AUSTRALASIAN ANTARCTIC EXPEDITION

1911-14.

UNDER THE LEADERSHIP OF SIR DOUGLAS MAWSON, KT., D.Sc., B.E.

SCIENTIFIC REPORTS.

SERIES A.

VOL. III.

GEOLOGY.

PART II.

THE METAMORPHIC LIMESTONES

OF

COMMONWEALTH BAY, ADELIE LAND.

BY

C. E. TILLEY, B.Sc.

WITH TWO PLATES.

PRICE: ONE SHILLING AND SIXPENCE.

Printed by Alfred James Kent, Acting Government Printer, Phillip-street, Sydney.—1923.

ISSUED JULY, 1923.

SERIES A—REPORTS.

HON. EDITOR: PROF. SIR DOUGLAS MAWSON, KT., D.Sc., B.E., University of Adelaide.

VOL.		PRICE. £ s. d.
I.	GEOGRAPHY AND PHYSIOGRAPHY. *(In preparation.)*	
II.	OCEANOGRAPHY.	
	PART 1.—SEA-FLOOR DEPOSITS FROM SOUNDINGS—By FREDERICK CHAPMAN, Ass. Linn. Soc. (Lond.), F.R.M.S., &c., National Museum, Melb.	0 6 0
III	GEOLOGY. *(Adelie Land and King George Land.)*	
	PART 1.—THE METAMORPHIC ROCKS OF ADELIE LAND—By F. L. STILLWELL, D.Sc., Aust. Antarc. Exped. Staff	2 2 0
	„ 2.—THE METAMORPHIC LIMESTONES OF COMMONWEALTH BAY, ADELIE LAND. By C. E. TILLEY, B.Sc.	0 1 6
	„ 3.—THE DOLERITES OF KING GEORGE LAND AND ADELIE LAND. By W. R. BROWNE, D.Sc., Lecturer, Geological Department, Sydney University	
	„ 4.—AMPHIBOLITES AND RELATED ROCKS FROM THE MORAINES, CAPE DENISON, ADELIE LAND. By F. L. STILLWELL, D.Sc., Aust. Antarc. Exped. Staff	
IV.	GEOLOGY. *(Will deal principally with Queen Mary Land.)* *(In preparation.)*	
	PART 1.—THE ADELIE LAND METEORITE. By P. G. W. BAYLY, F.I.C., and F. L. STILLWELL, D.Sc.	0 1 6
V.	GEOLOGY *(Macquarie Island).* *(In preparation.)*	
VI.	GLACIOLOGY. *(In preparation.)*	

AUSTRALASIAN ANTARCTIC EXPEDITION

1911-14.

UNDER THE LEADERSHIP OF SIR DOUGLAS MAWSON, KT., D.SC., B.E.

SCIENTIFIC REPORTS.

SERIES A.

VOL. III.

GEOLOGY.

PART II:

THE METAMORPHIC LIMESTONES

OF

COMMONWEALTH BAY, ADELIE LAND.

BY

C. E. TILLEY, B.Sc.

WITH TWO PLATES.

PRICE: ONE SHILLING AND SIXPENCE.

Printed by Alfred James Kent, Acting Government Printer, Phillip-street, Sydney. – 1923.

ISSUED JULY, 1923.

THE METAMORPHIC LIMESTONES OF COMMONWEALTH BAY, ADELIE LAND.

BY

C. E. TILLEY, B.Sc.

WITH TWO PLATES.

CONTENTS.

		PAGE.
I.	Introduction	231
II.	Petrography :—	
	1. Forsterite-Marbles	232
	2. Tremolite-Marbles	234
	3. Diopside-Tremolite-Marbles	235
	4. Pyroxene-Garnet-Marbles	236
	5. Pyroxene-Epidote-Marbles	237
	6. Epidote-Marbles	238
	7. Carbonate-free Calc-silicate Rocks	239
III.	Review of the Metamorphic Processes involved	240
IV.	Paragenesis	242
V.	Explanation of Plates	244

I. INTRODUCTION.

THE group of rocks which are described below represent a collection of erratics made from the moraines at Cape Denison, Adélie Land. With reference to their occurrence, Sir Douglas Mawson states ([1]) :—

"None of them were met *in situ*; but the evidence of their occurrence in certain moraines (their distribution), and the evidence of the rock types which do actually outcrop *in situ* on that coast of Adelie Land, point to the calc-silicate series being located under the ice Cap to the south-west of Cape Denison, probably in the depression at the head of Commonwealth Bay, between Cape Denison and Cape Hunter. This is rendered more likely, since this calc-silicate series would

---

[1] Personal communication.

erode more rapidly than the tougher schists and gneisses which appear in the visible outcrops thereabouts. There is no doubt that the rocks of this series represent phases of alteration of the same sedimentary series. The alteration has been effected, it would appear, by the intrusions of extensive granitic magmas now appearing as gneiss typically developed at Cape Denison and the Mackellar Islets."

