. Colour is practically wanting except for a few places where a more intense yellow is seen produced by the hydration of the little iron present. There is in this rock only a very minor development of calcite.

Rock 860.

This is a light green pyroxene rock in which darker bladed crystals of actinolite and veins of pink felspar are set. The rock is dense and very compact.

The microscope resolves the rock essentially into a mixture of pyroxene and amphibole. The pyroxene is at the hedenbergite end of the diopside-hedenbergite series. This suggests abundance of lime and relatively not much magnesia in the original sediment. The bladed nature of the actinolite (which is nearly colourless in section) is accentuated in the slide.

The rock has been exposed to the action of hot solutions in at least two subsequent stages. The first introduced the quartz and orthoclase which are found in the rock. These minerals, more especially the former, contain numerous inclusions, actinolite needles, zircons, and sphene. These minerals are practically confined to these areas, thus showing that the titanium required for the sphene, as well as the zirconium, was brought in by these solutions. Both minerals, but again more especially the quartz, are highly granulated. This points to considerable compression after the crystallisation of these two minerals.

The other solution mineral is calcite. This occurs along definite veins in the rock. These cross the pyroxene and amphibole at right angles to the length of the laths. This indicates that lines of weakness due to tension had been set up and the solution had thus been able to penetrate the rock. The calcite veins cross the quartz mortar-structure regions as well as the other parts of the rock. Hence we can conclude that this infiltration was subsequent to the other.

Rock 1221.

This rock consists of two sections. One is composed essentially of pale green pyroxene with subsidiary acicular green amphibole. The other is composed of pinkish felspar in which are found some of the pyroxene and a dull brown mineral, possibly rutile.

The slide shows mainly pyroxene and amphibole, although areas containing calcite and sphene are seen. The pyroxene is diopside.

(1) The pyroxene shows peculiar dull brown parallel bands which are perpendicular to the *c*-axis. These are twin lamellae, on (001), where a concentration of rejected matter has been made. The calcite is definitely secondary. The grains are small and appear along infiltration veins. They occur associated with the sphene some, at least, of whose composition was contained in the same liquid.

(2) The tremolite is being formed at the expense of the diopside. The change is shown by the degradation of the pyroxene at its edges and sporadically throughout its mass.

The above description is made of the region free from pink felspar.

Another section was cut across the well-defined border of the two zones which showed the following properties of the rock.

The felspathic portion has been almost entirely converted to sericite. Larger pseudomorphous masses of this mineral occur as kinds of porphyroblasts in a groundmass of similar but much finer grained matter. Other much more infrequent porphyroblasts in the same zone are of tremolite which is considerably chloritized. Some limonite and very occasional sphene constitute the accessory minerals.

The other zone is mainly composed of pyroxene which appears very much clearer and less altered than in the first section. Here is a little tremolite, no calcite, and practically no sphene.

(7a) Diopside-Actinolite-Gneiss.

Rock 958.

In the hand specimen the rock is gneissic, consisting of fibrous actinolite and paler green prismatic diopside. Also present are regions of quartz which represent vein-areas. Associated with this quartz are yellowish flakes of weathered mica and pale purple globular fluorite.

The slide was made from the diopside-actinolite areas.

The diopside occurs in large massive crystals which occasionally poikiloblastically include small laths of actinolite.

A chemical analysis of the diopside of this rock, made by J. C. H. Mingaye, F.I.C., gave the following composition :—

SiO_2	53·66
Al_2O_3	0·79
FeO	2·70
Fe_2O_3	----
MnO	0·38
CaO	24·26
BaO	absent
SrO	absent
MgO	17·14
K_2O	0·25
Na_2O	0·10
H_2O	0·92
Li_2O	present
TiO_2	0·04
P_2O_5	absent
CO_2	absent
Total	100·24

The extinction, $Z \wedge c$, is 38°. The mean index of refraction, $n\beta = 1{\cdot}680$. The double refraction is about 0·030 which suggests that $n\alpha = 1{\cdot}665$ and $n\gamma = 1{\cdot}695$ approximately. These optical characteristics and the chemical composition of the mineral show it to be almost pure diopside. There is a little excess Al_2O_3, but so little that it can be neglected. Alkalies and titania are also negligible. The ferrous iron and manganese show that the mineral is a member of the diopside-hedenbergite series which has diopside not less than 94 per cent.

The actinolite ordinarily occurs in irregularly arranged masses of pale prisms. In places a change to a talc-like mass has occurred. Very little secondary calcite is associated with the actinolite.

