LIME-RICH METAMORPHIC ROCKS, CREE LAKE, MANITOBA

Antrobus

A STUDY OF LIME-RICH METAMORPHIC ROCKS FROM CREE LAKE, MANITOBA

by

Edmund S. A. Antrobus

A Thesis

Submitted in partial fulfillment of
the requirements for the degree of
Master of Science

McGill University,
Montreal, Quebec,
Canada.

May, 1949

CONTENTS

CHAPTER I

INTRODUCTION

The rocks studied in this thesis have been the subject of considerable discussion as to their original nature. J. D. Bateman of the Geological Survey of Canada considers that they are of igneous origin whereas others believe that they are metamorphosed sediments. It was thought that a petrographical study might provide some information that would help to decide the problem and it was with this object in view that this study was undertaken.

Cree Lake, in the vicinity of which the rocks occur, is situated 2 miles North of the Sherritt-Gordon Mine, Manitoba, which lies about 20 miles east of the Manitoba-Saskatchewan border and 120 miles northwest of the north end of L. Winnipeg. The Sherritt-Gordon copper-zinc ore deposit is a very remarkable deposit in that it is a tabular body with a total outcrop length of 16,000 feet and an average width of 15 feet, thus being one of the longest exposed ore bodies in the world.

The rocks in question outcrop around Found Lake which lies very close to and just to the southeast of Cree Lake (see Map 44-4) and fall into two groups; firstly, thos that outcrop south of Found Lake in an area which was mapped by J. D. Bateman as an oval body of oligoclase granite (Map 44-4, No. 12) about one mile long and 1/4 mile wide and secondly, those that outcrop as three smaller masses north of Found Lake but enclosed by the arms of Cree Lake and mapped as anorthositic gabbro (Map 44-4, No. 11).

J. D. Bateman, who mapped the area in detail in 1943, is of the opinion that the bodies of rock north of Found Lake, mapped by him as anorthositic gabbros, were originally igneous intrusives and have arrived at their present state by metamorphism and widespread carbonatization whereas C. H. Stockwell, also of the Geological Survey, regards them as altered limey sediments; the latter also considers that a large part of the oval body of rock south of Found Lake, mapped as oligoclase granite, is derived from limey sediments.

Oligoclase granite is present both North and South of the lake but South of the lake it does not underlie such a wide area as that shewn on Map 44-4. Several specimens of the oligoclase granite were studied and it was found to have a very constant composition, its constituent minerals being quartz and oligoclase in equal amount, brown biotite and accessory hornblende, muscovite and garnet.

Megascopically the other specimens studied, which are all fine-grained, fall into two groups; firstly, those which were taken from the area south of Found Lake and which are composed predominantly of leucocratic minerals and secondly, those from the localities north of Found Lake which contain a higher percentage of melanocratic minerals. Both groups however are composed essentially of the same suite of minerals, plagioclase of variable composition, diopside which is much altered to amphibole, calcite, sphene, quartz, apatite, iron ore and secondary minerals. The relative proportions of these minerals vary greatly from specimen to specimen and they are not in any way comparable to the minerals of the oligoclase granite.

The author has concluded:

1) That a large part of the oval body south of Found Lake mapped as granite and the smaller bodies north of Found Lake mapped as anorthositic gabbro are all of sedimentary origin and are part of the same mass of sediments, despite their somewhat different mineralogical characters, and are now diopside-plagioclase-calcite gneisses. Map 2 is the geological map that would result from this conclusion.

2) That these sediments were originally dolomitic and calcareous arkoses.

3) That the present mineral assemblages and characters of these rocks are the result of high grade regional metamorphism and some pneumatolytic or metasomatic action by adjacent igneous intrusives.

HISTORY AND DESCRIPTION OF THE GENERAL GEOLOGY OF THE AREA

In 1928, J. F. Wright (1) made a geological reconnaissance in the area of Kississing Lake -- part of which is shewn in the northeast corner of Map 44-4 -- in which he drew up a rough map of the district and outlined the structure of the rocks in the vicinity of the Sherritt-Gordon mine. This work was of a very general nature and he undertook no detailed survey but he showed that the rocks of this area are a continuation of the Kisseynew Gneisses, so named by E. L. Bruce (3, p.27), of the Amisk-Athapapuskow Lake district which lies about 30 miles to the southwest.

Consequently he made no specific mention of the rocks in question except when describing the bed rock of a group of claims as gneissic quartzite, quartz-mica and quartz-hornblende gneisses (2, p.100); these claims lay just to the west of the southeast end of Found Lake, presumably in the area mapped as oligoclase granite but possibly in the area mapped as Sherridon quartzite.

In the summer of 1943, J. D. Bateman and J. M. Harrison carried out a more detailed survey of the area immediately around the Sherritt-Gordon mine and it was then that the question of the original nature of these rocks arose. They retained the group name of the Kisseynew gneisses and divided the series into the Pre-Sherridon, Sherridon and Post-Sherridon gneisses and quartzites but considered that the Pre-Sherridon may be separated from the Sherridon by a structural unconformity and so may not be of Kisseynew Age.

Most of the rocks of the area are crystalline schists and gneisses representing metamorphosed sedimentary and volcanic formations and they are all of Precambrian age. Throughout the Kisseynew gneisses it is commonly difficult to distinguish between true bedding and bedded-like or stratiform structures that have resulted from later foliations. In the Sherridon Map area, the two structures are essentially parallel, even around the noses of plunging folds.

The structure of the district is one of great interest and complexity and, in the area under consideration in this paper resembles a large drag-fold. It is the result of cross-axial folding on a series of simple folds and H. C. Cooke (4, p.436) shows that the district lies on the hinge where the east-west Precambrian folding of the eastern Canadian Shield is intersected by the north-south folding of the western Canadian Shield, thus accounting for the complexity of the structure.

Map 44-4 shows that the strike of all the rocks in the area is approximately north-south and that the dip is predominantly eastwards but with varying steepness. Found Lake lies on the crest of a southward plunging overturned anticline or elongated dome, plunging northwest and southeast, with a syncline to the east. The oligoclase granite is conformable with the structure of the area, tapering off around the nose of the syncline to the east and is thus phacolithic in shape; the rocks mapped as anorthositic gabbro also show a tendency for the outlines of the contacts to conform with the structure. Other rocks in the immediate vicinity are mostly of Pre-Sherridon Age, and if the rocks of this study are of sedimentary origin, it is probable that they too are of Pre-Sherridon Age.

The writer is indebted to C. H. Stockwell, who visited the area in 1944, J. D. Bateman and J. M. Harrison, who visited the area again in 1947, for the use of their notes, specimens, and thin sections, and wishes to express his appreciation of the guidance and advice given him by Dr. C. H. Stockwell and Dr. E. H. Kranck.

CHAPTER II

GENERAL DESCRIPTION OF THE SPECIMENS STUDIED

As a result of the study of the specimens and thin sections, descriptions of which are given in Chapter V, the specimens have been divided into four groups, and a general description of each group is given here.

These groups are:

1. The granite specimens.
2. The lime-rich specimens, subdivided into -
   (a) from localities south of Found Lake
   (b) from localities north of Found Lake
3. The quartzite specimens.
4. Other specimens.

The localities from which the specimens were taken are indicated on Map I by circles within which are the numbers of the specimens.

1. THE GRANITE SPECIMENS

Specimens Nos. 6, 11, 22 and 29 (see Map 1) are of the oligoclase granite and all are very similar. In hand specimens, the rock is dark grey and medium-grained consisting of quartz and oligoclase in about equal amounts (30 - 40%), the felspar generally being preponderant.

Deep brown biotite (10 - 15%) is common in sub-parallel flakes and gives the rock a distinct foliation which is more pronounced in some specimens than in others. Small grains of red-brown garnet are present in specimens 6 and 11; hornblende and muscovite are present in specimens 22 and 29.

In thin sections, the plagioclase is generally quite fresh but is occasionally altered to kaolin and clinozoisite, especially around the edges of the grains; in one case the plagioclase is altered to scapolite. The quartz in anhedral grains shows strain effects in the form of parallel bands with undulatory extinction (see Photograph No. 2). Indications of dynamic action are more clearly shewn by the biotite, pleochroic in brown and yellow, which is often bent, fractured and altered to chlorite with acicular inclusions of rutile (see Photograph No. 1). The hornblende, which is uncommon, is pleochroic in pale greens and yellows; it is characterized by a pronounced sieve-structure and shows every stage in the change-over to biotite. The garnet, which is present in specimens 6 and 11 only, occurring as anhedral grains, is coloured a very pale pink and is isotropic between crossed nicols. Accessory iron ore and apatite are common in all specimens.

The entire absence of potash-felspars is characteristic of the oligoclase granite.

2. THE LIME-RICH SPECIMENS

a) From localities south of Found Lake

Specimens 8, 9, 10, 12, 13, 14, 15, 18 and 20 were collected from this area. They are fine-grained, light-coloured rocks with a faint foliation and consist of plagioclase, primary calcite, diopside, hornblende, sphene and quartz in varying proportions with accessory iron ore, apatite, biotite and muscovite. They weather dark grey and the weathered surface has a distinctive texture which is characteristic of these rocks; this is due to the solution of the calcite leaving the more resistant equigranular grains of plagioclase and dark minerals protruding on a very rough surface. Due to the fineness of the grain and its clear glassy appearance, the plagioclase is easily confused with quartz and the resulting appearance is very much that of a weathered sandstone with resistant grains of quartz. This texture is significant as it is shewn by many of the specimens which themselves have different mineral percentages and it is considered to be indicative of a common metamorphic history for rocks of similar chemical composition.

In thin section the equigranular nature of the hand specimen is represented by the common mosaic texture of the slides but a pronounced poikiloblastic or diablastic texture is sometimes present since the felspar crystals may be intergrown with one another or with diopside, hornblende, sphene and quartz.

Except for the widespread alteration of diopside to hornblende, mentioned below, the minerals of this group are fresh and contrast strongly with those of the next group where alteration of the plagioclases is extensive.

The plagioclase, which varies in composition from An.15 to An.90 when all the specimens are considered, has a variable degree of twinning and is frequently irregularly zones. The crystals also show the effects of dynamic action by irregular extinction and minor fracturing; some of the twinning is secondary and this is clearly shewn in Photograph No. 7, where the irregular twinning bands terminate at a fracture filled with secondary calcite.

Potash-felspar was not identified in any of the sections.

The diopside is colourless and has optical properties which place it near the diopside end of the diopside-hedenbergite series (see Appendix B). It is extensively, sometimes practically entirely, altered to a colourless or very pale yellow hornblende which is intimately intergrown with it, not as a mass of small crystals but as large single crystals (see Photograph No. 7), frequently with the cleavages of the hornblende parallel to those of the diopside. Distinct sieve-texture is often shown by both minerals, and secondary calcite is also developed from this alteration.

The hornblende has optical properties which place it near to the pargasite end of the pargasite-hornblende series but it is optically (-) in all cases. In slide No. 12, the hornblende is unusual in that it is an original mineral of the rock and is not derived from diopside, occurring as euhedral crystals with well developed prism faces and distinct wedge-shaped basal sections.

The calcite, which varies in the amount present (as do all the other minerals), makes up as much as 50 - 60% of the rock in some cases and is present only as a secondary mineral in others. In those sections where it forms more than 10% of the rock, it is found in large very irregular crystals with well-developed cleavage and twinning lamellae and is distinctly part of the rock fabric, forming a matrix in which the other minerals are set (see Photograph No. 4). It is concluded from this and from the fact that the minerals present, such as diopside, sphene, apatite, lime-rich hornblende and plagioclase, are minerals likely to be developed in the metamorphism of a lime-rich sediment that the calcite was present in the rock at the time that the rock was metamorphosed to its present character. J. D. Bateman considers that the calcite is the result of widespread carbonatization; from the above conclusion it follows that this carbonatization must have taken place before the major period of metamorphism. It is difficult if not impossible to prove that the carbonatization took place before metamorphism but it will be shewn in the next chapter that the facts are in favour of concluding that the original rock was a lime-rich sediment.

Sphene is a very common constituent, forming as much as 11% of the rock in several cases. It occurs as fine-grained subhedral brown crystals of variable size and is strongly pleochroic. Many of the crystals contain a small round almost opaque area within them as though they had grown about a small fragment and it is thought that these semi-opaque areas may represent a constituent of the original sediments.

Quartz occurs as small irregular grains forming part of the matrix of the rock and is generally only a minor constituent, frequently of secondary origin. Its association in slide No. 20, where it forms 21% of the rock, with calcite which forms 57% of the rock is significant. Quartz and calcite are incompatible with one another when metamorphism is accompanied by hydrostatic pressure, thus indicating that the metamorphism must have been accompanied by directed pressure as the association of the two under these conditions is not anomalous.

Accessory iron ore and apatite in euhedral grains are found in all specimens.

b) From localities north of Found Lake

Specimens 23, 28, 31, and 75 were collected from those areas mapped as anorthositic gabbro. In hand specimen they are slightly darker in colour than those from south of the lake as the dark minerals are more prominent on fresh surfaces. However the weathered surfaces show the same rough texture and the rocks consist of the same minerals, plagioclase of variable composition, primary calcite, diopside, hornblende or actinolite, sphene and quartz in varying proportions with accessory iron ore, apatite and biotite.

In thin section, they show the same textures and relationships in the mosaic or diablastic texture, the variable composition of the plagioclase which ranges from An.34 to An.76, the alteration of diopside to amphibole, the disseminated character of the subhedral crystals of sphene and the evidences of dynamic action in the presence of fractures and the bending of the biotite. But there are differences in that the plagioclase crystals are irregularly and intimately intergrown with one another and are extensively altered to mizzonite, clinozoisite or epidote, (see Photographs Nos. 8, 9, 10), and in that the amphibole derived from the diopside in specimens 27, 31 and 75 is actinolite and is pleochroic in greens. In specimen 23, the amphibole is pargasite and is derived from pigeonite; in specimen 25, the hornblende is an original mineral as in specimen 12 (see Appendix B).

The significance of these differences is not very clear; the scapolitization of the plagioclases is indicative of some pneumatolytic action whereas the production of clinozoisite and epidote from the plagioclases is indicative of more intense dynamic action than was the case with the rocks south of Found Lake.

It will be shewn that the original composition of these rocks was probably the same as that of those rocks south of Found Lake and the assumption has been made that the more intense alteration of the plagioclases and the production of actinolite instead of hornblende indicating some enrichment in iron is due to the closer proximity of larger bodies of igneous rock than was the case with the rocks south of Found Lake. These bodies of igneous rock are the oligoclase granite which outcrop within the arms of Cree Lake and the pyroxenite and metagabbro which outcrop on the northeastern shores of Cree Lake.

The more intense dynamic action is probably the result of the location of these bodies on the limbs of the Found Lake 'dragfold' where they would be subjected to greater stresses than those rocks south of Found Lake which are situated within the nose of the fold where stresses would tend to be less.

3. THE QUARTZITE SPECIMENS

The quartzite specimens of which there are four can be divided into two groups: (1) Specimen 7 which is representative of the Sherridon quartzites and (2) Specimens 16, 21 and 24 which are related to the lime-rich rocks.

No description of them is given here as their individual characteristics are described in Chapter III, when the field relations and the mineralogical characters of the specimens are discussed.

4. OTHER SPECIMENS

Specimens 5 and 74 have been included in this group as they are unlike any of the other specimens.

Specimen 5 is a cream-coloured rock, megascopically similar to the lime-rich rocks, but it consists of andesine feldspar, corundum, sillimanite, and penninite with minor sphene and calcite, and thus does not have the same mineral composition. The corundum and the sillimanite, which occurs in sheaf-like aggregates of acicular crystals, are surrounded by a felted mass of platy crystals of secondary margarite or diaspore. The author was unable to identify positively these secondary minerals so that there are still some questions outstanding with regard to this specimen but the presence of the silica-poor minerals, corundum and sillimanite, as well as the equigranular mosaic texture of the thin section indicates that it may represent a silica-poor aluminium-rich facies of the lime-rich rocks and it has been considered as such in this paper.

Specimen 74 was considered by J. M. Harrison to be similar to the amphibolites of the Grenville. It is a coarse-grained heavy black rock consisting of andesine, augite, actinolite and red garnet with accessory apatite, iron ore, quartz and biotite with a strongly diablastic texture in thin section. In consequence of its mineral composition and diablastic texture, it has been named a plagioclase-garnet amphibolite.

It is entirely distinct from all the other rocks of this study and it is thought that it may be derived from a diabase or gabbro.

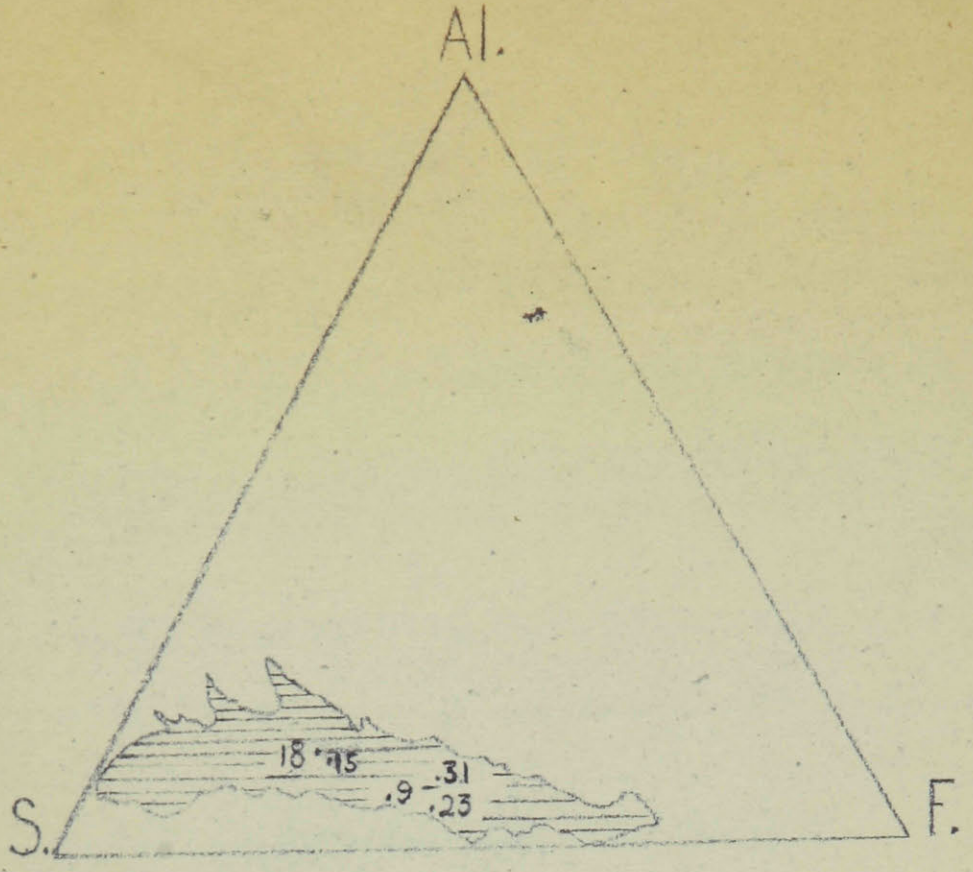
MOLECULAR PERCENTAGES

The molecular percentages of the oxides were calculated for Sections 9, 15, 18, 23 and 31.