The carbonate sediments 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. This group of rocks, however, with two exceptions, still possesses a content of free carbonate mineral. Its quantitative amount is dependent in some cases on the degree of metamorphism of the rocks concerned, and in others on the quantity of foreign material present in the original sediment, capable of chemical reaction with calcite or dolomite. Amongst these rocks, there is no example which suggests any extensive addition of material from magmatic sources, other than purely volatile constituents.

According to their mineralogic content, these rocks may be divided into the following classes :—

(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.

The description of these various classes can now proceed *seriatim*.

II. PETROGRAPHY.

(1) Forsterite-Marbles.

The rocks characterised by the presence of magnesian olivine, comprise the following :—Nos. 135, 137, 307, 318, 392, 395, 402, 653, 992, 993, 994.

As a class, they are medium-grained, white to grey rocks. The majority are characterised by the presence of yellowish-green pseudomorphs of serpentine after forsterite, and these project on weathered surfaces. In No. 395, serpentine veins the rock in two parallel bands, in the centres of which narrow venules of chrysotile asbestos are developed. Nos. 135 and 137 are characterised by the presence of orange-coloured crystals with vitreous lustre, and these on examination prove to be chondrodite. In No. 135, this mineral is largely developed along a plane surface. Flakes of light-coloured mica are sparingly distributed in a number of these rocks.

It will be sufficient to describe the nature of the minerals of these rocks as a whole, points of particular interest shown by any of them being refererd to in the course of this description.

The constituent mineral are *dolomite, calcite, forsterite, chondrodite, spinel, hornblende, diopside, phlogopite, serpentine*, and *magnetite*.

The minerals which characterise the class are dolomite, calcite and forsterite, the remainder forming a subordinate group, which, while often abundant, yet rank as accessory constituents to the class.

Dolomite.—While the ordinary method of differentiation between this mineral and calcite is the staining method of Lemberg, yet the criteria which have been found to operate in metamorphosed dolomites of other regions are often of use here. These include the different types of twinnning shown by dolomite and calcite respectively, and the degree of turbidity.

As earlier noted [1] the dolomite twinning on the $02\bar{2}1$ plane is sufficiently distinctive in favourable sections, and the turbid character of the calcite also affords a further means of discrimination. This polysynthetic twinning in dolomite suggests that a secondary twinning along a glide plane is involved.

Calcite is quite frequently twinned in these rocks and the turbidity often observed is due to the presence of minute inclusions which are probably carbonaceous.

Forsterite.—The usual habit is in rounded grains or prismatic crystals, in which the trace of the 010 cleavage parallel to the elongation is imperfectly developed. In rocks Nos. 137 and 318 the olivine is almost completely free from decomposition, but in the remainder all stages of serpentine development are revealed. Usually this is a colourless type, but in some cases it appears of a pale yellowish green tint. In No. 992 the serpentine is accompanied by granules of secondary magnetite. Where developed as an inclusion in the serpentine, the carbonate is usually calcite.

Chondrodite.—Orange yellow crystals of a member of the humite group of minerals are developed in rocks Nos. 135 and 137. In No. 135 they are partly arranged along a plane through the rock, as if indicating the passage of fluorine bearing vapours along a bedding plane or other surface of interruption.

In thin section the mineral is noticeably pleochroic, varying from golden yellow (X), to colourless (Y, Z). Twinning is faintly developed in some sections. The extinction measured from the 001 cleavage, the plane of lamellar twinning, corresponds to that of chondrodite in the section available, reading 20 degrees. Clinohumite is thus excluded.

There is no trace of intergrowth with forsterite, and serpentinisation proceeds in the same manner as in normal olivine.

[1] Geol. Mag., Vol. lvii, 1920, p. 453.

Spinel.—The spinel of these rocks is usually the colourless magnesia spinel developed in rounded grains or more rarely subidioblastic with octahedral outline. It occurs isolated in the carbonate minerals or may be intimately associated with forsterite, occasionally enclosed in the outline of the latter.

In No. 992, the spinel has the green colour of the pleonaste type, and is there associated with magnetite which is developed peripherally and along cracks. It is usually quite free from alteration, but in some examples has developed a peripheral ring of colourless serpentine.

Hornblende.—A colourless amphibole is sometimes abundantly developed in these rocks. This is especially the case in rocks No. 318. In this rock, the hornblende is developed as subidioblastic crystals enclosing grains of forsterite, and also as narrow corona-like rims to the same mineral. The mineral shows the typical amphibole cleavages, and cross-sections show the emergence of an optic axis, with the optic axial plane bisecting the obtuse intercleavage angle. These grains are optically positive, and there can be no doubt that the mineral is edenite, and not the normal tremolite. Moreover the extinction angle exceeds the value for this latter type. Tremolite is, however, not absent from these rocks, but is sparingly developed.

Diopside is present as an accessory constitutent in clear colourless grains, with prismatic habit. In No. 395 it is present with tremolite fringing a band of serpentine. There is no definite evidence however to suggest that the serpentine has a pyroxenic derivation. The bands in this rock, with their accompanying chrysotile venules are essentially of forsterite derivation.