Small colourless grains of quartz are infrequently seen.

Pale brown slightly pleochroic masses of phlogopite which is altering to chlorite are present.

(8) Tremolite-Epidote-Marbles.

Although Tilley has a group of Tremolite Marbles Group (2) it has no epidote, and a group of Epidote Marbles Group (6) which contains very subordinate actinolite he has no group for rocks in which both epidote and tremolite figure to some degree. In consequence of this it has been found necessary to form a new group which is called the Tremolite Epidote Marbles and to which belong the two rock species Nos. 742 and 818.

Rock 742.

This is a very light-coloured rock, consists mainly of calcite but it carries some recognizable grains of green epidote which have assumed a quasi-nodular form.

Variations in grain size of the layers of the original sediment are shown by the differences in the size of the calcite crystals of the rock. There are two distinct divisions one coarse and the other finer. Other points of interest concerning the calcite are its tendency to granulation, especially in the neighbourhood of actinolite, and the curved twin lamellae which show that even this mobile mineral was not able to accommodate itself to the conditions of stress which obtained.

Of the other leucocratic minerals present acid plagioclase is the most prominent. It is formed in long, clear crystals and also in equally large turbid ones which show sericitisation. The extinction is usually undulose which prevents an exact determination of the nature of the plagioclase. It exhibits pericline, carlsbad and albite twins. Some microperthite has developed.

Quartz also is prominently developed. It has its usual characteristics. There is some little apatite. Among the dark mineral components the most interesting are actinolite and zoisite which is found almost to the entire exclusion of epidote. This last mineral is present, however, in some pleochroic grains. The actinolite seems in places to have been derived from pre-existing pyroxene, in these rocks an evidence of retrograde metamorphism. The actinolite occurs in large green prismatic crystals sometimes remarkably intergrown with equally large, pale green, faintly pleochroic, granular crystals of zoisite. In other places, the actinolite has not such an intense colour nor such a compact nature. It then contains inclusions of calcite and quartz.

Sphene is present to a greater extent than in most of the rocks of this suite. It is dark brown in colour, assumes its typical form, arranges itself in more or less parallel alignment, and sometimes shows multiple twinning.

Rock 818.

This is a dense, dull green rock in which is set a vein of milky quartz. The hand specimen is seen to contain the minerals epidote, actinolite and garnet ; the last does not figure in the slide made.

The same minerals are seen under the microscope to comprise the great body of the rock. The epidote is very light coloured (in pale green-yellow) but it is easily recognized by the relief and moderate birefringence. It has been silicified by the recently introduced quartz with the resultant conversion into fibrous amphibole, very fine needles of which are frequently seen as inclusions in quartz where this last mineral borders epidote. Calcite is not infrequently an inclusion in the epidote. Some zoisite and allanite are present.

The fibrous amphibole tremolite is being derived from antecedent more compact hornblende. Oases of this earlier amphibole are set in large areas of finely felted derivative matter. The more recent amphibole is suffering chloritization to some extent.

Reaction between quartz and epidote is evidenced by the difference in optical properties (birefringence mainly) of the borders of epidote crystals which are found included in the quartz. Other inclusions in the quartz are calcite, tremolite, sphene and haematite.

The sphene, which is not only found in the quartz but sporadically through the whole rock, is much paler in colour than usual. This is particularly noticeable when it is associated with the epidote, which seems to have some genetical connection with it.

(9) Forsterite-Phlogopite-Marble.

The remarkable development of mica in Rock No. 741 marks it off from the group of forsterite marbles.

Rock 741.

The rock is not dark although considerable areas are brown in colour. The rest, occupied by calcite, is quite white.

The rock which is somewhat friable tends to be schistose. This is due to a very large development of a brown mica in the calcite base.

Under the microscope the rock seems to consist of calcite, colourless pyroxene, forsterite, pale brown to colourless mica. The calcite occupies only about one quarter to one third of the rock. It assumes its ordinary characteristics.

The light coloured pyroxene gives an extinction of 42° which indicates a member of the diopside-hedenbergite family with 80% diopside and 20% hedenbergite.

The forsterite is present in rounded particles showing very high relief. The mineral is serpentinized centrally, and occasionally along cracks which have developed in it. The colour of the serpentine varies from a very intense yellow to a much paler shade of the same colour.

As has been said above, the mica is pleochroic in pale brown and colourless, the absorption is $Z > X$, where Z is pale brown and X is colourless. Basal sections (where pleochroism is not so intense) are fairly common. The birefringence of these sections is very low. It is biaxial (2V small) and negative. These are all characteristics of phlogopite, and this kind of rock is favourable to the development of this mineral.