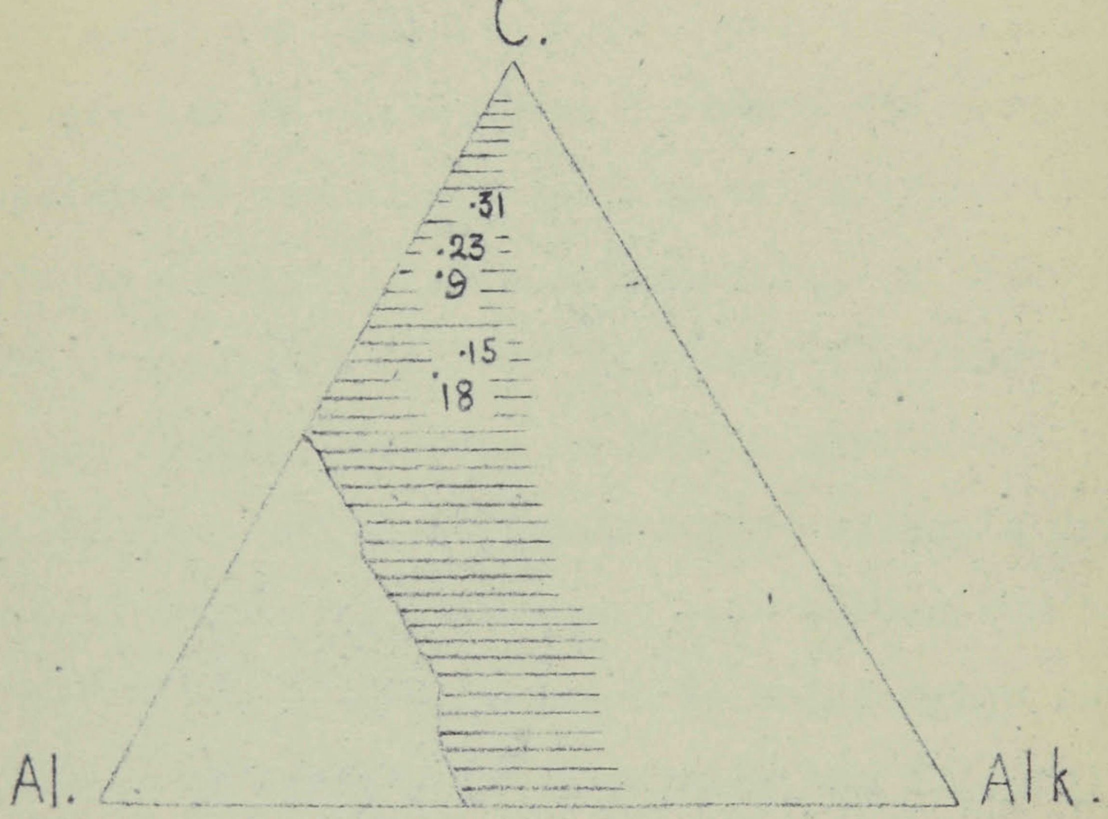
The volume percentages of the component minerals having been determined by the Rosiwal Method -- minerals forming less than 1% of the rock being ignored -- the density and chemical composition of the minerals were derived from the optical characters determined in thin section by reference to Dana's Textbook of Mineralogy and Winchell's Elements of Optical Mineralogy, Pt. II. Some of the minerals such as calcite, sphene, quartz, apatite and diopside were assumed to be pure and the percentages of the oxides used were taken from Dana's Textbook, but the composition of others, such as the felspar, hornblende, pigeonite and mizzonite was determined by interpolation on the curves and figures in Winchell's Elements of Optical Mineralogy.

Consequently, the molecular percentages calculated from these formulae are not entirely accurate but it is considered that they are sufficiently so to provide a basis from which deductions can be made as to the original composition of the rocks and on which comparisons with

A.



B.



A) S:Al:F. Triangle, after Osann

B) Al:C:Alk.Triangle, after Osann

The numbers in the triangles are the numbers of the specimens whose analyses are given in the text.

Lined areas are areas within which, according to Osann, the analyses of most igneous rocks would fall.

other analyses can be made.

The following analyses were obtained:

MOLECULAR PERCENTAGES

Specimen numbers

	9	15	18	23	31
SiO_2	52.2	43.3	49.0	48.4	39.4
Al_2O_3	5.28	8.6	9.47	4.85	5.5
MgO	16.25	1.12	10.2	22.02	9.35
CaO	19.0	23.0	16.10	17.8	26.75
Na_2O	1.77	5.39	3.90	1.20	2.14
TiO_2	0.78	2.72	3.52	0.37	0.13
Fe_2O_3	0.63	0.06	0.48	0.51	0.23
FeO	1.85	0.28	1.14	1.46	0.77
P_2O_5	-	0.44	-	-	0.05
CO_2	2.27	14.9	3.36	2.74	15.7
Cl	-	0.15	-	-	0.23
H_2O	-	-	2.88	-	-
	100.03	99.35	100.05	99.35	100.25

These molecular percentages were recalculated and plotted on the triangular diagrams of Osann's System. The relationships plotted were

1) $SiO_2:Al_2O_3:(Fe,Mg,Ca)O$ = S:Al:F.

2) $Al_2O_3:CaO:(Na,k)_2O$ = Al:C:Alk

All analyses fell within the area of the triangles where the analyses of igneous rocks would be located (see Plate I); this fact would seem to indicate that the rocks of this study are of igneous origin but it will be shewn in the next chapter that there are stronger grounds for believing that they are of sedimentary origin. Hence they are an exception to the general rule that the analyses of sedimentary rocks should fall outside the lined areas of the triangles.

The oxide percentages and densities used in the calculations were:

Mineral	Density	Formula	Weight %
Calcite	2.715	CaO	56
		CO_2	44
Quartz	2.65	SiO_2	100
Sphene	3.45	CaO	28.6
		SiO_2	30.6
		TiO_2	40.8
Apatite	3.2	P_2O_5	41.0
		CaO	53.8
		Cl	6.8
Penninite	2.7	SiO_2	32.5
		Al_2O_3	18.4
		MgO	36.1
		H_2O	13.0
Hornblende	3.2	SiO_2	50.7
		MgO	20.05
		CaO	15.68
		Na_2O	1.93
		FeO	6.68
		Fe_2O_3	4.96
Anorthite		CaO	20.2
		Al_2O_3	36.6
		SiO_2	43.2
Albite		Na_2O	11.8
		Al_2O_3	19.4
		SiO_2	68.8
Diopside	3.275	CaO	28.6
		MgO	18.6
		SiO_2	55.5
Pigeonite	3.25	CaO	15.54
		MgO	27.1
		SiO_2	57.36
Mizzonite	2.71	CaO	15.2
		Na_2O	6.0
		SiO_2	47.4
		Al_2O_3	26.9
		CO_2	3.5

CHAPTER III

In this chapter it will be shewn that the apecimens collected from the area south of Found Lake are not granitic in character, except for specimens 6 and 11, and also that they are not related to the Sherridon quartzites but must be mapped as a unit distinct from the granite and the Sherridon quartzites.

It will then be shewn, from the evidence of the field relations, variations in the composition of the plagioclase and from the comparison of the oxide percentages with the analyses of other rocks, that they are of sedimentary origin and were probably dolomitic and calcareous arkoses in their original state. Finally, the rocks from the area north of the Lake will be shewn to be related to them.

THE ROCKS SOUTH OF FOUND LAKE

The granitic specimens, 6, 11, 22 and 29, all show very similar characters; the essential minerals are quartz, oligoclase and biotite with accessory muscovite and sometimes pale hornblende with sieve-texture; the entire absence of potash-felspar is characteristic. The parallelism of the biotite flakes gives a foliation to the rock which is more marked in some of the specimens than in others but all show signs of slight granulation in the bending and alteration to chlorite of biotite, the uneven extinction of the quartz and the alteration of the plagioclase which seems to be concentrated round the outside of the crystals.

The oligoclase granite represented in this area by specimens 6 and 11 has thus distinctive characters and when specimens 5, 7, 8, 9, 12, 13, 14a and b, 15, 18, 20 and 21, which were collected from this area, mapped as granite, are compared with the oligoclase granite it is at once evident that they are not specimens of granite.

Table I lists the volume percentages of the essential minerals of these specimens.

From this it can be seen that specimens 7, 16 and 21 are definitely quartzites; all the other specimens with the exception of No. 5 are composed of plagioclase, calcite, diopside, hornblende and sphene in varying amounts, a suite of minerals not characteristic of granites. Furthermore the anorthite content of the plagioclase is generally too great, the character of the calcite is primary in all cases where it forms more than 10% of the rock and the

TABLE I

VOLUME PERCENTAGES

	Specimen	Plagioclase		Calcite	Diopside	Hornblende	Sphene	Quartz	Penninite	Corundum
Lime-rich Specimens	5	Andesine An.35	37.6	-	-	-	-	-	16.1	38.0
	8	Andesine An.35	42.5	28.25	-	7.75	11.75	-	-	-
	9	Labradorite An.67	31.8	4.2	20.8	32.0	2.18	8.5	-	-
	12	Labradorite An.60	55.3	.55	-	39.4	3.32	-	-	-
	13	Bytownite An.75	48.5	3.97	4.73	13.0	3.97	14.6	-	-
	14a	Andesine An.35	19.0	61.0	10.2	4.1	1.55	4.1	-	-
	14b	Andesine An.35	54.4	21.3	1.82	3.16	11.7	5.38	-	-
	15	Oligoclase An.25	62.75	24.27	-	3.10	6.7	-	-	-
	18	Andesine An.45	58.5	5.82	1.19	18.50	9.35	-	6.81	-
	20	Labradorite An.65	9.55	51.5	Present	4.95	-	21.3	12.35	-
Quartzites	7		20.0	-	-	5.0	-	70.0	-	
	16		-	-	-	-	-	100	-	
	21	Andesine An.37	20.0	-	-	-	-	70.0	-	

Note: 1. Corundum of Section 5 includes the sillimanite as well as alteration products of both.
2. Labradorite of Section 12 includes secondary clinozoisite derived from it.

percentage of quartz is too low. The minerals of No. 5 are equally distinctly non-granitic.

It is apparent therefore that these rocks are not oligoclase granites and the question of how they should be mapped then arises. Bateman has recognized that they are not granites and in Map 862A of the Geological Survey of Canada he has included some of them with the Sherridon Quartzites by moving the contact of the Sherridon quartzite with the oligoclase granite northwards to approximately the same position as the axial line of the anticline as shewn on Map 44-4. However the non-granitic specimens 8, 9,10 and 12 were collected to the north of this line and it follows that the oligoclase granite contact must lie to the north of the localities from which these specimens were taken but south of the localities from which the granite specimens 6 and 11 were collected.

It is doubtful, however, whether all or even some of these specimens can be included with the Sherridon quartzites. Specimen 7 is believed to be representative of the Sherridon quartzites. C. H. Stockwell's notes for the locality from which it was taken say: "Specimen 7 of Gneissic Quartzite. Abundant quartz seen on weathered surface and 'bedding' shows by alternating quartz-rich and felspathic bands." Such field relations are considered typical of the Sherridon quartzite and the presence of calcite-rich bands or lenses is not a characteristic. Calcite-rich bands and lenses are however commonly found in the area from which the specimens of this study were collected as will be evident when their field relations are described and consequently it is necessary to regard them as a unit which is distinct from the Sherridon quartzite. The necessity for this distinction is even more marked when the mineral composition of the two types is compared, the Sherridon quartzites consisting of dominant quartz and plagioclase with some garnet, biotite or hornblende whereas quartz is generally a very minor constituent in the rocks of this study which are made up of dominant plagioclase, diopside and calcite.

The Field Relations

C. H. Stockwell's notes for the locality in which specimens 20 and 21 were collected say: "Interbedded quartzose limestone beds, 3" to 3 ft. thick, alternate with more abundant coarse quartzite beds, 3" to 5 ft. or more thick. These 'beds' dip gently east and are not contorted. However one layer of limestone holds irregular inclusions of quartzite as if there had been some flowage of the limey material rather than that the limey rock was formed by replacement of the quartzite."

The occurrence of lime-rich bands is common in the area just south of Found Lake and this is well shewn on the isthmus of the peninsula where specimens 14, 15 and 16 were collected where there is, according to Dr. Stockwell's notes, another banded or bedded area. His notes say that specimen 14a represents a coarse 'limestone' with some quartz grains and secondary development of olive green mineral and that in this limestone, there is a 1/2 inch band of 'quartzite' (14b). A microscopic examination of slide 14a showed that it consists of dominant calcite with andesine and diopside/hornblende, and of 14b that it is made up of dominant andesine with calcite, sphene and diopside/hornblende. The limestone represented by 14a "appears to be a 1 foot bed, (at least a band), in dominant impure felspathic quartzite (specimen 15);" a microscopic examination of slide 15 showed that it is not a quartzite but a plagioclase-rich rock which compares very well both for mineral composition and volume percentages with 14b. Specimen 16 collected nearby is a pure quartzite and was taken from a "2 foot band of thin layered pure quartzite, possibly recrystallized chert."

Eastwards from the peninsula, on the opposite shore line of the bay at Pt. A (Map No. 1) "there are 3 inch layers of good quartzites interlayered with friable rusty-weathering rocks." At Pt. B, there are "calcite lenses and layers interlaminated with quartzitic material." This quartzitic material is probably plagioclase-rich, as were specimens 14b and 15. At Pt. C, "there is a quartzite (cf. specimens 14b and 15) with 1 inch bands of chert and with lenses of impure carbonate rock up to 6 inches wide."

The repeated references to banding or bedding, 'quartzites' and 'limestones' show that the field relations are those of sedimentary rocks and microscopic study has shewn that lime-rich, plagioclase-rich and pure quartzite rocks are intimately associated. This extreme variation in composition, as well as the field relations, lead to the conclusion that they are sediments.

Discussion and Comparison of the Mineral Compositions

Megascopically none of the specimens are characteristically igneous in appearance and the fine grained equigranular texture -- almost grit-like on the weathered surface due to the leaching out of the calcite -- is what would be expected from the thermal or high grade regional metamorphism of fine-grained sediments.

Under the microscope, further indications that the rocks are metamorphosed sediments are seen; the equigranular nature of the hand specimens being represented by the common mosaic or diablastic texture of the thin sections and in many sections calcite is present in such amounts as to be reminiscent of recrystallised marble.

The composition and appearance of the plagioclases are also indicative of a sedimentary origin. G. C. Carlson (5) and E. Steidtman (6) have discussed the felspars as indicators of the origin of metamorphic rocks and have concluded that variations in composition of the constituent plagioclases are indicative of a derivation from sediments. The mean composition of the plagioclases in sections 5, 8, 14a and 14b is An.35 (see Table I) but even within one section, there are variations; one determination in section 8 gave An.63; the zoned crystal in Photograph 5, Slide 14b, has a core of composition An.98 and a rim of composition An.75 whereas the other determinationsfor that slide agreed within 5 mols per cent. Similarly for sections 15 and 18, there were variations of 10 or more mols per cent in the composition of the plagioclase.

It is to be expected that the plagioclases of one thin section should have approximately the same composition, whether the rock be a metamorphosed igneous or sedimentary rock and hence the variation of 10 - 20 mols per cent of Anorthite within one slide are indicative of a sedimentary origin, since the plagioclases of a metamorphosed igneous rock are more likely to be of identical composition.

This variation is also found from slide to slide and becomes even more marked when sections 9, 12, 13 and 20 are considered, when the range of variation in the plagioclase composition is extended from An.15 to An.90 as section 9 has a mean composition of An.67, No. 12 a mean composition of An.60, and No. 13 a mean of An.75 with one crystal of composition An.90.

In addition to this variation in composition, the plagioclases in all sections frequently show irregular zoning and diablastic intergrowths, also characteristic of the plagioclases of metamorphosed sediments.

It was mentioned above that the sections were reminiscent of recrystallised marble. In their report on the Haliburton-Bancroft area, Adams and Barlow (7, pp. 87 - 120) describe the characters of a limestone metamorphosed by the intrusion of granite. As a result of this metamorphism a suite of silicate minerals very similar to those of this study was developed. These minerals are pale green pyroxene, hornblende, felspar, both orthoclase and plagioclase, calcite, sphene, scapolite and quartz. From their description the rock so developed and which they called an amphibolite appears to be very similar to these rocks in the mosaic texture, in the minerals present and the variable percentages of those minerals and in the sieve texture shewn by the pyroxene and the hornblende. They concluded that the amphibolite was developed from the limestone by the addition of SiO_2, Al_2O_3, oxides of iron, MgO and some alkalies from the invading granite. It is not proposed to adopt this conclusion entirely in this paper but it is considered that the similarity between the amphibolite of Adams and Barlow and the lime-rich rocks of this study is such as to indicate similar conditions of formation for the two types of rocks and hence, the rocks of this study were originally lime-rich sediments.

This is further substantiated by the similarity between the chemical analyses of the amphibolite given by Adams and Barlow (p. 104) and the oxide percentages determined for these slides. These are compared in Table II below.

Three analyses were taken from Adamsand Barlow's report; the first analysis represents the initial stage of the alteration of the limestone by granite and at this stage there was still some free calcite remaining in the rock; the second represents the analysis of the silicate portion of this stage after the oxides present in the free calcite had been deducted and the analysis recalculated; the third analysis represents the second stage in the alteration when there was little if any free calcite present in the rock which was then a typical amphibolite, as defined by them.