Phlogopite.—The colourless mica which is a frequent member of these rocks is a type with very small optic axial angle, approaching uniaxiality, being the magnesia-rich phlogopite variety common to metamorphosed dolomites.

(2) Tremolite-Marbles.

This class includes the following rocks: Nos. 306, 306a, 355, 406, 673, and 707. The distinct habit of crystalline schists is given to these rocks by the abundant development of fibrous amphibole. They are grey to green-grey rocks in which the amphibole is present in light-green fibres often with a parallel orientation. This, however, is not a constant feature, the porphyroblasts of tremolite being developed as in No. 406 in diverse orientations.

A radiate arrangement appears in the lighter-coloured rock No. 707. On weathered faces the more resistant amphiboles usually project from the general surface.

The constituent minerals are *dolomite, calcite, tremolite, phlogopite, biotite,* (*chlorite*), *magnetite,* and *apatite.*

Dolomite is again revealed by the characteristic type of twinning, and both it and the calcite are universally twinned on a polysynthetic scale.

Tremolite is a general constituent in idioblastic prisms, with positive elongation, negative sign and large optic axial angle. It is colourless in thin section, but macroscopically may develop a pale-green tint indicative of the presence of the actinolite molecule.

Phlogopite is colourless to pale yellow-green, and slightly pleochroic and always with a very small optic axial angle.

Brown *biotite* is present in No. 355, and shows peripheral alteration to a light-green chlorite. The phlogopite molecule is probably present in solid solution in its constitution. It is associated with highly refracting and birefringent prisms of rutile, which are of secondary origin, and result from its degradation. The remaining constituents of these rocks call for no special remark.

(3) Diopside-Tremolite Rocks.

Two rocks are strictly included within this class, Nos. 303 and 657. No. 651 may be considered here for while tremolite is absent, calcite and diopside are the chief constituents.

No. 303 is a coarse-grained grey rock with large crystals of diopside measuring up to 1 inch or more in length. It is associated with light-green fibrous amphibole. Pink-coloured calcite is sparsely distributed, and quartz can also be recognised macroscopically.

No. 657 is a finer grained rock in which on weathered surfaces, the new-formed silicates project. As such, can be recognised biotite, mica and green diopside.

No. 651 is a flesh-coloured crystalline marble containing porphyroblasts of light-green diopside.

The constituent minerals of these rocks are *calcite, diopside, tremolite, actinolite, biotite, plagioclase, titanite, zircon, apatite,* and secondary white *mica*. Dolomite has not been recognised in thin sections by the twinning, nor in those sections examined by staining. In No. 651 all carbonate can be decomposed in dilute hydrochloric acid.

The colourless *pyroxene* of No. 303 shows a lamellar twinning, and parting planes parallel to the 001 and 100 faces. The extinction angle $Z \wedge c$ is 41°. In No. 657 the pyroxene is a colourless to pale green type. The colourless *tremolite* of No. 303 is fibrous parallel to the c axis and is wedged between larger crystals of diopside. The amphibole of No. 657 is distinctly coloured and pleochroic in light-green tints. Tremolite in this rock is also a constituent of pseudomorphous assemblages of white mica and zoisite, which in some cases can be shown to take the place of plagioclase felspar.

Plagioclase is developed in rounded grains, sometimes with twinning lamellæ after the albite and pericline laws. The more basic types are the less stable, giving rise to pseudomorphs in which mica and zoisite are important constituents. There are rounded grains whose refractive index approximates to that of canada-balsam, and appear to be near oligoclase in composition.

Biotite is present in flakes showing a brown to pale-yellow pleochroism.

A crystal of a mineral showing parallel intergrowth of several individuals with good crystal outline, is developed in this rock. It is pleochroic in bluish-green to yellow-green with brown tints, is optically negative, and an optic axial plane perpendicular to the elongation, the sign of which is negative. The pleochroic tints are those of soda amphiboles, and the extinction is oblique (14 degrees). The position of the optic axial plane cannot be the symmetry plane, however, if prismatic habit obtains. The only metamorphic soda amphibole in which the optic plane is perpendicular to the 010 face is crossite. In the absence of further sections, no definite determination is possible.

(4) Pyroxene-Garnet-Marbles.

Under this class come the rocks Nos. 658, 730, and 849. They are essentially types which would be grouped under the term "Kalksilikatgneise" by German and Scandinavian petrographers.

No. 658 is a dark-coloured banded rock, consisting of layers of pink calcite in which silicate minerals are sparingly distributed, alternating with bands rich in greenish-black pyroxene, white felspar, and thin layers of brown garnet.

No. 730 is also a banded calc-silicate-gneiss, showing layers of flesh-coloured calcite containing greenish-black pyroxene, and porphyroblasts of garnet intimately associated with epidote. Such a band is separated from finer-grained bands rich in felspar and pyroxene, by narrow layers of pyroxene and epidote.

No. 849 shows large grains of dark-brown garnet, pyroxene, and yellowish-green epidote in addition to calcite and colourless silicates.

These banded rocks with varying mineralogical composition attest the changing composition of the original carbonate sediment during its deposition.