The phlogopite shows signs of strain. Curved laths are very commonly developed. It also shows very slight indications of change to chlorite. Pale green patches of low birefringence are occasionally seen.

Accessory minerals include graphite, magnetite and haematite.

APPENDIX.

Contorted-Felspathic-Marble.

No. 535.

This is a very dense, fine-grained, highly contorted, light-coloured rock which consists mostly of calcite, but in which is set very fine felspathic and sericitic matter as fine bands. The mica is pale green in colour and when present as fine particles in the calcite it gives this hue to that mineral.

Little more is revealed by a microscopic study of the rock. In places the felspar is found to be microcline, but usually it is so highly saussuritized that no attempt can be made optically to determine its character.

The folding of the rock seems to have produced small lines of weakness in the calcitic rock along which the felspathic and sericitic matter entered. But it is possible that the two divisions were present before the folding and that the contortions now seen represent a folded calcite-felspar gneiss.

III. REVIEW OF THE METAMORPHIC PROCESSES INVOLVED.

The final mineralogical content of this group of rocks has been determined by :—

(i) the range of chemical composition of the original sediment;

(ii) the grade of metamorphism to which the various classes have been subjected, and (ii) involves:

(a) the nature of the metamorphic process proper, whether mainly thermal or mainly dynamic (including thermodynamic); and, in certain instances

(b) the modifications consequent on the introduction of volatile matter from the intruding magma.

It will be seen that we have rejected any suggestion that during metamorphism material has been added to the rock, except when we find chondrodite, scapolite, considerable apatite, allanite, etc., in the rock. We are thus led to conclude that the original rock in classes (1), (2) and (3) was a dolomite, that the rocks in classes (4) and (5) were more calcareous, and that the rocks in classes (6), (7) and (8) were calcareous limestones carrying detrital material of a siliceous and (possibly) felspathic nature. Class (9) was represented by a dolomite carrying considerable detrital mica (possibly) accompanied by some potash felspar.

Although occasional mention will be made hereafter of the presence of minerals whose formation requires the assistance of " mineralisers " it will be well to deal with this particular phase immediately and so co-ordinate what would otherwise be a series of disconnected remarks on the matter. In the sequel the writer is much indebted to the work of Harker which he calls "Introduction of Fluorides and Chlorides," op. cit., pp. 123-128. He shows that phlogopite is the most widespread mineral which indicates the presence of flourine during the metamorphism of impure dolomites and magnesian limestones. Clarke assumes that the ideal composition is $H_2KMg_3 Al(SiO_4)_3$, with partial replacement of H by HF in the colourless varieties, but the brown and yellow varieties have some content of iron. Seeing that phlogopite is fairly common in some of the rocks under discussion in the present work, it seems reasonable to suppose that flourine and other fluxes have operated in the production of the degree and kind of crystallinity of other minerals in those rocks where phlogopite occurs. Chondrodite is not well represented, but it may have been present on a much larger scale, and, like olivine, have been replaced by pseudomorphous serpentine, a mineral to which it is readily converted. No blue or green fluo-apatite has been met in the investigation of these rocks although Harker cites it as a common accessory of phlogopite and chondrodite.

Hydroxyl as volatile, in the place of flourine, has not been very operative in these rocks.

That chlorine has been an effective flux is seen by the comparatively frequent formation of scapolite in this suite of rocks. Here we have examples of plagioclase being converted to scapolite (and to muscovite, also, showing that some hydroxyl has been incorporated on occasion). The part played by chlorine in the formation of chlor-apatite has been indicated in the actual description of individual rocks in Part II above. As stated there, this is a necessary explanation of the very common occurrence of this mineral in some of these rocks.

There is evidence that some of the rocks have been subjected to a kind of metamorphism where temperature controls the mineralogical and textural alterations, and some of the rocks have undergone metamorphism of an essentially dynamic nature.

(1) Forsterite Marbles.