It can be seen from Table II that there is quite a good correspondence in percentages between columns 1 and 2, column 1 being the analysis of the initial stage in the alteration of the amphibolite and column 2 the analysis of section 15 in which there was 24.27 per cent of free calcite; the high percentage in column 1 could be equalled if not surpassed by the analysis of such a specimen as No. 20 which contains 51.5 per cent of calcite. There is also a good correspondence between the analysis of the silicate portion of the initial stage in the alteration of the amphibolite and the analyses of specimens 9 and 18, rocks practically free from calcite shewn in columns 3, 4 and 5 respectively.

Column 6 is the analysis of the typical amphibolite and the agreement in the percentage of the oxides is not so pronounced, Al_2O_3, Na_2O, FeO, Fe_2O_3, having

TABLE II

OXIDE PERCENTAGES

	1	2	3	4	5	6
SiO_2	32.88	43.3	50.20	52.2	49.0	50.0
Al_2O_3	9.04	8.6	13.80	5.28	9.47	18.84
MgO	4.18	1.12	6.38	16.25	10.20	4.63
CaO	30.90	23.0	17.71	19.0	16.10	10.65
Na_2O	1.17	5.39	1.79	1.77	3.90	4.46
K_2O	0.85	-	1.30	-	-	1.18
TiO_2	0.49	2.72	0.75	0.78	3.52	0.82
Fe_2O_3	0.77	0.06	1.18	0.63	0.48	2.57
FeO	3.48	0.28	5.31	1.85	1.14	5.51
P_2O_5	-	0.44	-	-	-	-
CO_2	15.20	14.9	-	2.27	3.36	0.10
Cl	-	0.15	-	-	-	0.10
H_2O	1.08	-	1.66	-	2.88	1.00
MnO	-	-	-	-	-	0.08
	100.04	99.35	100.08	100.03	100.05	99.97

1. First stage in alteration of limestone (Adams and Barlow).
2. Analysis of section 15 with 24.27% calcite.
3. Analysis of silicate portion of limestone when free calcite is deducted (Adams and Barlow).
4. Analysis of section 9.
5. Analysis of section 18.
6. Analysis of typical amphibolite (Adams and Barlow).

increased considerably. It was on the increase in percentage of these and other oxides that Adams and Barlow based their conclusion that there had been addition of material from the invading granite. If there has been addition of material to the rocks of this study, that process has not progressed beyond the initial stage but it is considered that there has been no such extensive addition of material in this case and that these oxide percentages are closely related to the original composition of the sediments.

The purpose of this comparison has been to show that the composition of these rocks is very similar to that of a rock which is undoubtedly of sedimentary origin and which was originally lime-rich and the probability is therefore that they are also derived from sediments which were lime-rich before metamorphism, but since the origin of these rocks is uncertain, their analyses were compared with those of igneous rocks to see whether an analysis could be found that was comparable with them.

However, no analysis could be found that compared with these percentages, particularly when the relative percentages of CaO, MgO, Al_2O_3, FeO and Fe_2O_3 were considered, and Adams and Barlow drew attention to the fact that even the silicate portion of their analysis was higher in CaO than any igneous rock whose analysis had hitherto been recorded; specimens 9 and 18 are almost entirely made up of silicates and their content of lime corresponds closely with that of the silicate portion of Adams and Barlow's analysis.

For example, for those igneous rocks with an SiO_2 content of about 50 per cent, the average of 41 analyses of gabbro (8, p. 27) gave Al_2O_3 = 17.9, MgO = 7.5, CaO = 11.0; the average of 31 analyses of peridotite (8, p. 29) gave Al_2O_3 = 4.8, MgO = 32.2 but CaO = 4.4; the average of 21 analyses of nepheline basalt (9, p. 486) gave Al_2O_3 = 12.6, MgO = 11.6, CaO = 12.9 but FeO and Fe_2O_3 = 13.3; the analysis of a pyroxenite from Cebolla Springs, Colarado (10, p. 741) gave Al_2O_3 = 2.74, MgO = 12.04 and CaO = 20.21. This last is in approximate agreement but FeO and Fe_2O_3 = 18.21 and it is generally true that the analyses of pyroxenites and hornblendites show a high iron oxide percentage, and hence it has been concluded that the oxide percentages determined in this study must represent the analyses of lime-rich metamorphosed sediments.

These sediments were undoubtedly calcareous when formed and the field evidence indicates that there was an alternation in the conditions of deposition resulting in lime-rich, quartz-rich and probably felspathic layers and thus the rocks may have been calcareous arkoses. The high content of MgO as shewn by the analyses is indicative of the presence of either dolomitic or chloritic material; as the rocks are now highly metamorphosed it is not possible to decide which of these two materials was present but if the clay minerals such as chlorite, kaolin, limonite and the micas were constituents of the sediments to any appreciable extent, the percentages of Al_2O_3, FeO, Fe_2O_3, K_2O and Na_2O would be greater than they are and it is thought probable that the magnesian content is therefore derived from dolomite and that the sediments were originally dolomitic and calcareous arkoses.

The probability of this conclusion is increased when the minerals developed as a result of metamorphism are considered. These minerals are diopside, calcite, sphene, apatite and plagioclase of variable composition, all minerals likely to be developed in the regional metamorphism of impure magnesian limestones and related rocks (11, p. 260).

The revised contacts for those rocks south of Found Lake, suggested as a result of these conclusions are shewn on Map. 2.

THE ROCKS NORTH OF FOUND LAKE

Specimens 23, 24, 27, 28, 31, 74 and 75 were collected from areas on the northern side of Found Lake; Nos. 23 and 24 were collected from an area mapped as oligoclase granite whilst Nos. 27, 28, 31, 74 and 75 were collected from areas mapped as anorthositic gabbro. The nature of these is different from those discussed above but it will be shewn that there are good grounds for concluding that they are of the same origin.

As in the previous section, the field evidence will be given first, followed by a discussion of the microscopic characters and a comparison of the mineral percentages.

The Field Evidence

For the locality from which specimens 23 and 24 were collected, J. M. Harrison's notes say: "Definitely crystalline limestone with impure zones altered to igneous-looking rocks and probably contain considerable scapolite; gentle rolls in dip; plunge N.20W. 0° - 15°; rock is generally typical of altered limey rocks so common in Grenville." For the same area, C. H. Stockwell's notes say: "A light grey rock composed of a little colourless amphibole but chiefly of felspar (?) or a lime-silicate in which are lenses and narrow bands of lime." These field notes indicate that the area is not underlain by granite and it will be shewn below, when the mineral composition of these specimens is discussed, that they are not granitic.

For the locality on the shores of Cree Lake (Pt. C) northwest of the above locality, Harrison's notes say that weathering gives a pronounced edged appearance to the rock surface, like the quartzitic limestones of the Grenville.

Specimen 27, a calcareous highly felspathic rock, represents "the predominating hard material from a well laminated rock, greatly contorted, the contortions plunging gently north. The laminations are due to alternating layers of hard and soft material. The hard material predominates and the soft layers are chiefly of carbonate. Some of the soft calcareous bands and lenses contain grains of quartz. The whole suggests metamorphosed calcareous sediments."

Specimen 28, a richly calcareous highly felspathic rock, was collected in an area of banded limey rocks with the development of secondary pyroxene and a little biotite.

Specimen 29, a fine grained granite, was collected from one of a number of 6 inch to 1 foot sills which occur "as interbeds in dominant uncontorted banded hornblendic limey rock which is reminiscent of the impure argillaceous limestones of the Late Pre-cambrian of Great Slave Lake."

Specimen 31, composed of plagioclase, calcite, diopside and actinolite, was collected from a high hill of "unbedded rock which is probably amphibolitised lime-stone with abundant hornblende (?) crystals in a matrix of calcite."

For the localities on the eastern shore of Found Lake, Pts. D and E, the field notes of C. H. Stockwell and J. M. Harrison are very similar; for Pt. D, the former's notes say that there is an excellent exposure of limey sediment on a cliff face which appears to be definitely of sedimentary origin; the lower 5 feet of the cliff face is of interbedded 'quartzite' (cf. specimen 15 which was called a 'quartzite' but is plagioclase-rich) and sandy limey material in sharply defined layers, 3 inches to 6 inches thick, each type in about equal amounts. This is overlain by 'limestone' with plentiful development of secondary hornblende or pyroxene and within this 'limestone' are a few 6 inch beds of 'quartzite'. The dip is gently east and the layers are straight and uncontorted. For Pt. E, Harrison's notes say: "Very well-bedded limey rocks, quite impure for the most part but some beds are crystalline limestone, 1 foot thick; in places there are alternating layers of silicate and limestone layers less than 1/4 inch thick; some granite and even some quartzite is present; like much of the Grenville even to the granular texture of the decomposition products at the base of a 35 foot cliff; strong fluting on a small scale with an eastward dip of 35 degrees." Specimen 75 is a sample of the limestone and is composed of plagioclase, calcite, diopside and secondary hornblende.

From these field notes, it is evident that both C. H. Stockwell and J. M. Harrison are of the opinion that those rocks mapped as anorthositic gabbros are probably of sedimentary origin. Their notes also show that the bedding is much contorted and plunges north in the area where specimen 27 was collected and that it is less contorted and plunges east at points D and E. These attitudes are to be expected in view of the structure but they are a necessary consequence if the rocks were originally sedimentary.

Discussion and Comparison of the Mineral Compositions

Megascopically and microscopically, the sedimentary characters are not so evident but it will be shewn that these rocks, with the exception of No. 74,have many features in common with those south of Found Lake and that they are probably parts of the same body of sediments.

Megascopically these rocks are darker in colour than those south of Found Lake but they still show the rough grit-like, ridged weathered surface due to the equigranular nature of the minerals and the leaching out of the calcite.

Microscopically, they have the same suite of minerals, calcite, plagioclase of variable composition, diopside much altered to actinolite, apatite, sphene, with secondary iron ore, quartz and mica. The mineral relationships are considerably more complex and the minerals have been altered to a greater extent. For example, the amphibole derived from the diopside is actinolite and is strongly pleochroic indicating a higher content of iron, the plagioclase shows irregular zoning, is frequently altered to scapolite, zoisite, epidote or calcite and where fresh, the crystals show a curious irregular intergrowth with one another (Photographs 8, 9, 10).

These differences are due to the more intensive deformation that the rocks have undergone and also to the proximity of igneous intrusives as previously described.

Table III lists the volume percentages of the essential minerals of these specimens. For purposes of comparison, the volume percentages of secondary minerals derived from the plagioclases have been included with the volume percentages of the plagioclase.

These percentages show that specimens 23 and 24, taken from an area mapped as oligoclase granite, are not granitic. No. 24 is a quartzite and is very similar to No. 21 with the same minerals in the same proportions; these minerals are sericitized andesine, sutured quartz and flakes of muscovite, much altered to a colourless mineral of low birefringence containing oriented inclusions of acicular rutile (see Photograph 3) which is apparently the same as that described by Harker (11, p. 159) as "chloritic material with oriented needles of rutile." In hand specimens both rocks are fine to medium-grained cream-coloured quartzites with a pronounced parallelism of dark grey and colourless lenses, the latter composed of quartz. It is probable therefore that these two were taken from similar types of sediments.

Under these circumstances, No. 23, which was

TABLE III

VOLUME PER CENT

Number of Specimen	Plagioclase		Calcite	Diopside	Actinolite	Biotite	Chloritic Material	Quartz
No. 23	Bytownite An.76	30	5.4	35.4	26.65	-	-	1.58
No. 24	Andesine	20	-	-	-	-	15	65
No. 27	Labradorite An.68	68.3	20.6	1.18	2.8	-	-	-
No. 28	Andesine An.30	51.3	37.4	-	12.9	8.52	-	-
No. 31	Labradorite An.60	40.4	24.6	17.0	13.2	-	-	4.18
No. 75	Undeter-mined	42.9	36.4	8.5	12.4	-	-	-

TABLE IV

VOLUME PER CENT

Number of Specimen	Plagioclase		Calcite	Pyroxene		Amphibole		Sphene	Quartz
No. 23	Bytownite An.76	30	5.4	Pigeonite	35.4	Pargasite	26.65	1.15	1.58
					62.05 (Pyroxene + Amphibole)				
No. 9	Labradorite An.67	31.8	4.2	Diopside	20.85	Hornblende	32.0	2.18	8.55
					52.85 (Pyroxene + Amphibole)				

collected near No. 24 might be expected to show some relations with No. 20, collected from the same place as No. 21 but apart from the occurrence of bands of 'limestone' at both localities there is no resemblance, No. 23 being a pyroxene and amphibole-rich rock whilst No. 21 is a calcite-rich rock. No. 23 however shows very close mineralogical relationships with No. 9, which was collected south of Found Lake,as can be seen in Table IV which lists the constituent minerals and the volume per cent of those minerals for each rock.

This similarity is also shewn by the molecular percentages of the oxides for each rock, listed in Table V.

TABLE V

OXIDE PERCENTAGES

	No. 23	No. 9
SiO_2	48.4	52.2
Al_2O_3	4.85	5.28
MgO	22.02	16.25
CaO	17.80	19.0
Na_2O	1.20	1.77
TiO_2	0.37	0.78
Fe_2O_3	0.51	0.63
FeO	1.46	1.85
CO_2	2.74	2.27

These similarities are strongly indicative of a genetic relationship between the two specimens. The comparison of mineralogical composition can be extended to other specimens of this group and members of this group can also be compared with specimens taken from areas south of Found Lake, as has just been done, and it will be shewn that many of the specimens of both groups are apparently related, both in mineral characters and field relationships. In many cases, as for No. 23 and No. 9, the similarities are marked and it follows that both groups must be part of the same body of sediments.

Thus, specimens 31 and 74 are very similar in hand specimen and also in mineralogical composition and microscopic characters. In both the plagioclase crystals are irregularly zoned and intergrown and have in each case been altered to mizzonite to the same extent (see Table VI) indicating the same degree of and susceptibility to alteration. It is felt that this agreement becomes more significant when the field relationships are considered, No. 31 being obtained from a massive rock whereas No. 74 came from a well bedded locality.

Specimen 9, collected south of Found Lake shows a correspondence of mineral components and to a lesser extent of volume percentages with specimen 31, the disagreements being due to the considerably higher percentage of calcite in specimen 31. Both contain Labradorite and a high percentage of pyroxene and amphibole.

TABLE VI

VOLUME PERCENTAGES

	No. 31	No. 74	No. 9
Plagioclase	20.2(An.60)	19.1	31.8(An.67)
Mizzonite	20.2	19.3	-
Calcite	24.6	36.4	4.2
Diopside	17.0	8.5	20.85
Actinolite	13.2	12.4	32.00
Epidote	Present	4.5	-
Quartz	4.18	Present	8.55
Sphene	Present	Present	2.18
Apatite	Present	Present	Present

When the molecular percentages of the oxides are compared (see Table VII below), this dissimilarity is reflected but the same general trend of high CaO, MgO, low Al_2O_3 and SiO_2 is still evident and is the more pronounced in section 31 because of the relatively high content of free calcite.

TABLE VII

MOLECULAR PERCENTAGES

	No. 31	No. 9
SiO_2	39.4	52.2
Al_2O_3	25.51	5.28
MgO	9.35	16.25
CaO	26.75	19.0
Na_2O	2.14	1.77
TiO_2	0.13	0.78
Fe_2O_3	0.23	0.63
FeO	0.77	1.85
CO_2	15.7	2.27
Cl	0.23	-

Except for the composition of the plagioclase, specimen 27 compares very well with specimens 15 and 14b both in volume percentages and in field relations. Specimen 27, consisting of dominant plagioclase with calcite represents the predominating hard material in a well laminated much contorted area, in which the soft material is chiefly of carbonate. Specimens 14b and 15 represent the dominant felspathic 'quartzite' containing 'limestone' bands, which are represented by 14a; 14b and 15 consist of dominant plagioclase with calcite and 14a consists of dominant calcite with plagioclase. There is thus a strong resemblance in the field relations and the similarities in the mineral percentages, shewn in Table VIII below are as distinct.

TABLE VIII

VOLUME PERCENTAGES

	Plagioclase		Calcite	Diopside	Amphibole	Sphene
No.27	Labradorite	68.3	20.6	1.18	2.8	5.05
No.15	Oligoclase	62.75	24.27	-	3.10	6.7
No.14b	Andesine	54.4	21.3	1.32	3.16	11.7

Features clearly shewn by this table are the high percentages of sphene and the close agreement in the total percentages of diopside and amphibole as well as that of calcite. These three specimens provide the closest agreement in characters and this is probably the most significant comparison that has been made in showing that the rocks south of Found Lake are closely related to those north of Found Lake.

It has been concluded therefore from the field evidence, the variation in the composition of the plagioclase and the close mineralogical similarities of these rocks that the bodies of rock north of Found Lake, mapped as anorthositic gabbros have the same origin as those south of Found Lake and that they are therefore metamorphosed dolomitic and calcareous arkoses, and are now diopside-plagioclase-calcite gneisses.

The revised contacts suggested as a result of this conclusion are shewn on Map 2. Since specimen 74 is entirely different from all other specimens, it has been provisionally mapped as hornblende-plagioclase gneiss (No. 2, Map 44-4) and the contacts with the northwesterly mass of diopside-plagioclase-calcite gneiss, by which it is surrounded, have not been defined. However the author does not possess sufficient information to determine whether specimen 74 is definitely related to the main body of hornblende-plagioclase gneisses, and this correlation is based on the fact that the main body of hornblende-plagioclase gneiss may be in part intrusive and that specimen 74 may be derived from a basic igneous rock.

CHAPTER IV

PERIODS OF METAMORPHISM

Two distinct periods of metamorphism have been distinguished by the study of the thin sections. The earliest period was one of high grade regional metamorphism in which the main features of the present rock fabric were developed; this was followed by one or more periods of dynamic metamorphism -- not of great intensity -- in which the minerals formed in the first period underwent retrograde alteration of variable degree.

It must be emphasized, however, that what follows is in the nature of an academic discussion and is based entirely on the results of the examination of thin sections. Many more sections would have to be examined and considerably more field evidence than was possessed by the author would be needed before the metamorphic history of the area could be definitely established.

This chapter does however give some idea of the probable metamorphic history of the area.