The constituent minerals of these rocks are *calcite, pyroxene, garnet, epidote, scapolite, microcline, titanite, actinolite, quartz, apatite, magnetite and plagioclase.*

The pyroxene of No. 658 is green in colour and noticeably pleochroic: X = yellow-green, Y and Z = sea-green. The value of the extinction $Z \wedge c > 48$ degrees, and this figure when considered with the colour of the mineral in thin section indicates that the hedenbergite molecule must dominate, but that a content of sesquioxides is also present. The pyroxenes of Nos. 730 and 849 are also green in thin section, and have a high extinction-angle corresponding to a content of hedenbergite. The *garnet* of these rocks has a clove-brown colour very similar to that of the associated titanite. It is not idioblastic, and is often moulded on the green pyroxene. It is always isotropic. In No. 658 it is associated with green pyroxene, and may enclose the other minerals. In No. 730 it usually forms a core to the epidote-garnet aggregates, the central garnet being enclosed by a narrow corona of pleochroic epidote.

From its associations the garnet would be expected to consist largely of the grossularite and andradite molecules. The refringence of the garnet as measured from fragments in No. 849 is somewhat greater than 1·78.

Epidote is xenoblastic. In No. 730 it is essentially a corona mineral, and is found as such surrounding garnet, pyroxene, scapolite plagioclase, and calcite. Around garnet it is often closely associated with quartz in vermicular intergrowth. In these intergrowths calcite is often included, and they correspond to the symplektitic structures of Sederholm.[1] The epidote shows a well-developed basal cleavage, and is pleohroic in yellow-green tints.

Uniaxial grains of *scapolite* of negative sign and elongation is an abundant constituent of No. 658. A typical pflaster texture is often given by this constituent. The birefringence approximates 0·03. A secondary white mica with positive elongation is a common alteration product. In No. 730 scapolite is absent and plagioclase takes its place. Rock No. 849 shows pseudomorphs after (?) scapolite, in which white mica and zoisite are the prime constituents. The birefringence of the unaltered mineral of these rocks indicates that the meionite member is predominant.

Microcline grains with noticeable cross twinning are present in association with pyroxene, and give a pflaster texture to bands which are rich in this felspar.

In No. 730 *plagioclase* is much decomposed, yielding aggregates of white mica. These grains are often surrounded by a narrow rim of epidote. Some acid plagioclase near oligoclase is interspersed among potassic felspar grains.

Quartz is a variable constituent, but is present in all three rocks. In No. 658 a number of vermicular intergrowths between scapolite and quartz are revealed (*cf.* symplektites of Sederholm).

Actinolite is developing at the expense of pyroxene in No. 849.

Titanite is a constant member of these rocks. It may be associated with garnet, but there is never any indication that it is secondarily derived from this mineral.

(5) Pyroxene-Epidote-Marbles.

Rocks Nos. 38, 310, 394, 996, and 1168 are included within this class. They are medium-grained rocks, rich in calcite (with the exception of No. 1168). On weathered surfaces, pyroxene and epidote project, the latter with the characteristic yellow-green colouration. The epidote may be developed in narrow bands through the rock. Metamorphic felspar and quartz likewise project from the general surface of the rock.

The constituent minerals are *calcite, pyroxene, epidote, microcline, scapolite, plagioclase, titanite, quartz, and actinolite.*

The *pyroxene* of these rocks is of a hedenbergitic type in Nos. 38 and 310, with noticeable pleochroism, as in the rocks of class (4). In No. 1168 the pyroxene in thin section is less strongly coloured, but the extinction $Z \wedge c$ is not less than 47° to 48°,

[1] Sederholm Bull. Comm. Geol. Finl. No. 48, 1916, p. 60.

so that the presence of sesquioxides is indicated. As a whole the pyroxenes may be regarded as hedenbergitic rather than diopsidic. A parting parallel to the 001 face is often developed (*cf.* No. 1168).

Epidote is a very characteristic mineral of these rocks, present in irregular grains and again as narrow rims to other minerals. A basal cleavage is usually strongly manifest. The extinction in sections parallel to the optic axial plane is approximately 30° from the 001 cleavage. The optic sign is negative, with the optic plane perpendicular to the cleavage. It is strongly pleochroic in yellowish-green tints, and a high content of Fe_2O_3 is indicated by a high birefringence of 0·04 (as in No. 38). Intergrowths with quartz are not uncommon.

A potash felspar with *microcline* twinning is present in variable amount, and calls for no special remark.

Scapolite is present in Nos. 38 and 310, but is absent in the remaining rocks. It has the high birefringence of the scapolites of the pyroxene garnet rocks. In No. 38 it may be surrounded by a narrow shell of basic plagioclase. In many cases this cannot be regarded as a secondary development of scapolite from plagioclase, as the boundaries are quite sharp. Rather it has the appearance of primary growth, and suggests that plagioclase appeared in place of scapolite when the supply of essential mineralisers for the formation of the latter mineral became exhausted.

Bluish-green *actinolite* is present in No. 996, but is absent in the other rocks. It forms independent crystals in the rock.