Of the dolomitic rocks which have suffered dominant thermal metamorphism there are those of classes (1) and (9). The presence of forsterite with the entire absence of wollastonite shows the preferential or selective displacement of carbon dioxide by silica in the carbonate of magnesium relative to the carbonate of calcium, and, at the same time, shows that dedolomitization is incomplete, or, that the displacement of CO_2 in $CaCO_3$ by SiO_2 has been inhibited by pressure. The well-known equation for dedolomitization is

$$2\,(Ca, Mg)CO_3 + SiO_2 \longrightarrow CaCo_3 + MgSiO_4 + CO_2.$$

Usually, serpentinization, the hydration of the olivine, has proceeded to some extent. In some instances this change has resulted in the complete alteration of the olivine with the consequent formation of an ophicalcite as in No. 316. The occurrence of colourless spinels points to some alumina in the original sediment possibly in the form of detrital chlorite. If the temperature reached is at all considerable amphiboles are unstable and alumina instead of going into pyroxene appears as octahedra of colourless spinel. The presence of magnetite could be accounted for in a similar way where ferrous iron plays the role of magnesium and the ferric iron that of aluminium.

(2) THE MEMBERS OF GROUPS (2), (3) AND (7).

Tyrrell in his "Principles of Petrology" (pp. 298-300) states in detail the stages of dedolomitisation which occur according to the amount of silica present as an impurity in the dolomite is relatively large, intermediate or small. He indicates that the silicate minerals formed are respectively diopside, tremolite and forsterite if the metamorphic process is essentially thermal. Now, it may seem that as we have tremolite, tremolite-diopside and diopside-marbles represented in the collection as well as forsterite marbles these three types are products of thermal metamorphism as well as the fourth. That this is not tenable becomes apparent when the relative proportions of tremolite and diopside in these rocks are considered. The two are present in all gradations from almost diopside-free rocks to almost tremolite-free ones. If the forsterite marbles were formed under the same conditions as the members of the other three groups then we would rightly expect representatives of intermediate groups between the forsterite-marbles and the tremolite-marbles (at least) to be present. An investigation shows most clearly that this is not so. The only other hypothesis which seems reasonable is that the conditions of metamorphism that obtained for group (1) were different from those of groups (2), (3) and (7).

The same general textural characteristics and specific mineral properties of those minerals common to groups (2) to (8) show that they have been formed under like conditions save for differences which must have held for the production of different types (difference in mineral content, detrital impurities, but not in the metamorphic conditions proper.)

The grades of metamorphism of impure magnesium limestones as set forth by Harker (pp. 256-258), are clearly shown by this group. In group (2) we have representatives of the lowest grade, the tremolite-marbles ; and the impurities present are those listed by Harker. The assumption of alumina into the amphibole has resulted in the production of edenite in some members of the group. At least one rock (a member of group 15), viz., No. 713, has, however, been subjected to sufficiently powerful and prolonged metamorphic conditions that it has reached the highest stage where even the aluminous hornblendes are unstable and give place to diopside and forsterite. The forsterite is not present as such, but is represented by pseudomorphs of serpentine.

(3) THE CALC-SILICATE-ROCKS PROPER. MEMBERS OF GROUPS (4), (5), (6) AND (8).

The minerals developed, epidote, some little lime-felspar, diopsidic-pyroxene, and green hornblende but no forsterite, reveal that the sediments from which these rocks were formed were highly calcareous shales and slates rather than impure dolomites. The presence of garnet and the absence of biotite in group (4) show two facts, one positive and the other negative. The first is that here the sediment must have been locally rich in lime, and the other is that Goldschmidt's hypothesis that these two minerals do not occur together is confirmed by these examples.

The poikiloblastic nature of the garnet, and the frequently sericitised felspar indicate that retrograde metamorphism has been operative to some extent at least.

These rocks have, of course, been produced by a metamorphism fundamentally thermal. In consequence we find that in some of the lower grades minerals like graphite, detrital tourmaline and muscovite have merely recrystallised without further change. (Harker, p. 88). The microcline, so frequently referred to, indicates a higher grade. We have one very good example of the incorporation of titanic acid with lime to form sphene in Rock No. 486.

(4) The Forsterite-Phlogopite-Marble.

Here the sediment is assumed to have contained local patches rich in mica.

EXPLANATION OF PLATE XIV.

Fig. 1. *Epidote-felspar-marble*: Specimen 1165, erratic, Cape Denison.

The illustration shows small veins of calcite crossing a large felspar crystal. The photograph was taken with nicols crossed, in consequence the felspar appears quite black. Mag. 66 diams.

Fig. 2. *Tremolite-epidote-marble*: Specimen 742, erratic, Cape Denison.

The microphotograph shows a remarkable intergrowth of tremolite (shaded) and zoisite (clear). Mag. 44 diams.

Fig. 3. *Pyroxene-epidote-marble*: Specimen 713, erratic, Cape Denison.

A zoning arrangement of reaction minerals is shown. The minerals from centre to outside are quartz, felspar, epidote, calcite. Mag. 80 diams.