The First Period

Metamorphosed lime-rich sediments are very stable under weathering conditions (12, p.284) and thus it is always possible to determine the highest grade attained in the last period of metamorphism. After the period of regional metamorphism but before the period of dynamic metamorphism, these lime-rich sediments consisted of an equigranular aggregate of calcite, plagioclase, diopside, hornblende, quartz, sphene, biotite, apatite, and corundum, these minerals being an original part of the present fabric and it is concluded that they represent the minerals developed as the result of the highest grade of metamorphism attained.

Some of these minerals, such as diopside, plagioclase and corundum are antistress minerals indicating that directed pressures were absent during their formation and the equigranular texture of the rock is evidence supporting this conclusion.

On the other hand, the frequent association of quartz and calcite -- which should combine to form wollastonite under high hydrostatic pressure and the high temperatures mentioned below -- indicates that directed pressure must have been active during the metamorphism since directed pressures tend to inhibit the above reaction.

The occurrence of an original stress mineral hornblende (in slides 12 and 28) is also indicative of directed pressures.

Diopside and plagioclase are considered by Harker (11, p.256) as high grade minerals developed from impure limestones or calcareous sediments under conditions of regional metamorphism. Bowen (13, p.257) has compiled a list of Index Associations for metamorphic limestones and dolomites which he considers can be used as a quite reliable indication of the temperatures attained during metamorphism. Thus the association of calcite and diopside is indicative of a temperature slightly less than 800°C; the Index Association for the stage below this is calcite, diopside and forsterite but no forsterite was identified in these rocks so it is probable that the maximum temperature attained during the first period of metamorphism was in the neighbourhood of 800°C. Bowen also points out that the diopside stage is never passed in regional metamorphism.

Further, under conditions of high grade regional metamorphism, accompanied by shearing stress, the association of quartz and calcite and of stress minerals with antistress minerals is no longer anomalous and hence it was concluded from the association of quartz and calcite, diopside, plagioclase and hornblende in these rocks that the original sediments were subjected to high grade regional metamorphism, the results of which have been little destroyed.

This period of metamorphism was in all probability coincident with the folding which gave rise to the structure of the area.

The Second Period

The oligoclase granite, the youngest intrusive in the area, is phacolithic in shape and conforms with the areal structure as do the bodies of pyroxenite and metagabbro. It is possible, therefore, that these were intruded during the period of folding and as it has been assumed that one of these bodies is the cause of the scapolitization of the felspars, it follows that metasomatic and pneumatolytic alteration must have taken place soon after the metamorphism of the sediments. The field evidence shows that the oligoclase granite is intrusive into the sediments in the form of sills in many places (cf. specimen 29 which was taken from one of these sills) and since granitic magmas, due to their higher content of volatiles, are more likely to cause scapolitization than are more basic magmas, it is probable that the oligoclase granite is the cause of the scapolitization of the plagioclase of these rocks.

However, the specimens of the oligoclase granite show a distinct foliation which could be of primary origin but the uneven extinction of bands in the quartz crystals (see Photograph No. 2), the sericitization of the felspars concentrated on the outside of the crystals and the bending and alteration to chlorite of the biotite (see Photograph No. 1) are indicative of cataclastic movements subsequent to its consolidation.

Other evidences for a period of slight dynamic metamorphism are numerous; the most widespread is the alteration of diopside to hornblende or actinolite (see Photograph No. 7); Harker (11, p.351) mentions that the amphibolization of diopside in semi-calcareous sediments is common under conditions of shearing stress and G. D. Osborne (14, p.209) describes the alteration of diopside of limestone to actinolite under stress conditions. In these rocks, the alteration of the diopside to pargasitic hornblende rather than actinolite is an unusual change but it is not unnatural in view of the low percentage of iron. The formation of actinolite from diopside in specimens 27, 31 and 75 may be due to an originally higher content of iron for these rocks but it has been mentioned that it is assumed to be the result of metasomatic action, probably by the granite and it follows that the later period of dynamic metamorphism must have been accompanied by the intrusion of the oligoclase granite and may have been in the nature of a resurgance of the first period of regional metamorphism; in which case the cataclastic texture of the oligoclase granite is indicative of yet a third period of dynamic metamorphism.

Other evidences of dynamic action are the formation of secondary twinning, clinozoisite and epidote in the plagioclases (see Photographs Nos. 7 and 9), the strained extinction of the quartz and the bending and alteration to chlorite of the biotite in the quartzitic and lime-rich sediments (see Photograph No. 3). It is not apparent however whether these are due to the first or the doubtful later periods of dynamic metamorphism but it is evident however that the effects of later dynamic action, irrespective of the number of periods, have been slight and it is considered that the main features of the fabric of the lime-rich and quartzitic sediments date from the period of folding which gave rise to the structure of the area.

CHAPTER V

MEGASCOPIC AND MICROSCOPIC DESCRIPTION OF THE SPECIMENS

The groups outlined in Chapter II have been retained here, the description of the granitic specimens being given first followed by that of the lime-rich specimens, then that of the quartzite specimens and finally that of specimens which cannot be included in the other groups.

The localities from which these specimens were obtained are shewn on Map 1.

1. THE GRANITE SPECIMENS

Specimen No. 6 — Photograph No. 1

	Vol.%
Quartz	40.0
Oligoclase	40.0
Biotite	5.0
Clinozoisite, Epidote	5.0
Garnet	5.0
Apatite, Chlorite, Iron Ore	5.0

In hand specimen, this is a dark grey fine-grained rock with large grains of quartz visible throughout, the weathered surface being brown or grey. Felspar in small grains is common and red-brown garnet occurs in small aggregates. Scattered flakes of biotite give the rock its dark colour.

In thin section, the rock is seen to consist essentially of quartz and oligoclase felspar, the size of the quartz grains varying as in hand specimen; large anhedral grains of brown biotite are common and are often bent and slightly fractured, and frequently altered to chlorite (see Photograph No. 1). Isotropic garnet, tinted a very pale pink, is present as irregular grains, somewhat larger than the average; it is also altered to chlorite in places. Accessory apatite and iron ore are present in minor amounts, the apatite in euhedral grains.

The oligoclase is generally fresh but shows quite extensive alteration to sericite, especially around the edges (see Photograph No. 1) and also to clinozoisite or epidote. These alterations together with the bending and alteration to chlorite of the biotite suggest that the rock has been subjected to a certain amount of granulation.

Specimen No. 11

In hand specimen, this is a medium-grained dark grey granular rock consisting of quartz and felspar in about equal amounts, scattered grains of transparent red-brown garnet and subparallel flakes of deep brown biotite which give a poorly developed foliation.

In thin section, it is a fine to medium-grained hypidiomorphic granular aggregate of quartz (30%), oligoclase (45%), brown biotite (15%), muscovite (5%) with accessory apatite, iron ore and isotropic pale pink garnet. No potash-felspar was identified.

The quartz shows strain effects in the form of parallel bands with undulatory extinction; the oligoclase shows faint albite twinning and is extensively altered to kaolin and calcite and in one case to secondary scapolite. The biotite, pleochroic in brown and yellow, is extensively altered to chlorite with acicular inclusions of rutile and shows the same parallelism of flakes as seen in hand specimen.

<u>Specimen No. 22</u> <u>Photograph No. 2</u>

In hand specimen this is a medium grained granular dark-grey rock consisting of quartz, felspar and deep brown biotite flakes which are parallel throughout the specimen and give a distinct foliation.

In thin section the rock is seen to be a medium grained granular aggregate of quartz (30%), plagioclase (45%), biotite (15%), minor hornblende and muscovite (5%) with accessory apatite, iron ore and secondary calcite.

The quartz shows strain effects in the form of parallel bands with uneven extinction (see Photograph No. 2); the oligoclase felspar is generally fresh and untwinned but is sericitized around the edges as was the case with specimen No. 6 but no clinozoisite is present in this slide. No potash-felspar was positively identified but possibly some orthoclase -- not in great amount -- is present.

The hornblende which is pleochroic in pale greens and yellows shows every stage in the transition to dark brown biotite with a resultant sieve-texture, and the secondary biotite itself is intergrown with secondary quartz giving a well developed kelyphitic texture. The primary biotite, pleochroic in brown and yellow, is less altered to chlorite than in the other slides but various stages in the alteration process are present.

Accessory iron ore and euhedral apatite are found throughout the slide. No garnet is present in this section.

Specimen No. 29

In hand specimen, the rock is a fine grained granular blue-grey aggregate of quartz and felspar with deep brown parallel flakes of biotite which give a distinct foliation. This specimen was taken from a 6 inch to 1 foot thick sill of granite within banded limey rocks, which accounts for its fine grain.

In thin section, it is seen to be fine grained. Otherwise, the characters are the same as those of specimen No. 22.

2. THE LIME-RICH SPECIMENS

Specimen No. 8 Photograph No. 4

	Vol.%
Andesine(An.35)	42.5
Calcite	28.25
Hornblende	7.75
Sphene	11.75
Muscovite	3.75
Iron Ore	3.35
Chlorite	2.25
	99.60
Quartz	

In hand specimen, the rock is light coloured and fine-grained consisting of felspar and calcite with disseminated pale brown crystals of sphene, small grains of pyrrhotite and pale green crystals of hornblende, the dark minerals giving the rock a spotty appearance.

In thin section, the rock is mosaic-textured and consists of anhedral grain of dominant andesine, much interstitial primary calcite with subhedral sphene, irregular sieve-textured grains of hornblende with inclusions of calcite and quartz, muscovite and disseminated iron ore. The andesine is generally quite fresh but shows strain effects and is altered to sericite and kaolin. The sieve structure of the hornblende may be due to the fact that it is derived from completely altered diopside and the inclusions may be "left overs" from this change.

Specimen No. 9

	Vol.%
Labradorite(An.67)	31.8
Hornblende	32.0
Diopside	20.85
Quartz	8.55
Sphene	2.18
Calcite	4.12
	99.50
Iron Ore	
Graphite	
Biotite	

In hand specimen, the rock is light purplish-grey and fine grained, weathering dark brown or grey. It consists of colourless felspar, transparent to dark brown hornblende/diopside with disseminated graphite and biotite. Indications of layering are visible.

In thin section, the rock is a fine grained mosaic of labradorite and colourless diopside altered to pale yellow slightly pleochroic hornblende and calcite; the two minerals show well developed poikiloblastic and sieve-textures. The interstitial calcite is mostly secondary but some may be primary. Interstitial quartz is quite abundant and disseminated euhedral sphene occurs here as in other specimens.

Specimen No. 12

	Vol.%
Labradorite(An.60)	32.6
Hornblende	39.4
Clinozoisite	22.70
Sphene	3.32
Apatite	1.55
Calcite	.55
	100.12

In hand specimen, the rock is light grey and fine to medium grained weathering buff, the constituent minerals being difficult to distinguish.

In thin section, the rock consists of a poikiloblastic aggregate of euhedral crystals of colourless hornblende, sphene and apatite set in a matrix of and intergrown with anhedral labradorite, which is much altered to clinozoisite. The basal sections of the hornblende are distinctly wedge-shaped whereas the prism sections show no terminations, a characteristic of the growth of amphiboles under metamorphic conditions. The hornblende is a primary metamorphic mineral and is not derived from diopside as in other sections.

Specimen No. 13

	Vol.%
Bytownite(An.75)	48.5
Quartz	14.6
Hornblende	13.0
Diopside	4.73
Sphene	3.97
Calcite	8.97
Scapolite	1.55
Iron Ore	5.05
	100.37

In hand specimen the rock is rust-stained and has small grains of sphene and iron ore set in a fine grained matrix of felspar, hornblende and quartz. The rock is massive and weathers a deep brown.

In thin section, the rock is mosaic-textured and consists of irregular crystals of diopside/hornblende, subhedral sphene and iron ore set in a matrix of bytownite and quartz with some primary as well as secondary calcite.

The bytownite is anhedral and the grains are much inter-grown and often distorted or slightly shattered, frequently enclosing grains of diopside, hornblende, sphene and iron ore giving a well developed poikiloblastic texture; patches of symplektite are also present; though generally quite fresh, the plagioclase is altered to mizzonite in some places.

The diopside is considerably altered to

colourless hornblende with the formation of secondary calcite and iron ore. Accessory iron ore and sphene are scattered throughout the slide, the iron ore having a tendency to occur in clusters.

Specimen No. 14

	Vol.%
Calcite	61.0
Andesine(An.35)	19.0
Diopside	10.2
Hornblende	4.1
Quartz	4.1
Sphene	1.55
	100.15
Apatite	
Iron Ore	

This specimen was taken from a 1 foot band of coarse 'limestone' in dominant felspathic 'quartzites', represented by specimen 15.

In hand specimen the rock is light greyish green, fine-grained and partly banded, consisting of calcite, felspar and olive-green diopside. Grains of sphene are scattered throughout the rock and it is pock-marked with limonite stains, apparently due to the weathering of iron ore. On weathered surfaces the rock is dirty grey and the transparent felspar grains stand out, giving somewhat the appearance of weathered sandstone with resistant grains of quartz; differential weathering accents the layering. This surface results from the solution of calcite leaving the small equidimensional grains of felspar and dark minerals protruding on a very rough surface. As the felspar is usually glassy in appearance it is easily confused with quartz and hence the similarity to a weathered sandstone. This surface is characteristic of these lime-rich rocks and will be mentioned frequently when other specimens are described.

In thin section, the rock consists of large grains (2 to 3 mm) of primary calcite, which shows some fracturing. The other minerals are andesine, diopside, quartz and sphene in small grains (1 to 2 mm), and the anhedral granular shape of these minerals give the rock a mosaic texture. The andesine shows the effects of strain but the diopside is fresh and comparatively little altered to hornblende.

<u>Slide 14b</u>, Photograph No. 5

	Vol.%
Andesine(An.35)	54.4
Calcite	21.3
Diopside	1.82
Hornblende	3.16
Muscovite	2.7
Sphene	11.7
Quartz	5.38
	100.06

Biotite
Apatite
Iron Ore

No hand specimen was collected and this section was made from a chip of rock taken from a 1/2 inch band of quartzite within the 1 foot band of 'limestone' represented by specimen 14. The mineral composition of this slide is similar to that of specimen 15 which represents the dominant 'quartzite' associated with specimen 14 and the occurrence of a 1/2 inch band of material within the 'limestone' is strongly suggestive of variations in the conditions of deposition.

In thin section, the rock shows a mosaic texture of fine-grained anhedral minerals and consists of dominant andesine and calcite which is mostly primary. The plagioclase shows some irregular zoning throughout the slide but the determinations of composition all gave results in close agreement (An.35), except for the zoned crystal in Photograph No. 5 which has a core of composition An.98 and a rim of composition An.75.

The diopside is much altered to colourless hornblende. Subhedral sphene is a plentiful accessory, whilst anhedral quartz, euhedral apatite, muscovite and biotite occur throughout the rock in lesser amounts.

Specimen No. 15

	Vol.%
Oligoclase(An.25)	62.75
Calcite	24.27
Sphene	6.7
Hornblende	3.10
Apatite	2.1
Biotite	.81
	99.73
Muscovite	
Quartz	

This specimen represents the dominant 'quartzite' with which is associated the 'limestone', represented by specimen 14.

In hand specimen, this is a light-grey fine-grained rock and consists of felspar, a pale greenish-coloured hornblende and minute disseminated grains of sphene; rust-coloured spots, where the iron ore has weathered, are scattered throughout the rock.

In thin section it consists primarily of oligoclase and calcite with sphene, sieve-textured pale yellow hornblende and accessory biotite, muscovite and quartz.

The oligoclase is fresh and unstrained but small areas of symplektite are visible throughout the rock.

Except for the absence of diopside, this specimen compares quite well with section 14b, indicating a relationship in their formation and it is assumed that the alteration of the diopside has gone to completion in this section.

Apatite and sphene are common accessories, the apatite in small euhedral crystals and the sphene in subhedral grains.

Specimen No. 18 Photograph No. 6

	Vol.%
Andesine(An.45)	58.8
Calcite	5.82
Diopside	1.19
Hornblende	18.5
Clintonite	6.81
Sphene	9.35
	100.47

In hand specimen the rock is fine-grained, and consists of plagioclase with pale brown hornblende and very small grains of iron ore and sphene. It has a brown rust-stained appearance on the fresh surface and weathers grey. There is no banding but a tendency towards clotting of the felspar and hornblende is visible.

In thin section, andesine is the dominant mineral giving a fine grained mosaic with colourless diopside, now almost entirely altered to colourless hornblende, primary and secondary calcite and common subhedral grains of sphene.

This section shows a feature not seen in any of the others: a mineral which is believed to be seybertite, a member of the clintonite group, occupies the interstices and gives the effect of having been deposited from solution along cracks in the rock but more probably it replaces calcite which has been leached out (see Photograph No. 6). The rusty appearance of the fresh surface of the rock may be due to this mineral.

The plagioclase shows albite and pericline twinning and irregular zoning is quite common. Many of the grains show strain extinction effects and some are slightly fractured.

One small grain of fluorite was present, this being the only occurrence of this mineral in the sections examined.

Specimen No. 20

	Vol.%
Calcite	51.5
Quartz	21.33
Labradorite	9.55
Actinolite	4.95
Saussurite	12.35
Sphene	.62
	100.30
Diopside	
Apatite	
Iron Ore	

This specimen represents the 'quartzose limestone' occuring in beds 3 inches to 3 feet thick which alternate with more abundant quartzite beds 3 inches to 5 feet or more thick, represented by specimen 21.

In hand specimen, the rock is light coloured and fine grained with specks of pale green hornblende throughout giving a speckled effect. It consists essentially of calcite with quartz, felspar and hornblende, weathering a pale brownish-white with the characteristic rough surface.

In thin section calcite in large anhedral grains is dominant with subhedral labradorite and anhedral quartz. Diopside is practically absent and the hornblende which has replaced it is faintly pleochroic in pale greens and yellows with a distinct sieve-texture and is commonly associated with secondary calcite.

The labradorite is extensively saussuritized and frequently unaltered relics of plagioclase are surrounded by a confused mass of clinozoisite, zoisite, calcite and some quartz.

Specimen No. 23

Photograph No.7

	Vol.%
Pigeonite	35.4
Pargasite	26.65
Bytownite(An.76)	30.0
Calcite	5.4
Sphene	1.15
Quartz	1.58
	100.18
Iron Ore	
Phlogopite	

This specimen was taken from a light grey rock in which there were lenses and narrow bands of limestone.

In hand specimen, the rock is grey-white and medium grained consisting of felspar, colourless pyroxene and amphibole, the amphibole occurring as bladed colourless aggregates. Iron ore, phlogopite and sphene are thinly disseminated throughout.