Quartz is sparingly distributed in these rocks, and very characteristically in association with epidote. Its presence here suggests that it is a by-product in the synthesis of epidote.

Two single grains of pleochroic *tourmaline* are observed in No. 996. The pleochroism scheme is $O > E$ with O = dark green and E = reddish-brown.

(6) Epidote-Marbles.

The rocks of this class are Nos. 132, 305, 308, 384, 386, 534, 654, 676, 995, 997, and 1163. As a class they are fine-grained rocks, which on weathered surfaces show an abundant development of yellow-green epidote. Some of them are banded, due to streaks and lenses of this mineral, and irregular segregations can often be observed.

The constituent minerals are *calcite, epidote, actinolite, microcline, plagioclase, titanite, biotite, quartz, chlorite, apatite* and *magnetite.*

Calcite shows abundant lamellar twinning, and the grain-size is very variable. It is especially fine-grained in rocks Nos. 305, 386, 534, and 1163. In some examples distorted twin lamellæ and mortarisation of the larger calcite grains (as in No. 997) bear witness to the shearing movements which have affected the rocks.

Epidote is present in yellowish-green crystals, which are often idioblastic, with a dominant basal cleavage. It is not infrequently disposed in layers through the rock, associated with quartz and felspar. This is strikingly seen in No. 132, where the felspar is largely microcline. The epidote is always a variety rich in ferric oxide, as is indicated by its birefringence and pleochroism. It is only accessorily present in No. 654. In No. 1163 the mineral is undergoing change to a chloritic product with anomalous interference tints.

Actinolite in pleochroic plates of blue-green to yellow-green tint is often present in association with the epidote.

Microcline, plagioclase, and quartz are the colourless silica containing minerals. The potash felspar with microcline twinning is closely associated with epidote and quartz. The twinning is, however, not a constant feature, and in the absence of cleavage and twinning, it is sometimes difficult to discriminate from plagioclase.

The *plagioclase* present in these rocks is usually of an acid type. It may possess both pericline and albite twinning lamellæ. The felspar of No. 995, for example, is an optically positive type, whose refractive index is greater than that of canada-balsam, but less than that of quartz. It corresponds to albite-oligoclase. Secondary paragonitic (?) flakes are distributed through the grains. In the other rocks the plagioclase very generally shows a refractive index less than that of quartz. The place of the more basic felspars is evidently taken by the abundant epidote.

Quartz is quite common as a constituent of the ground mass with calcite, and may sometimes vein the rock as in No. 997.

In the bands of epidote in No. 132, the associated quartz shows rows of pores along cracks, oriented at right-angles to the long axes of the bands.

Green *biotite* is present in No. 132, associated with epidote, and a single grain of highly pleochroic *tourmaline* is also to be observed.

(7.) Carbonate-free Calc-Silicate Rocks.

Two rocks which cannot strictly be defined in the classes already instituted complete the suite of rocks. Both these rocks are completely free from primary carbonate minerals. No. 1153 is a pinkish-white rock with a band of calc-silicate minerals, partly diopside and partly a dark fibrous amphibole.

Under the microscope, the calc-silicate band shows a very pale tremolitic actinolite, on the outer edge of which colourless diopside is present. This band is succeeded by a band of saussuritic material, in which secondary white mica is plentifully distributed. Quartz is abundant in streaks and lenses. It shows the effects of shearing stress in the undulose extinction and mortar texture.

No. 128 is of greater interest. The hand specimen is a greenish-grey rock, in which small porphyroblasts of felspar can be seen. In thin section the constituent minerals are observed to be felspar, epidote, and clinozoisite as porphyroblasts, whilst the ground mass is constituted of tremolite, zoisite (clinozoisite), quartz, felspar, titanite, and apatite. Epidote is present in idioblasts measuring up to 1·5 mm. in length. It shows a light yellow tint, but is seldom noticeably pleochroic. A basal cleavage is strongly developed. The double refraction does not exceed 0·027. The optic axial plane is perpendicular to the elongation and the cleavage, and the optic sign is negative. Twinning on the 100 plane is rarely developed, and is seen in sections cut parallel to the optic axial plane. The extinction is 3 to 4 degrees from the plane 100. From the basal cleavage the angle $Z \wedge a$ is 30°.

In sections nearly perpendicular to the optic axes, the interference tints are often anomalous. A few of the porphyroblasts are optically positive. These are clinozoisite. It is clear that the porphyroblasts are types comparatively poor in Fe_2O_3, and grade in composition from clinozoisite (optically positive) with increasing iron content to the more birefrigent epidote (negative).

The porphyroblasts of felspar are dominantly plagioclase. They often show both albite and pericline twin lamellæ. In composition they grade from albite-oligoclase to oligoclase. Both optically positive and negative varieties are present, and the refractive index is usually equal to or greater than that of canada-balsam. The refrigence is, however, always less than that of quartz. Potash felspar is sparingly represented, optically negative and has a refringence less that that of canada-balsam.