Fig. 4. *Tremolite-marble*: Specimen 486, erratic, Cape Denison.

The microphotograph shows a large crystal of sphene with nuclear calcite. Mag. 125 diams.

Sydney: Thomas Henry Tennant, Government Printer—1940.

Fig. 1.

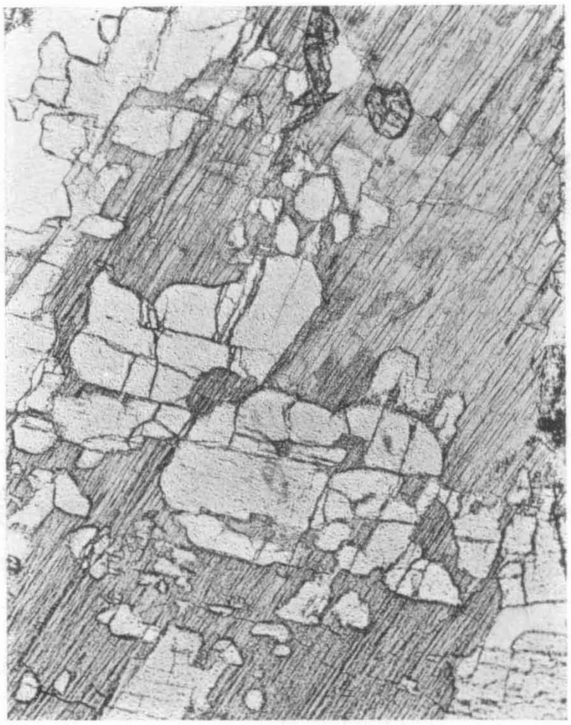

Fig. 2.

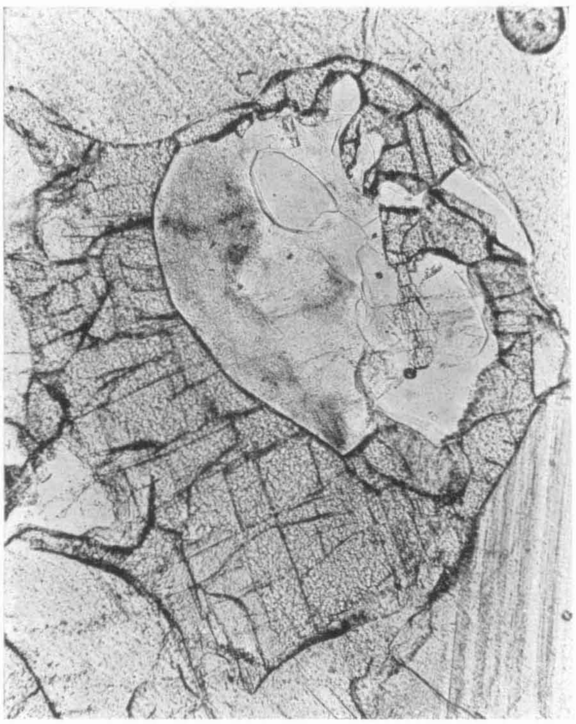

Fig. 3.

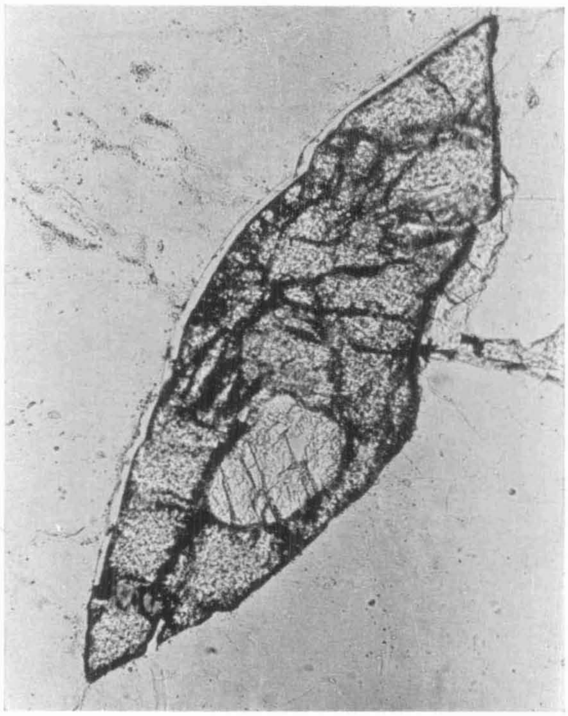

Fig. 4.

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