In thin section, the rock consists of a coarsely poikiloblastic intergrowth of pigeonite and bytownite; the plagioclase is quite fresh but is much fractured with some evidences of movement, the fractures being filled with secondary calcite (see Photograph No. 7). There is apparently some slight displacement of the twinning bands on either side of the crack, shewn in this photograph, but more probably the twinning bands are secondary, as they are irregular in shape and terminate at the crack.

The colourless pigeonite is extensively altered to colourless optically (+) pargasite and secondary calcite. Photograph No. 7 shows very clearly the intimate relationship between the pyroxene and the amphiboles as seen in all the thin sections.

Accessory sphene in subhedral grains and some iron ore and phlogopite are present.

Specimen No. 27 Photograph No. 8

	Vol.%
Labradorite(An.68)	46.7
Calcite	20.6
Actinolite	2.8
Diopside	1.18
Sphene	5.05
Clinozoisite	14.4
Mizzonite	6.0
Penninite	1.23
Apatite	1.66
Iron Ore	.38
	100.00
Muscovite	
Quartz	
Biotite	

This specimen represents the dominant hard material from an area of well laminated much contorted rocks, the laminations being of alternating hard and soft material; the soft material is chiefly carbonate and thus their field relations are closely similar to those of the locality from which specimens 14 and 15 were collected, where there are layers of 'limestone' alternating with dominant felspathic 'quartzite'.

In hand specimen, the rock is grey-coloured and fine to medium grained consisting of felspar and calcite with small scattered crystals of actinolite, sphene and iron ore. The rock weathers dark grey and there is a suggestion of the characteristic surface.

In thin section the rock presents a very complex appearance. Very irregular intergrowths of labradorite crystals make up the body of the rock; these crystals show curious extinction effects with little twinning but incomplete zoning -- possibly oscillatory -- is common. Photograph No. 8 shows the complex intergrowth texture and also a zoned crystal. Alteration of the plagioclase is complex and widespread with the development of mizzonite, calcite, clinozoisite and penninite.

Diopside and actinolite are uncommon, the actinolite having formed from the diopside as was the case with hornblende in other specimens. This is the first instance described in which actinolite has developed from the diopside and this was found to be the case also with the specimens 31 and 74 described below, all of which were collected north of Found Lake.

The sphene departs from its usual mode of occurrence as disseminated grains in that it occurs as lenselike aggregates of 10 to 20 crystals in several places in the slide; elsewhere it is evenly distributed.

Specimen No. 28 Photograph No. 9

	Vol.%
Calcite	37.4
Andesine(An.34)	26.10
Epidote	13.9
Hornblende	12.9
Biotite	4.15
Chlorite	4.37
Sphene	0.85
Iron Ore	0.28
	99.95

This rock was taken from an area of "banded limey rocks with the development of secondary pyroxene and a little biotite".

In hand specimen it is a dark grey fine-grained rock with a speckled appearance due to the scattered nature of the small grains of dark minerals, consisting of calcite and plagioclase with biotite and hornblende and shows a distinct parallelism of grains but no banding. The weathered surface has the characteristic roughness and the parallelism of the minerals -- seen to apply to the felspar crystals also as the rock weathers into crude ridges.

In thin section, it consists of large grains of calcite with anhedral andesine, hornblende, brown biotite, minor sphene, apatite and iron ore.

The plagioclase is much altered to epidote and calcite but where unaltered is clear and well twinned. No diopside is present and the pale brown hornblende, pleochroic in yellow and brownish-green is an original mineral occurring in euhedral crystals. The biotite, pleochroic in brown and yellow is partly altered to chlorite and shows a parallelism of well developed tabular crystals.

The accessory minerals are sphene, iron ore and apatite.

Specimen No. 31

	Vol.%
Calcite	24.6
Labradorite(An.60)	20.2
Diopside	17.0
Actinolite	13.2
Scapolite	20.2
Quartz	4.18
Sphene	0.33
Apatite	0.37
	99.08
Epidote	
Iron Ore	

This specimen was collected from an unbedded rock which formed a high hill and was considered to be an "amphibolitised limestone".

In hand specimen, it is a fine to medium grained grey rock with large (5 mm) crystals of dark green amphibole set in a matrix of felspar and calcite and has a distinct parallelism of dark minerals. The rock weathers to a dark grey with the characteristic rough surface, the felspar standing out as white grains.

In thin section, it consists of large crystals of calcite, anhedral labradorite and diopside which is much altered to actinolite, with secondary mizzonite and accessory apatite, iron ore and sphene.

The labradorite crystals are irregularly intergrown as in specimen No. 37, with irregular zoning and rare ill-developed twinning; small areas of symplektite are associated with it. Alteration to mizzonite is widespread and minor epidote is another alteration product (see Photograph No. 10).

The pyroxene is plentiful and is faintly pleochroic, having the optical characters of the diopside-hedenbergite series but being nearer diopside in character. It is much altered to strongly pleochroic actinolite.

Quartz occurs sparingly in small anhedral grains and accessory anhedral crystals of sphene, apatite and iron ore are disseminated throughout the section.

Specimen No. 75

	Vol.%
Calcite	36.4
Plagioclase	19.3
Scapolite	19.1
Diopside	8.5
Actinolite	12.4
Epidote	4.5
	100.2
Quartz	
Sphene	
Apatite	

This specimen, representative of the limestone, was taken from a locality on the eastern shore of Found Lake where very well-bedded limey rocks outcrop together with beds of silicate rocks, quartzites and sills of granite, all of variable width.

In hand specimen, it is very similar to specimen 31 being a fine to medium-grained grey rock consisting of felspar, calcite and crystals of dark green amphibole which are roughly parallel and there is a faint banding of light and dark constituents. The weathered surface is dark grey and shows an approach to the characteristic rough surface.

In thin section, the rock has a fine-grained diablastic texture and is very much altered; it consists of much primary calcite, irregular grains of plagioclase, colourless diopside, green actinolite, euhedral grains of sphene with accessory apatite and quartz.

The plagioclase whose composition was indeterminable in the section available, shows every stage in the alteration to mizzonite and epidote.

The diopside is colourless and is extensively altered to pleochroic green actinolite as in specimen 31. One crystal was unusual in that it included a grain of sphene from which cracks radiated into the diopside as though the sphene had grown after the diopside had formed.

3. THE QUARTZITIC SPECIMENS

Specimen No. 7

In hand specimen, this is a grey fine to medium-grained quartzite showing a distinct layering on the weathered surface, the layering being due to 1/16 inch thick bands of more easily weathered felspar-rich layers. Scattered grains of very pale green hornblende are visible on the fresh surface, and the rock weathers slightly rusty, probably as a result of the decomposition of this mineral.

In thin section, the rock consists of dominant fine to medium-sized grains of quartz (70%) with sutured outlines which show a parallelism of the length of the grains. Other minerals present are plagioclase (20%), hornblende (5%) and secondary calcite; the plagioclase shows a tendency to layering as mentioned above. The colourless hornblende is in small anhedral grains and is altered to calcite and penninite.

Specimen No. 16

This specimen was taken from a 2 foot wide band of pure quartzite in an area of alternating layers of calcite-rich and felspathic rocks represented by specimens 14 and 15.

In hand specimen, it is a brown-stained fine to medium-grained quartzite weathering to a dark brown, with a very fine lamination (1/20 inch) which is discernible because of slight colour differences in the bands.

In thin section it consists of recrystallized anhedral grains of quartz of varying sizes with sutured outlines, the brown stain of the hand specimen being due to a yellow ferriferous stain, probably limonite, which surrounds all the grains.

Specimen No. 21 Photograph No. 3

This specimen represents the dominant quartzite from a locality in which this quartzite, in beds 3 inches to 5 feet or more thick, alternates with beds of coarse 'quartzose limestone' 3 inches to 3 feet thick.

In hand specimen, it is a fine to medium-grained rock with a pronounced parallelism of lenses of colourless and dark-grey minerals. The minerals present are quartz, a dark grey mineral which is probably chloritic material (see below) and some flakes of muscovite visible on the grey weathered surface.

In thin section, a pronounced parallelism of minerals is seen with an indication of banding. Quartz in anhedral grains with sutured outlines is the dominant mineral; anhedral andesine (An.37) which is considerably sericitised is also present and forms about 20 per cent of the rock, together with some flakes of muscovite. The muscovite, which originally formed about 10 per cent of the rock is altered to a colourless mineral of low birefringence which contains oriented inclusions of acicular rutile (see Photograph No. 3) which is apparently the same as that described by Harker (11, p.159) as "chloritic material with oriented needles of rutile". Some secondary calcite is present.

<u>Specimen No. 24</u>

In hand specimen, this is a cream coloured quartzite showing banding as for specimen 21 but finer grained and with less obvious dark grey lenses of chloritic material.

In thin section, it has the same characters as No. 21, consisting of sutured grains of dominant quartz, much sericitized andesine (20%), the chloritic material previously described and some residual grains of muscovite (15%).

4. OTHER SPECIMENS

Specimen No. 5

	Vol.%
Andesine(An.35)	38.6
Corundum	13.5
Sillimanite	12.7
Diaspore, Margarite	12.75
Penninite	16.1
Rutile	3.35
Calcite	2.75
	99.95
Sphene	

In hand specimen, the rock is light grey, fine-grained and equigranular, weathering brown. Parallel to one weathered surface there is a pronounced layer of platy muscovite but this feature was not visible elsewhere in the specimen although a banding due to lenses of red-brown corundum is present.

In thin section, the rock is fine-grained and mosaic-textured with no parallelism of minerals and presents several features which were not seen in the other specimens; the presence of corundum and sillimanite is unique and the penninite has inclusions of well developed but very small crystals of green-brown rutile, an association not seen in other sections.

The corundum occurs as distinct irregular grains and is always surrounded by a felted mass of platy crystals which are colourless and of variable birefringence, undeterminable due to the superposition of the crystals; this mass is thought to be composed of margarite and/or diaspore, common alteration products of corundum as it has some of the properties of these minerals.

The sillimanite occurs in sheaf-like aggregates of acicular crystals. The form of the aggregates is unusual and the occurrence of the mineral here would best be described by the varietal name, fibrolite. In all cases, the aggregates are surrounded by the same felted mass of crystals as the corundum.

Andesine felspar forms the body of the rock, occurring in anhedral crystals which are generally quite fresh but are extensively altered to kaolinite and calcite in some places.

The penninite, in irregular interstitial crystals, is very faintly green and is not clearly derived from any other constituent mineral; it has numerous inclusions of rutile which occurs as minute euhedral often geniculated crystals which are greenish-yellow in colour and highly birefringent.

Secondary calcite and disseminated sphene are present in small amounts, the sphene in subhedral crystals.

The mineral composition does not correspond with that of any other specimen and the relationship of this rock to the others is therefore obscure. It does, however, show some features that are similar; these are the mosaic texture, the presence of plagioclase felspar, the absence of potash-felspar and the occurrence of an antistress mineral, corundum, which shows the effects of later dynamic action in its alteration to diaspore or margarite.

The tentative conclusion reached therefore is that it represents a silica-poor aluminium-rich facies of the sediments and it has been regarded as such in this paper.

Specimen No. 74

	Vol.%
Andesine(An.35)	45.0
Augite	13.9
Actinolite	27.4
Garnet	6.3
Apatite	3.2
Iron Ore	3.76
	99.36
Calcite	
Quartz	
Chlorite	
Biotite	

This rock, described by J. M. Harrison as a "garnet-hornblende-felspar rock like some amphibolites of the Grenville" is also different from all the other specimens. In hand specimen, it is a heavy black coarse-grained rock, consisting of black amphibole and white felspar in equal amount with numerous round crystals of red-brown garnet.

In thin section, the rock is an intimate intergrowth of anhedral plagioclase and actinolite with some residual augite, the minerals being so intergrown that the actinolite, in one instance, has penetrated into a twinned crystal of plagioclase along the plane of one of the twins.

The plagioclase, andesine, is anhedral and shows little twinning; throughout it shows incipient alteration to a brownish mass of saussurite and in some crystals the alteration is almost complete.

The augite, which is present only as residual grains, having been extensively altered to actinolite, is colourless and has schiller inclusions. The secondary actinolite is green-brown in colour and is strongly pleochroic with X= yellow, Y=greenish-brown, Z=dark brownish-green.

The garnet, which is isotropic, occurs in pale pink anhedral crystals with numerous inclusions of apatite, calcite, quartz and felspar and is extremely altered to chlorite.

Apatite, quartz, iron ore and secondary calcite are common accessories; sphene and biotite, altered to chlorite, are present in small amounts.

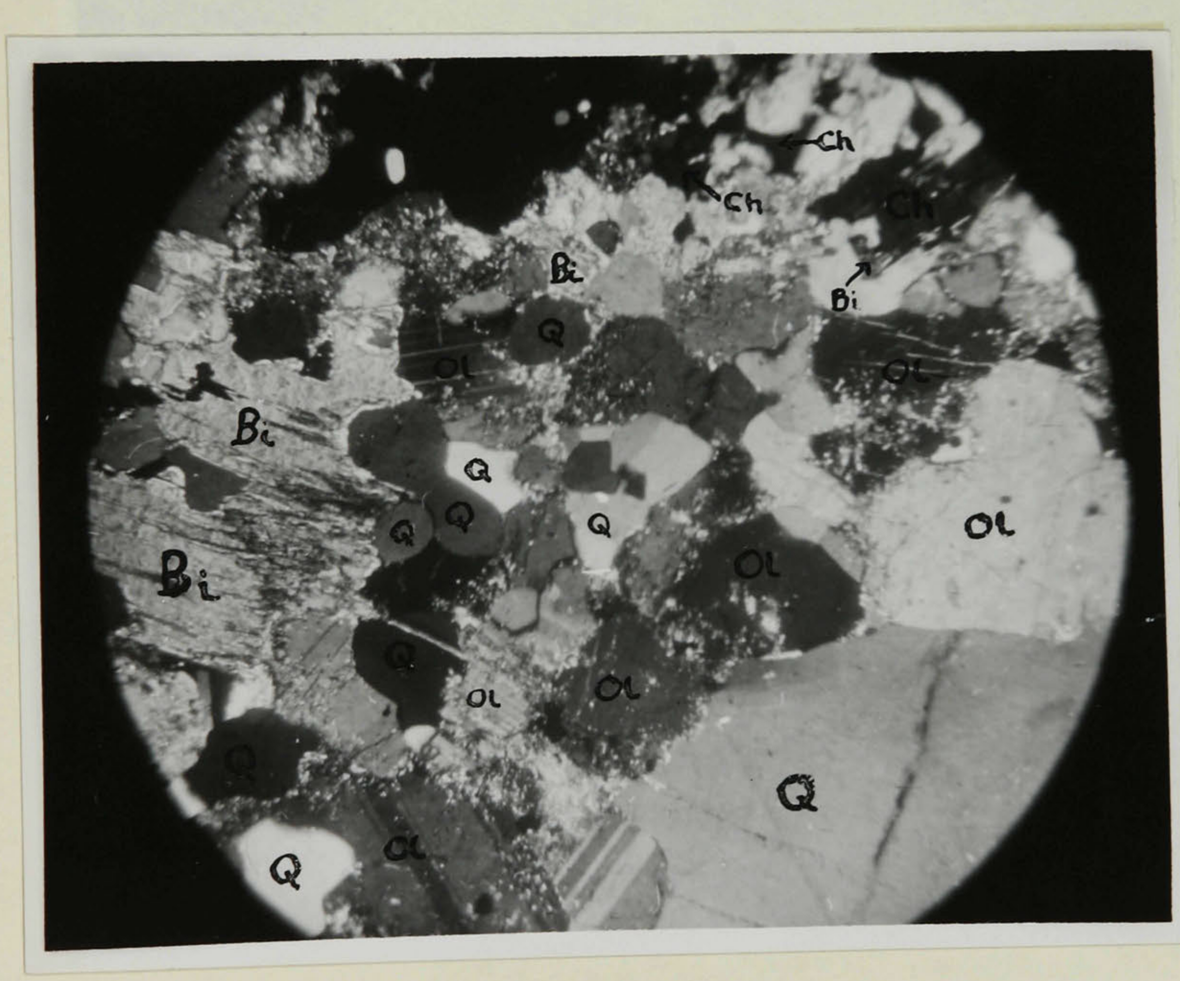
The pronounced diablastic texture and the association of andesine, augite, actinolite and garnet indicate that this rock is a garnet-plagioclase amphibolite, possibly derived from a diabase or gabbro by metamorphism.