The ground mass is constituted of quartz and alkali felspar, in which are set fibres of colourless tremolite, prisms of zoisite, and less frequently highly refringent grains of titanite and apatite. The porphyroblasts of felspar are remarkably free from the constituents of the ground mass.

III. REVIEW OF THE METAMORPHIC PROCESSES INVOLVED.

The mineralogical variation of the suite of rocks described in the foregoing is clearly resultant of two independent factors, viz. :—

(*a*) The range of chemical composition of the original sediment,

(*b*) The grade of metamorphism which the several classes have experienced.

Accepting throughout that an additive metamorphism has been inoperative, the rocks of classes (1), (2) and (3) are examples of metamorphosed dolomites. Classes (4) and (5) represent types in which a gradation to a more calcareous sediment is apparent, whilst in class (6) the metamorphosed equivalent of calcareous limestones are revealed. A varying grade of metamorphism is apparent.

The forsterite marbles bear witness to a metamorphism of essentially thermal type. The silica and alumina of detrital origin have reacted with the carbonate minerals, bringing about a partial dedolomitisation. The presence of fluorine is established by the occurrence of chondrodite. The halogen is doubtless derived from the igneous magma to which the metamorphism of these rocks is due.

In the second class of marbles, however, whilst dolomite is present with the calcite, the dominant silicate mineral is neither forsterite nor diopside, but tremolite. The habit of crystalline schists which these rocks possess suggests that in their metamorphism the element of shearing stress was dominant. Under these conditions the antistress mineral, forsterite, does not develop.

In the diopside-tremolite-marbles, dedolomitisation has been complete, and the residual carbonate mineral is calcite. With the disappearance of dolomite, the entry of magnesia-free silicate is permitted, and in accordance with this, these rocks develop subordinate plagioclase. The composition and texture of the rocks of this class allows them to be regarded as contact types.

In class (4) the pyroxene-garnet-marbles, an abundance of detrital constituents has given rise to a varied assemblage of metamorphic minerals. Microcline arises from detrital sericite, the excess alumina being absorbed in the accompanying silicates, and scapolite develops in place of plagioclase, when the necessary volatile elements are present.

The pyroxene, garnet and epidote, show by their optical properties that a not inconsiderable amount of iron is present in their molecules. The source of this iron oxide, is doubtless ferrous carbonate or hydrated iron oxide (limonite), in the original sediment. The hedenbergitic character of the pyroxene shows that portion of the magnesia is replaced by FeO.

The coloured garnet must be regarded as a grossular andradite solid solution. This is confirmed by its paragenesis, and optically by the refringence. A possible type of reaction which has led to the development of this mineral may be represented as follows :—

$$6CaCO_3 + H_4Al_2Si_2O_9 + Fe_2O_3 + 4SiO_2 = 2Ca_3AlFeSi_3O_{12} + 6CO_2 + 2H_2O.$$

Epidote must be regarded as the youngest of the silicates. The presence of the epidote-quartz symplektites around the garnet suggests that the development of epidote in these cases is attributable to a degradation of the garnet molecule in a later stage of decreasing metamorphism,

$$3Ca_3(AlFe)_2Si_3O_{12} + H_2O = 2HCa_2(AlFe)_3Si_3O_{13} + 3SiO_2 + 5CaO.,$$

the lime with carbon dioxide giving the associated calcite. A development from the anorthite member of the plagioclase has also played a part.

In the rocks of class (5) epidote is an abundant constituent, and must be given a place as a primary constituent, derived either from a reaction of carbonates and ferric oxide, with kaolin or sericite, in the latter case being accompanied by microcline. The rocks of this class resemble those of class (4) with the distinction that garnet is not represented and its place is taken by epidote.

The rocks of class (6) resemble the products of the outer zone of contact metamorphic regions. Pyroxenes are absent, and they are represented by actinolite. Epidote is the most abundant coloured silicate. The rocks are characterised by their fine grain, and both structurally and texturally they bear witness to a comparatively low grade of metamorphism. This metamorphism has been sufficient however to give rise to metamorphic felspar in association with epidote. Much of the acid plagioclase, however, must be considered as being originally developed in the rocks, for its mineralogical association with calcite or with quartz points to this conclusion. The degree of metamorphism has allowed recrystallisation, probably with increase of grain size.

In the carbonate-free rock, No. 128, the epidote and tremolite reactions have proceeded to the exhaustion of the carbonate mineral.

IV. PARAGENESIS.

In the following table, the occurrence of the various minerals in the suite of rocks is shown in their paragenetic relationships :—

	Calcite.	Dolomite.	Spinel.	Forsterite.	Chondrodite.	Edenite.	Tremolite.	Pyroxene.	Microcline.	Plagioclase.	Scapolite.	Garnet.	Epidote.	Quartz.
Calcite	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Dolomite	+	+	+	+	+	+	+	+						
Spinel	+	+	+	+	+	+	+	+						
Forsterite	+	+	+	+	+	+	+	+						
Chondrodite ...	+	+	+	+	+	+	+	+						
Edenite	+	+	+	+	+	+	+	+						
Tremolite	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Pyroxene	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Microcline	+						+	+	+	+	+	+	+	+
Plagioclase ...	+						+	+	+	+	+	+	+	+
Scapolite	+						+	+	+	+	+	+	+	+
Garnet	+						+	+	+	+	+	+	+	+
Epidote	+						+	+	+	+	+	+	+	+
Quartz	+						+	+	+	+	+	+	+	+

The part played by the lime-alumina silicates is clearly shown in the paragenetic relations of such minerals as plagioclase, scapolite, garnet and epidote. In dolomitic limestones, they enter only after dolomite and the pure magnesian silicates and aluminate (spinel) have disappeared. Microcline appears in a similar fashion. Detrital sericite is first converted into the magnesian-mica, phlogopite, which is characteristically a member of the forsterite marble group of rocks. This mineral reacts later with silica and calcite giving pyroxene and microcline.

In these rocks pure magnesium-aluminium silicates do not occur. Of these latter, cordierite and pyrope garnet are the types. Cordierite is unknown amongst metamorphosed carbonate rocks, and is unstable in the presence of monoclinic pyroxene. Goldschmidt ([1]) considers that its absence may be attributed to a reaction of the form—

$$Mg_2Al_4Si_5O_{18} + 2CaMgSi_2O_6 = 4MgSiO_3 + 2CaAl_2Si_2O_8 + SiO_2$$

yielding enstatite or hypersthene, as in the limestone contact zones of the Christiania region. A rhombic pyroxene is, however, wholly wanting in these Antarctic rocks, as in the product of other areas of regional metamorphism. In this respect the metamorphism in the Christiania region may be regarded as the ideal thermal type unaccompanied by any notable shearing stress ([2]).

In the rocks now studied, the alumina of potential cordierite is represented in plagioclase, and the magnesia in monoclinic pyroxene.([3]) According to Eskola ([4]) garnets containing more than 75 molecules per cent. of pyrope are unknown, and even these are confined to eclogitic rocks, and unknown amongst metamorphosed dolomites. In this respect pyrope and grossularite differ widely in their paragenesis.

Throughout this suit of rocks quartz is stable in the presence of calcite. Even in the carbonate-free calc-silicate rock (No. 128) there is no development of wollastonite. The application of Nernst's heat theorem to the equilibrium—

$$CaCO_3 + SiO_2 \rightleftarrows CaSiO_3 + CO_2$$

gives a PT curve which rises with the pressure. For aluminous and ferromagnesian lime silicates the corresponding curves, as Goldschmidt ([5]) has pointed out, run at less elevated temperatures.

Whilst these more complex silicates (epidote, tremolite, pyroxene, &c.) were abundantly produced, the development of wollastonite—the high-water mark of metamorphism in calcareous sediments—was not attained.

---

[1] V. M. Goldschmidt, Vidensk. Skrifter, 1911, No 1, p. 138. [2] A. Harker, Pres. Address Geo. Soc., 1918, p. LXXVIII. [3] Geol. Mag., vol. lvii, 1920, p. 496. [4] P. Eskola, Norsk. Geol. Tidsskr. vi, p. 172-3. [5] V. M. Goldschmidt, Vidensk Skrifter, 1912, No. 22, p. 12.

V. EXPLANATION OF PLATES.

Plate XXXVI.

Fig. 1.—*Calc-silicate marble.* Photo of the natural surface developed by weathering under Antarctic conditions of wind and drifting snow. The softer carbonates are removed, leaving the harder silicates standing prominently in relief. Concomitant with the metamorphism of the rock, are evidenced contortion and brecciation of the harder bands. Two-thirds natural size.

Fig. 2.—*Calc-silicate-Gneiss* (Garnet-pyroxene-Marble.) Specimen No. 658. The photograph shows alternating bands of calcite, green pyroxene and felspar, and brown garnet.

The continuous black bands are seams of grossular-andradite, and the remaining black lenses and streaks are hedenbergitic pyroxene associated with white felspar. About natural size.

Plate XXXVII.

Fig. 1.—*Forsterite-Marble.* Specimen No. 318. The microphotograph shows calcite, dolomite, forsterite, spinel, and the aluminous amphibole, edenite.

The amphibole is typically developed as coronæ around the forsterite grains. Isolated grains with amphibole cleavage are present in the lower half of the photograph. The clear carbonate grains immediately above are dolomite. Magn. 40 diameters.

Fig. 2.—*Garnet-pyroxene-marble.* Specimen No. 658. The constituents shown are garnet, green pyroxene, scapolite, microcline, a symplektitic intergrowth of scapolite and quartz, and grains of titanite, apatite and calcite. Magn. 40 diameters.

Fig. 3.—*Garnet-pyroxene-Marble.* Specimen No. 730. The constituents are garnet, epidote, plagioclase, green pyroxene, calcite, and quartz. The garnet is surrounded by a shell of epidote, intergrown with quartz and some calcite. The large plate of plagioclase is filled with a sericitic decomposition product, and is itself bordered by a perimorph of epidote. Magn. 40 diameters.