APPENDIX A

PHOTOMICROGRAPHS OF THE SPECIMENS

P H O T O G R A P H NO. 1

SPECIMEN 6



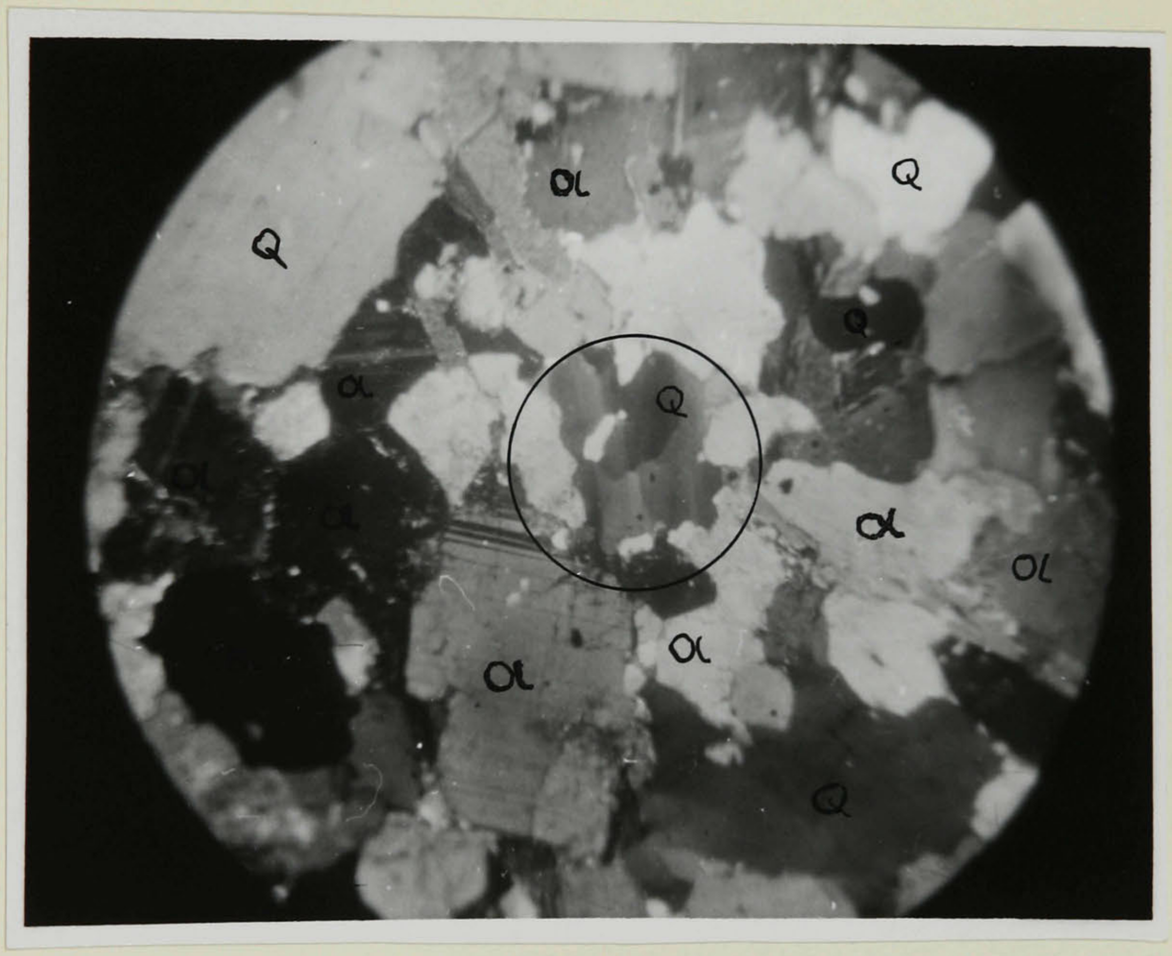
Magnification = x70

GRANITE. Showing evidences of granulation in the alteration of the plagioclase around the edges, and the bending and alteration to chlorite of the biotite

Q = quartz, Ol = oligoclase, Bi = biotite, Ch = chlorite

P H O T O G R A P H NO.2

SPECIMEN 22



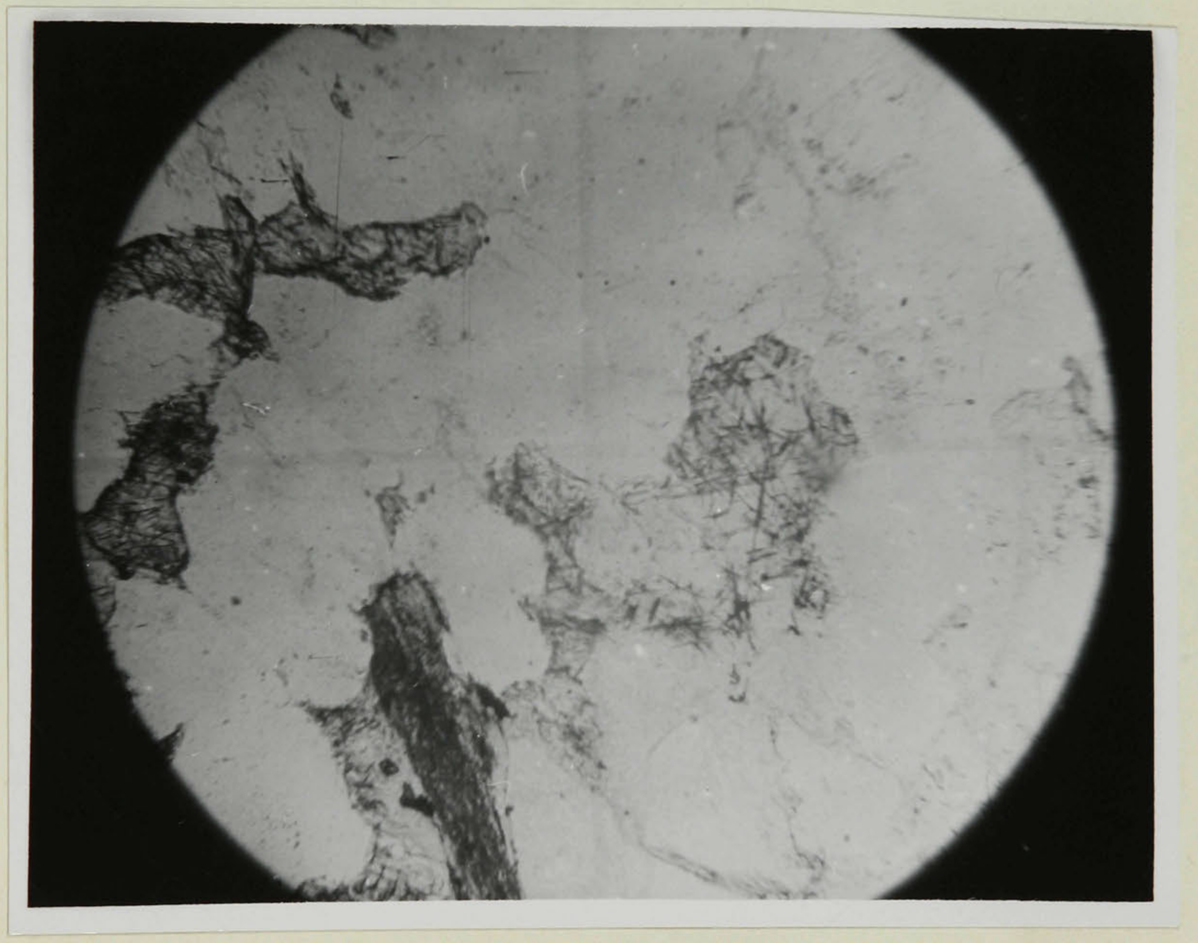
Magnification = x35

GRANITE. Showing strained extinction of quartz (in circle); also some alteration of the oligoclase around the edges of crystals.

Q = quartz, Ol = oligoclase

P H O T O G R A P H NO.3

SPECIMEN 21

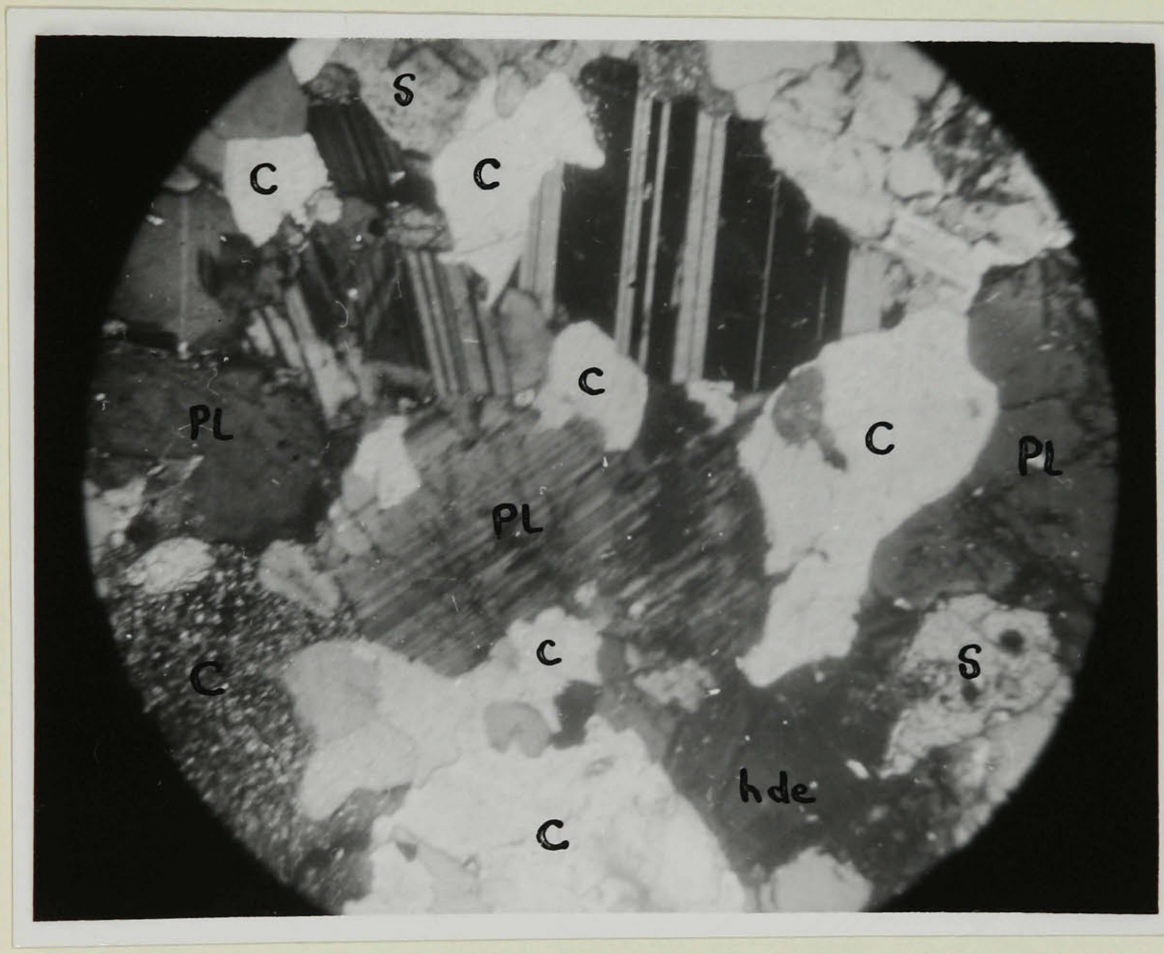


Magnification = x70

QUARTZITE. Showing chloritic material with oriented inclusions of rutile set in a matrix of quartz.

P H O T O G R A P H NO.4

SPECIMEN 8



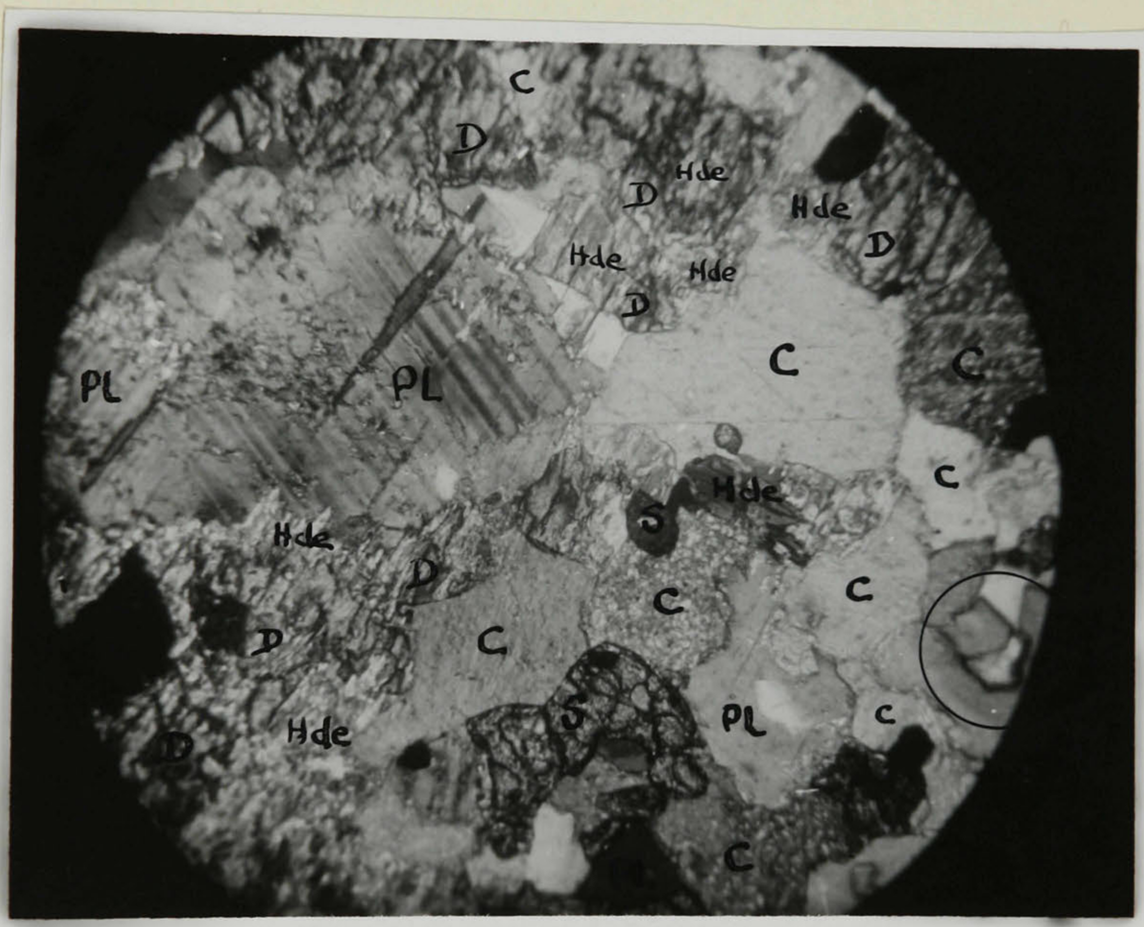
Magnification = x70

LIME-RICH ROCK. Showing the mosaic texture and large grains of primary calcite with plagioclase, sphene and hornblende.

C = calcite, Pl = plagioclase, S = sphene, hde = hornblende

P H O T O G R A P H NO.5

SLIDE 14b



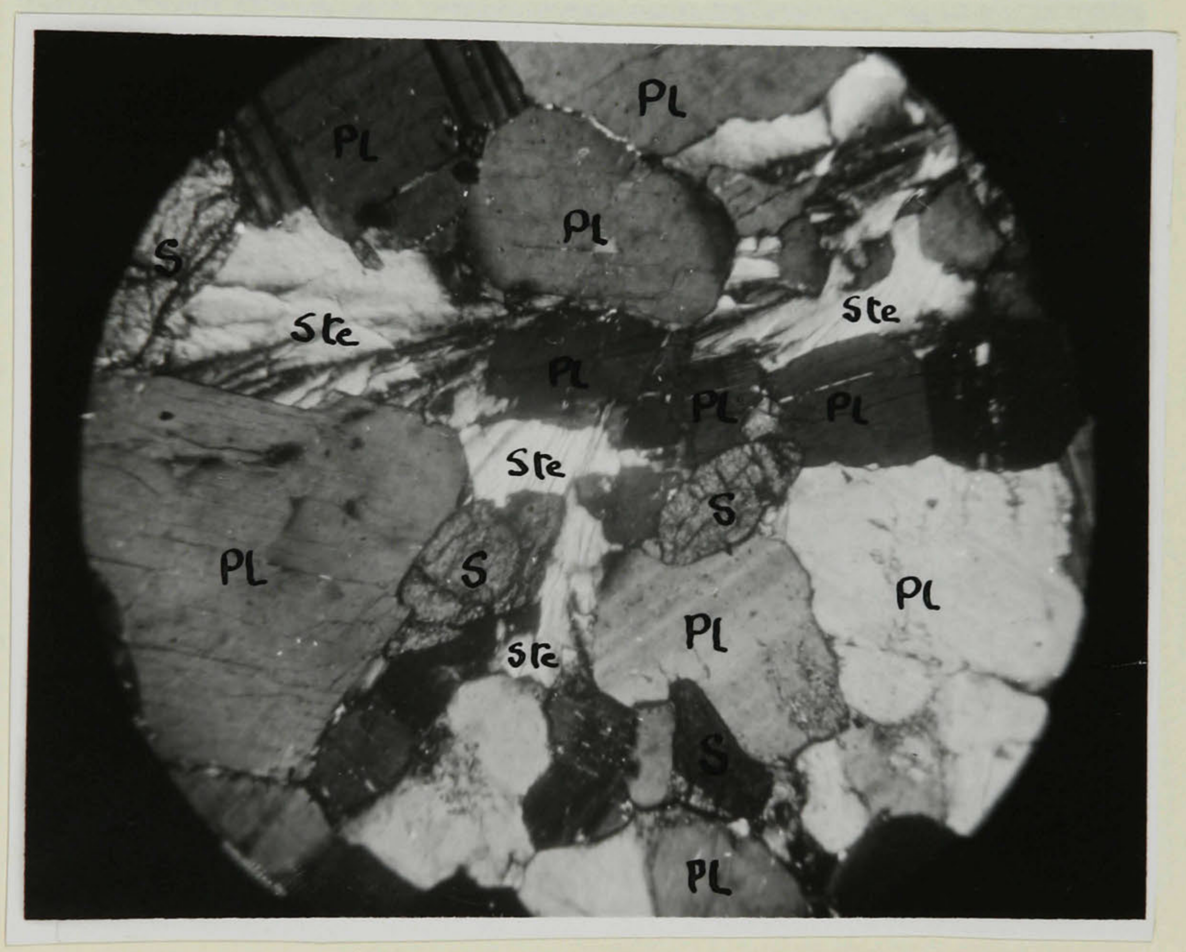
Magnification = x70

LIME-RICH ROCK. Showing the mosaic texture and the alteration of diopside to hornblende. The zoned plagioclase crystal within the circle has a core of composition An.95 and rim of An.75. This photograph also shows how the calcite forms an essential part of the rock fabric.

Pl = plagioclase, D = diopside, Hde = hornblende, S = sphene
C = clacite

PHOTOGRAPH NO.6

SPECIMEN 18



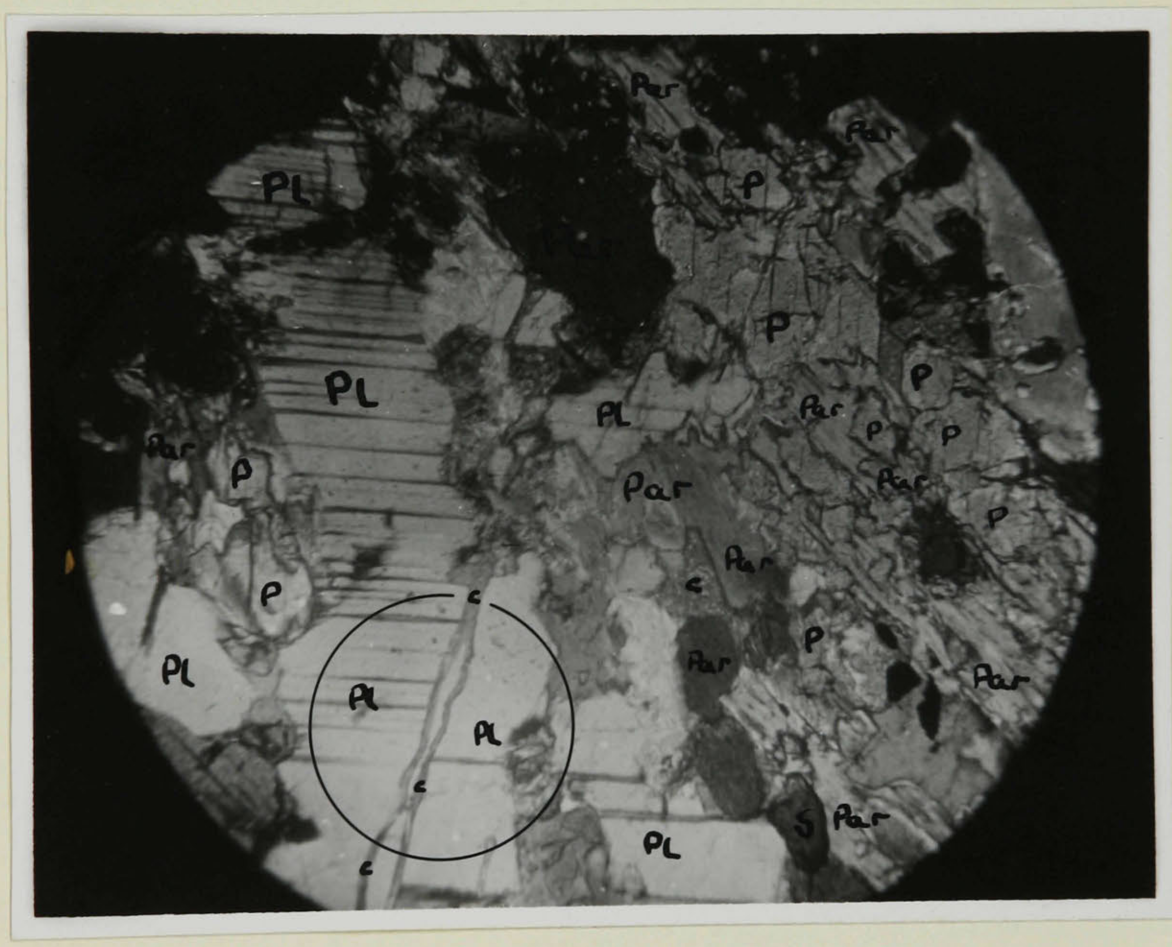
Magnification = x70

LIME-RICH ROCK. Showing seybertite filling the interstices.

Pl = plagioclase, S = sphene, Ste = seybertite

P H O T O G R A P H NO.7

SPECIMEN 23



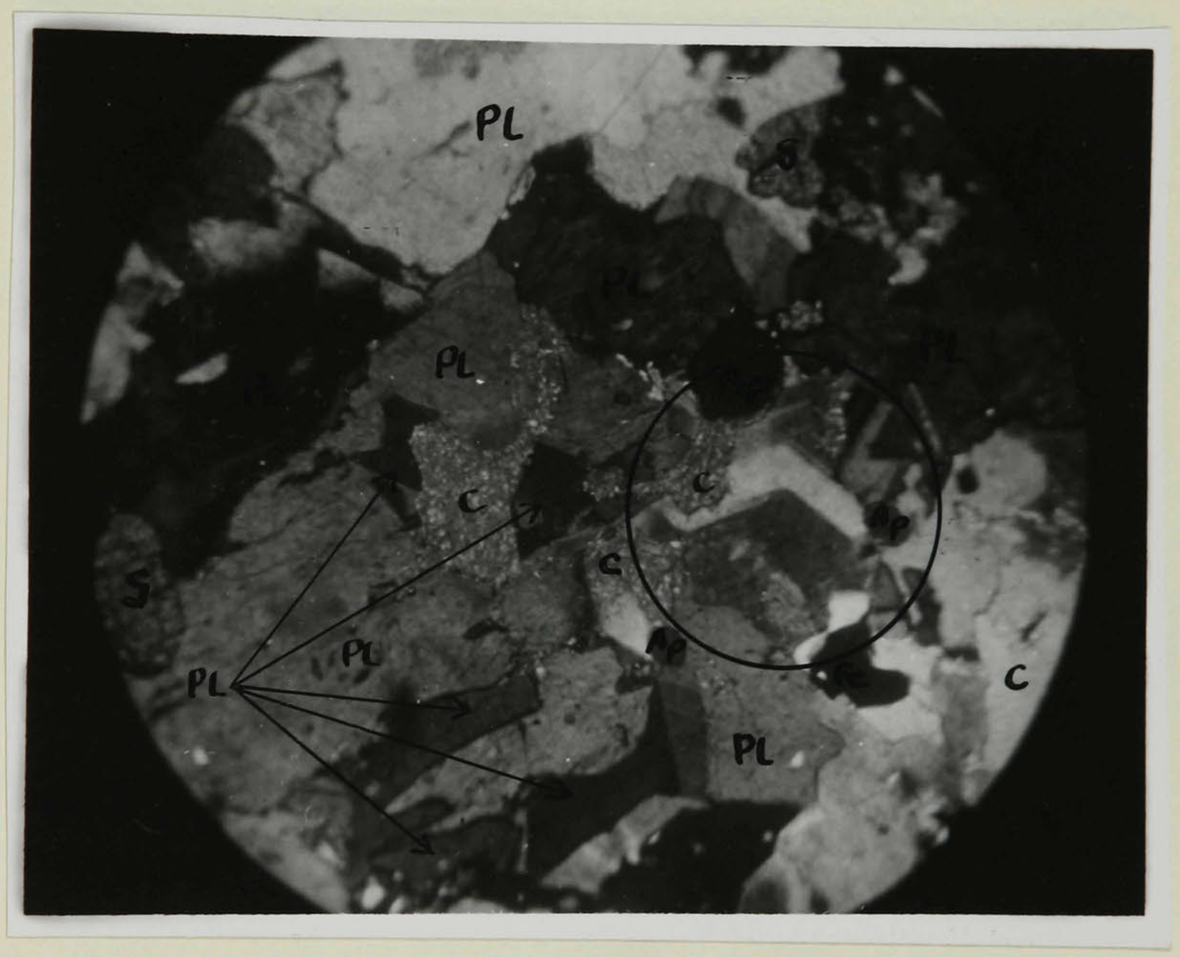
Magnification = x70

LIME-RICH ROCK. Showing the extensive alteration of pigeonite to pargasite and secondary twinning of the plagioclase terminated by a fracture (within circle).

P = pigeonite, Pl = plagioclase, Par = pargasite, S = sphene
C = calcite

PHOTOGRAPH NO.8

SPECIMEN 27



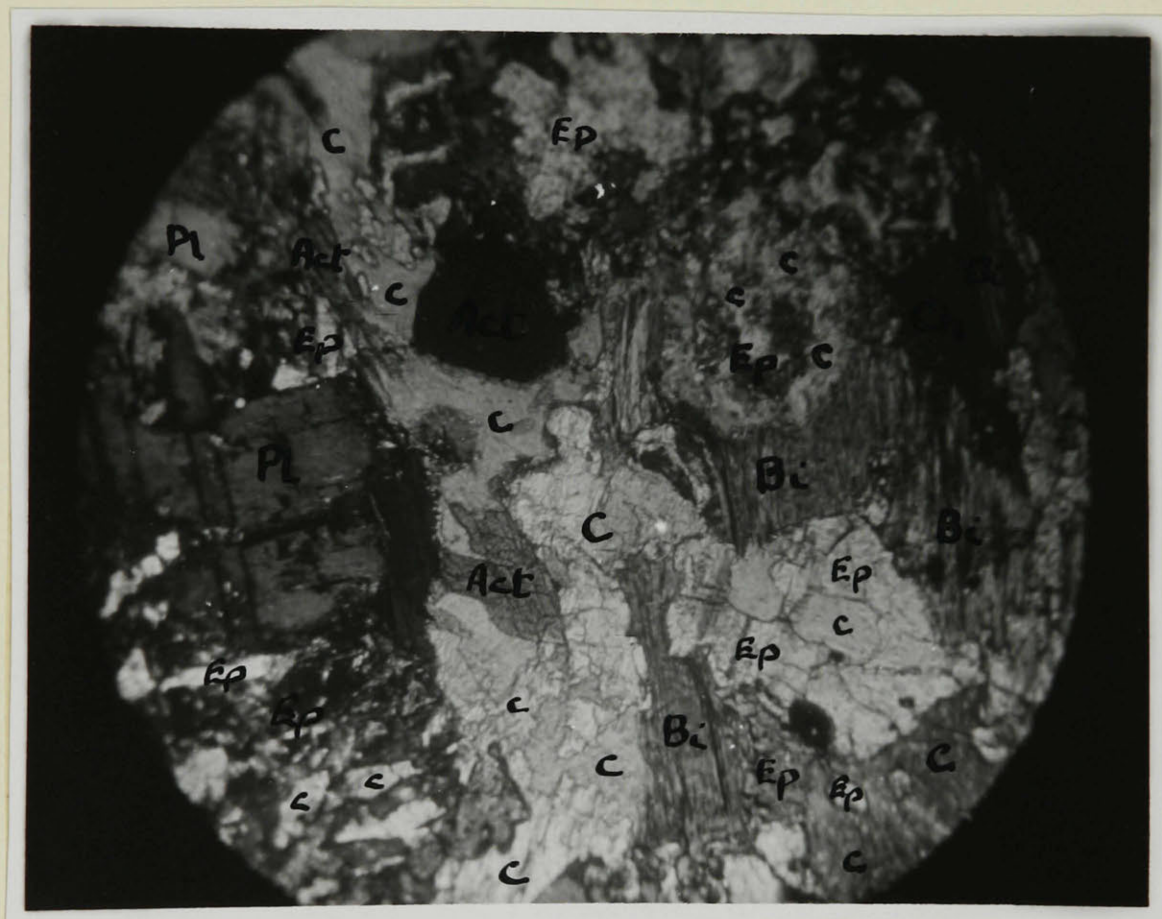
Magnification = x70

LIME-RICH ROCK. Showing the intimate and irregular intergrowth of the plagioclase, as well as some irregular zoning (in circle).

Pl = plagioclase, C = calcite, S = sphene, Ap = apatite, Fe = iron ore

P H O T O G R A P H NO.9

SPECIMEN 28



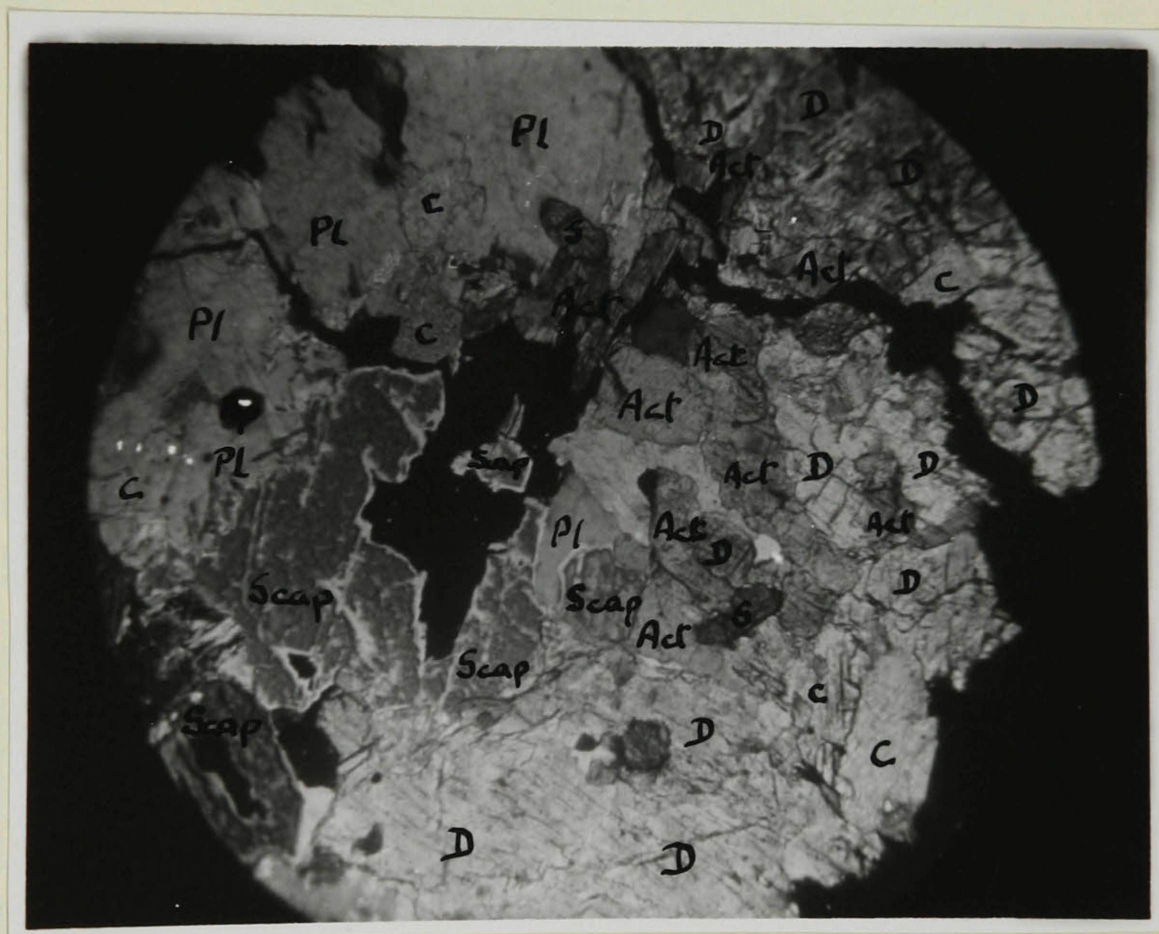
Magnification = x70

LIME-RICH ROCK. Showing extensive alteration of those rocks North of Found Lake; the plagioclase is much altered to epidote and clinozoisite, and the biotite to chlorite.

Pl = plagioclase, Act = actinolite, Bi = biotite,
C = calcite, Ch = chlorite, Ep = epidote and clinozoisite

PHOTOGRAPH NO.10

SPECIMEN 31



Magnification = x70

LIME-RICH ROCK. Showing extensive alteration of plagioclase to scapolite, and of diopside to actinolite.

Pl = plagioclase, D = diopside, Act.= actinolite,
Scap = scapolite, C = calcite, Ap = apatite, S = sphene

APPENDIX B

GENERALISED PROPERTIES OF PYROXENES AND AMPHIBOLES IN THE LIME-RICH ROCKS

	Birefringence	$Z \hat{} C$	β (approx.)	2 V	Optical Sign	Colour
Diopside	.027	38°	1.67	60°	+	Colourless
Secondary Hornblende	.021	20-24°	1.65	80°	−	Colourless
Primary Hornblende	.017	17°	1.61	80°	−	X = Yellow Y = Yellow-green Z = Brown-green
Actinolite	.018	14-18°	-	Large	−	X = Yellow Y = Green-brown Z = Bluish-green
Pigeonite	.023	31-33°	1.68	44°	+	Colourless
Pargasite	.020	16°	1.65	Large	+	Colourless

BIBLIOGRAPHY

1. Bateman, J. D. Sherridon Map Area, Manitoba. Geol. Sur. Can. Paper, 45-15, 1945

2. Wright, J. F. Kississing Lake Area, Manitoba. Geol. Sur. Can. Sum. Rpt. 1928 pt.B

3. Bruce, E. L. Amisk-Athapapuskow Lake District. Geol. Sur. Can. Mem. 105, 1918

4. Cooke, H. C. Land and Sea on the Canadian Shield in Precambrian Time. Am. J. Sci. Vol.26, 1933

5. Carlson, G. C. The felspar method for the determination of the origin of metamorphic rocks. J. of Geol. Vol.28, 1920

6. Steidtman, E. The felspar as indicators of the sedimentary or igneous origin of gneisses and schists. Geol. Soc. Am. Vol.31, 1920

7. Adams, F. D. and Barlow, A. E. Geology of the Haliburton and Bancroft Area, Province of Ontario. Geol. Sur. Can. Mem. 6, 1910

8. Daly, R. A. Igneous rocks and their origin. 1914

9. Osann-Rosenbusch. Gesteinslehre. 1923

10. Washington, H. S. U.S.G.S. Prof. Paper 99, 1919

11. Harker, A. Metamorphism, Methuen and Co., Ltd., 1939

12. Eskola, P. Gneiss and Limestone Contact Phenomena in Western Massachussetts. J. of Geol. Vol.30, 1922

13. Bowen, N. L. The metamorphism of Limestone and dolomite J. of Geol. Vol. 1940

14. Osborne, G. D. Metamorphic Limestones and associated igneous rocks of the Carlingford District Co. Louth. Geol. Mag. Vol.69, 1932

LEGEND

ARCHÆAN AND/OR PROTEROZOIC.

- 13 GRANITE.

CREE LAKE INTRUSIVE ROCKS.

- 12 OLIGOCLASE GRANITE.
- 11 ANORTHOSITIC GABBRO.
- 10 GARNETIFEROUS METAGABBRO.
- 9 PYROXENITE.

KISSEYNEW GNEISSES.

POST - SHERRIDON.

- 8 STRATIFORM OLIGOCLASE-QUARTZ GNEISS.

SHERRIDON GROUP.