Fig. 4.—*Carbonate-free calc-silicate* rock. Specimen No. 128. The constituents are clinozoisite, epidote, plagioclase, microcline, tremolite and quartz. The porphyroblasts of epidote and felspar are set in a ground mass of tremolite, zoisite, quartz and felspar. The felspar porphyroblasts are remarkably free from the groundmass constituents. Magn. 40 diameters.

Sydney: Alfred James Kent, Acting Government Printer—1923.

Fig. 1.

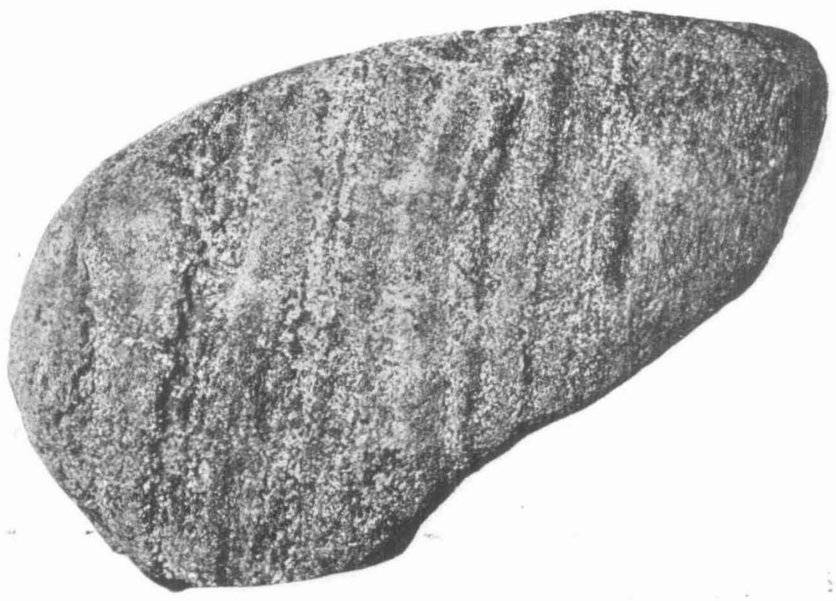

Fig. 2.

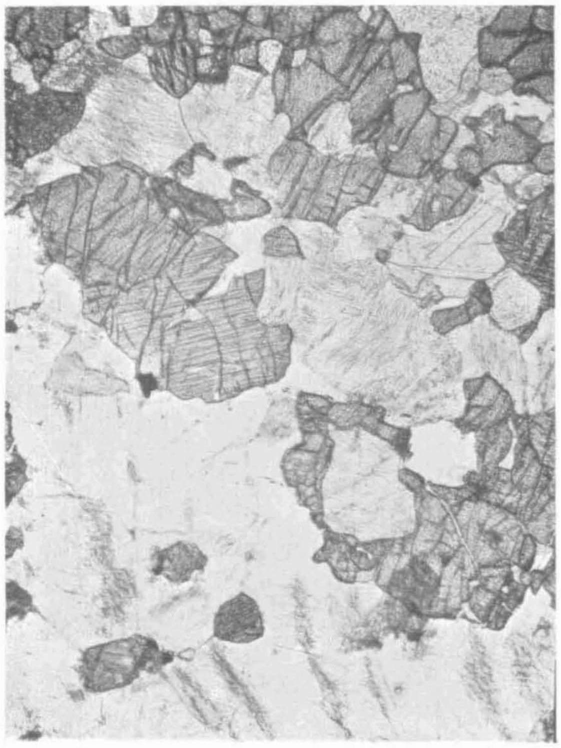

Fig. 1.

Fig. 2.

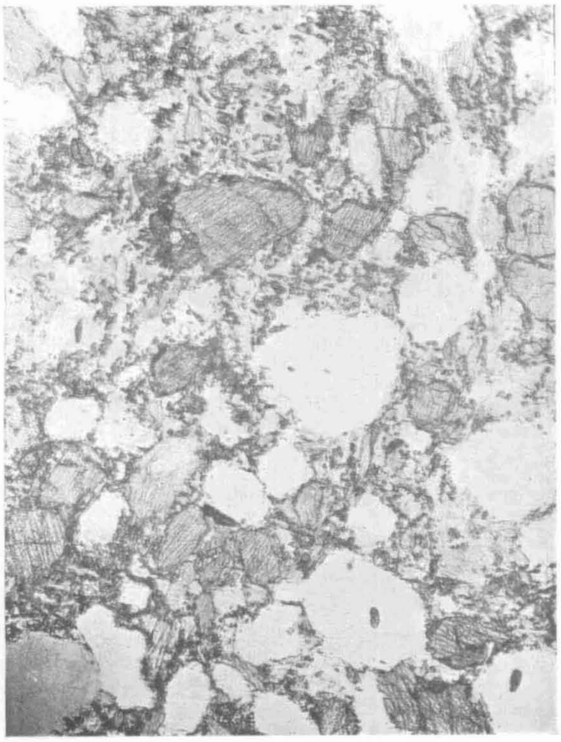

Fig. 3.

Fig. 4.