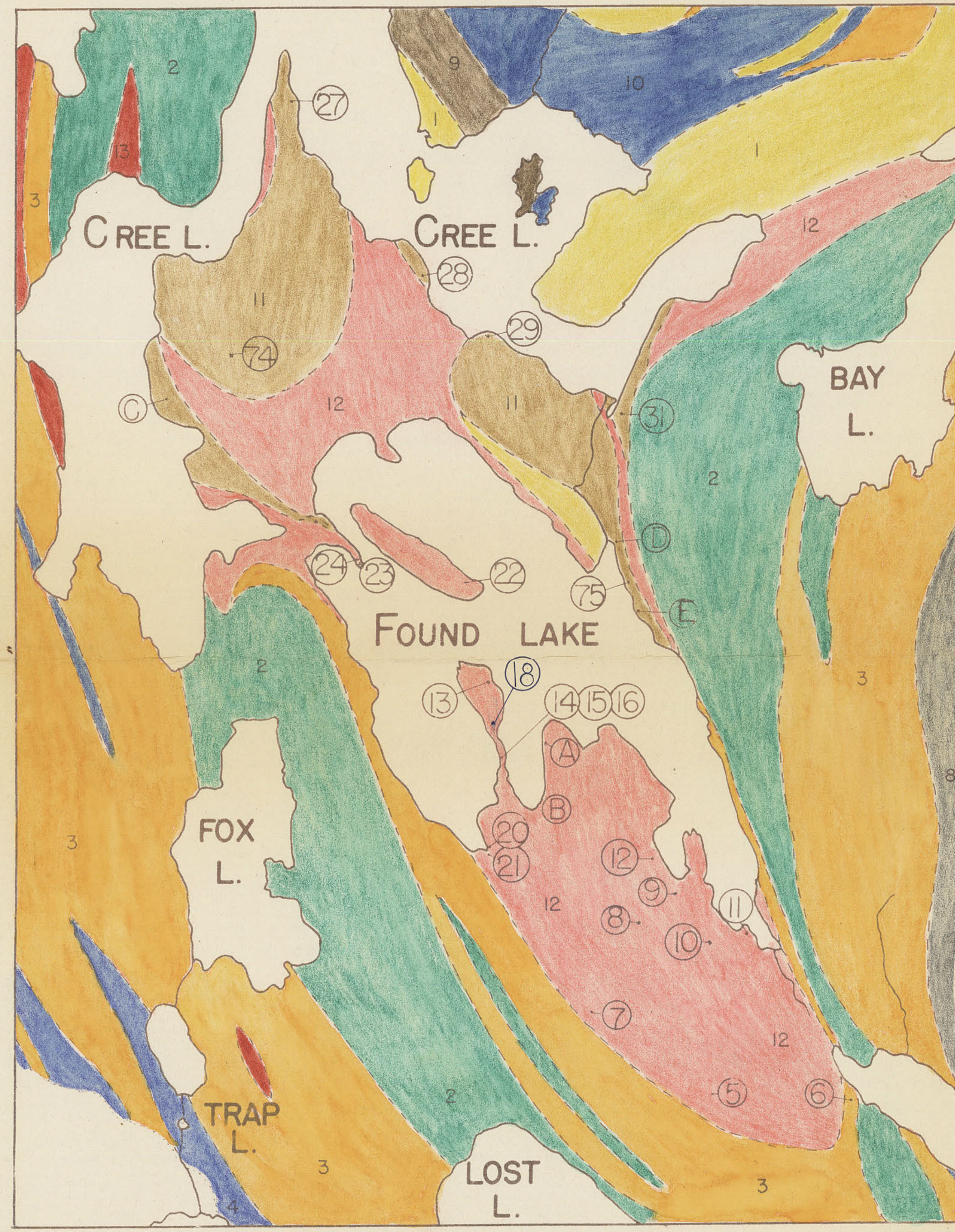
- 4 HORNBLENDE-PLAGIOCLASE-GARNET GNEISS.
- 3 GNEISSIC QUARTZITE.

PRE-SHERRIDON.

- 2 HORNBLENDE-PLAGIOCLASE GNEISS.
- 1 STRATIFORM GNEISS.

(6) LOCALITY FROM WHICH SPECIMEN WAS OBTAINED.

(A) LOCALITY TO WHICH FIELD NOTES REFER.



FOUND LAKE AREA.

FROM MAP 44-4.

MAP 2.

LEGEND

ARCHÆAN AND/OR PROTEROZOIC.

- GRANITE.

CREE LAKE INTRUSIVE ROCKS.

- OLIGOCLASE GRANITE.
- GARNETIFEROUS METAGABBRO.
- PYROXENITE.

KISSEYNEW GNEISSES

POST - SHERRIDON.

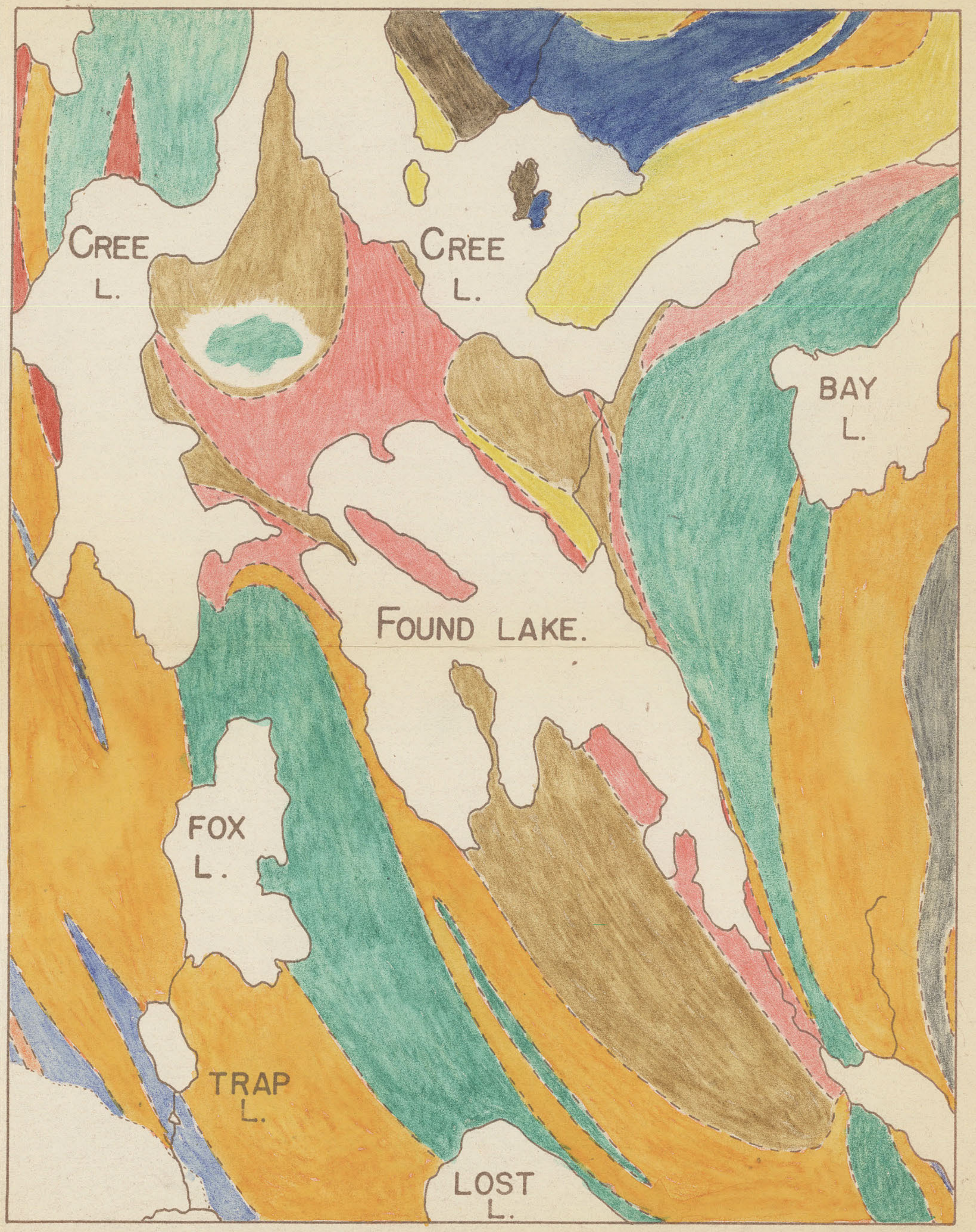
- STRATIFORM OLIGOCLASE - QUARTZ GNEISS.

SHERRIDON GROUP.

- HORNBLENDE PLAGIOCLASE GNEISS.
- GNEISSIC QUARTZITE.

PRE - SHERRIDON.

- HORNBLENDE-PLAGIOCLASE GNEISS.
- DIOPSIDE PLAGLIOCLASE - CALCITE GNEISS
- STRATIFORM GNEISS.



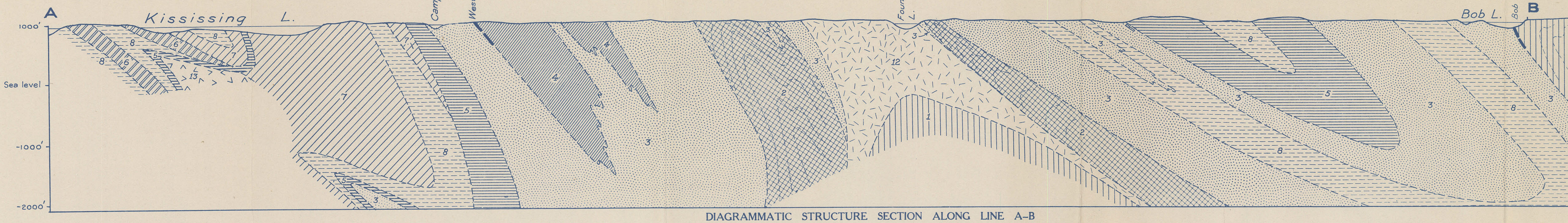
FOUND LAKE AREA.

CANADA

DEPARTMENT OF MINES AND RESOURCES

MINES AND GEOLOGY BRANCH

BUREAU OF GEOLOGY AND TOPOGRAPHY



DIAGRAMMATIC STRUCTURE SECTION ALONG LINE A–B

GEOLOGICAL SURVEY

LEGEND

ARCHAEAN AND/OR PROTEROZOIC

KISSEYNEW GNEISSES

13 Granite, granite-gneiss; pegmatite

CREE LAKE INTRUSIVE ROCKS
(Post-Sherridon, relation to post-Sherridon Kisseynew gneisses uncertain)

12 Oligoclase granite

11 Anorthosite, anorthositic gabbro

10 Garnetiferous metagabbro

9 Pyroxenite

POST-SHERRIDON

8 Stratiform, granitoid oligoclase-quartz gneiss

7 Stratiform "granitized" gneiss including lit-par-lit and other injection gneisses

6 Stratified quartz-feldspar-biotite-garnet gneiss; minor hornblende gneiss

5 Hornblende-plagioclase gneiss, in part garnetiferous, pseudodiorite

SHERRIDON GROUP

4 Hornblende-plagioclase-garnet gneiss, in part pseudodiorite

3 Gneissic quartzite, feldspathic quartzite, biotite, hornblende, and garnet-bearing quartzites; granitized equivalents, minor hornblende gneiss; small bodies of granite, granite-gneiss, and pegmatite

PRE-SHERRIDON

2 Hornblende-plagioclase gneiss, pyroclastic breccia; part may be intrusive

1 Stratiform quartz-oligoclase-biotite-garnet gneiss

Copper-zinc orebody (exposed, top projected vertically to surface)

Pyrrhotite deposit (exposed, top projected vertically to surface)

Bedding (horizontal, inclined, dip unknown)

Schistosity, gneissosity, foliation (inclined, dip unknown)

Direction of plunge (indicated by arrow)

Anticlinal axis

Synclinal axis

Geology by J.D. Bateman, 1943

Road

Trail

Marsh

DESCRIPTIVE NOTES

Most of the rocks in the area are crystalline schists and gneisses that represent metamorphosed sedimentary and volcanic formations. The oldest rocks (Pre-Sherridon) consist of stratiform quartz-oligoclase-biotite gneiss (1) which weathers buff and contains many garnetiferous beds. This gneiss is a metamorphosed sedimentary formation and is overlain by dark green hornblende-plagioclase gneiss (2) that is locally garnetiferous. The dark gneiss is, in places, thinly foliated and, elsewhere, is massive and without visible structures. Part of it contains light-coloured lenticular fragments and was probably a volcanic breccia.

The Sherridon group (3, 4) lies in places upon the pre-Sherridon basic gneiss (2) but elsewhere upon the older sedimentary gneiss (1). This may be due to the thinning out of the former volcanic member along the strike, or it may represent an unconformity at the base of the Sherridon. The latter alternative is indicated by structural evidence. The Sherridon consists of a group of distinctive white to grey quartzites interbedded with dark green to black hornblende-plagioclase gneisses that are metamorphosed volcanic flows. The different quartzite beds contain various minor amounts of feldspar, biotite, hornblende, and garnet. They have a distinct gneissic texture that is emphasized by the quartz, which stands out in relief on weathered surfaces. The hornblende gneisses are most abundant northeast of the Sherritt Gordon west orebody. Remnants of pillow structures were observed in them, but the rock is generally so thoroughly recrystallized that it resembles diorite.

The Sherridon group is overlain by dark green hornblende-rich gneiss (5) that is in sharp contact with the distinctive Sherridon quartzites. The hornblende gneiss is succeeded by widespread metamorphic types representative of the prevailing Kisseynew gneisses throughout the district. They vary from recognizable stratified rocks (6) to others of similar origin that have been so injected by granite and pegmatite that the bulk of the rock is intrusive and, for purposes of mapping, are classed as "granitized" gneisses (7). In addition there are granitoid gneisses (8) that resemble granite or granodiorite in the hand specimen but that have a stratiform structure similar to that of the bedded gneisses. These differ from the true granites in that they contain more quartz and little or no potash feldspars (microcline and microperthite). They probably represent sedimentary gneisses in an advanced state of granitization.

In the vicinity of Cree Lake the older formations, including the Sherridon group, are cut by a related sequence of basic to granitic intrusive rocks. These include black to rusty weathering pyroxenite (9), and black to dark green massive peridotite and hornblende metagabbro (10), the latter carrying abundant garnet. Between Cree and Found Lakes are several bodies of anorthosite and anorthositic gabbro (11) that consist principally of plagioclase feldspar with more or less pyroxene, hornblende, carbonate, titanite, and scapolite. The youngest member of this sequence is a buff coloured oligoclase granite (12) that is locally sheared and rusty weathering. The Cree Lake intrusive rocks are considerably altered and the pyroxenite and anorthosite have a decayed appearance. They are considerably carbonatized and some calcite is developed locally. It is probable that these rocks were involved in at least some of the folding.

The younger granite and granite-gneiss (13) was intruded after the main folding had occurred and is mostly in the form of small sills. It is characteristically pink and commonly has some faint stratiform structures that correspond in attitude to the bedding in the sedimentary gneisses.

The broad structural picture at Sherritt Gordon resembles a large drag fold. Actually it is not a drag fold, but the result of complex cross-axial folding on a series of simple folds. Evidence of a still earlier folding is represented by a folded anticline in the pre-Sherridon hornblende-gneiss encircling Found Lake. This structure accounts for the presence of some Sherridon quartzites on the Found Lake side of the hornblende-gneiss (See structure section). Similar types of folds occur within the Sherridon group. The principal folding, however, is along the north-south axes, the folds being overturned to the west so that both limbs dip eastward. The present structural picture is the result of a cross-axial anticline on the southeast limb of which the prevailing northward plunge of the principal fold axes is reversed. This anticline commences as a gentle fold near Cold Lake and extends eastward between the Sherritt Gordon east and west orebodies, swinging northeastward across Found Lake and northward across Cree Lake. North of Found Lake the anticline steepens until, northeast of Cree Lake, it becomes the principal fold, superceding the main syncline on the east, which dies out to the north. As a result of the cross-axial folding this syncline plunges southward, except at the south part of the map-area where the prevailing northward plunge is resumed. Similarly the cross-axial fold has resulted in a southward plunge of the anticlinal axis that extends through Found Lake southward through Sherlett Lake; but to the northwest of Found Lake, on the north limb of the cross-axial fold, the plunge is northward.

The combined effect of these folds has resulted in an anticlinal dome or structural "high" at Sherritt Gordon, in which the older formations of the Kisseynew gneisses have been exposed. The Sherridon group may represent the lowest Kisseynew rocks, separated by a structural unconformity from pre-Sherridon formations. The Sherritt Gordon orebodies occur, therefore, in a structurally complex area of Kisseynew gneisses. These gneisses extend over a large part of northern Manitoba and Saskatchewan and, generally, do not provide favourable host rocks or structures for economic mineral deposits. However, there is every possibility that structures similar to those at Sherritt Gordon may be found elsewhere in this region wherever sharp anticlines have brought the older Kisseynew formations to the present erosion surface. Such structures may be recognized by the presence of more abundant honblende gneisses (dark rocks) that occur in the lower part of the Kisseynew group.

The Sherritt Gordon east and west orebodies are one of the most remarkable mineral deposits in the world, having a combined total length of almost 16,000 feet, of which 3,600 feet between the two orebodies carries no ore. As the cross-axial anticline passes through this barren interval it is probable that the two orebodies formed a single one before being reduced to the present erosion surface, The main orebodies have an average width of about 15 feet. The east orebody is approximately 250 feet deep, whereas the west orebody is 500 to 800 feet deep and rakes northward to a maximum depth below surface of about 1500 feet. As the orebody tends to flatten out down the northward rake (the flattening of the dip resulting from an internal fold in the Sherridon formations), the vertical projection of the top of the ore to the surface is shown on the map as angling across the formations, although it actually follows a stratigraphic horizon. A relatively pure quartzite member of the Sherridon group forms the footwall (overturned hangingwall) of the ore, whereas hornblende-gneiss is generally on or near the hangingwall.

In the west orebody, particularly, there were subsidiary orebodies that contained up to one-half million tons of ore, and that occurred as bulges or offsets into the hangingwall. These offset orebodies are almost entirely in pegmatite. Small amounts of pegmatite are also found at several places in the main orebodies, and the Bob Lake deposit is almost completely enclosed in such rock. The ore is later than the pegmatite and has evidently been introduced along channelways in which the pegmatite was intruded. The ore consists chiefly of pyrrhotite containing quartz nodules and more or less chalcopyrite and sphalerite, the east orebody being higher in zinc. Pegmatite is less conspicuously associated with several pyrrhotite deposits that contain little or no copper-zinc minerals. The pyrrhotite deposits are commonly in shear zones containing graphite.

All the sulphide deposits, including the orebodies at Sherritt Gordon, occur in the Sherridon quartzites, either near contacts with the underlying or overlying formations or adjacent to hornblende-gneiss within the Sherridon. As these contacts represent lines of structural weakness the sulphide deposits are generally beneath drift-filled depressions or lakes, and thus not exposed to view.

PRELIMINARY MAP 44-4

SHERRITT GORDON MINE AREA

WEST OF PRINCIPAL MERIDIAN

MANITOBA

Scale:- 1 inch to 1000 feet

1000 0 1000 2000 3000 4000 5000