A STUDY OF CERTAIN ROCKS OF THE CALIFORNIA
LAKE MAP AREA, NORTHERN MANITOBA

A THESIS

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A STUDY OF CERTAIN ROCKS OF THE CALIFORNIA LAKE MAP AREA, NORTHERN MANITOBA

Abstract

The geology of the Precambrian rocks of the California Lake Area was mapped in 1953. The area is mainly of granitic Rocks which surround a northern and a southern volcanic-sedimentary belt. The metamorphism of the northern belt (Bigstone Lake group) has been studied and it is found that regional metamorphism of the grade of the garnet zone is general throughout. The Merritt formation which in the main part was probably a greywacke, is the most highly metamorphosed, reaching the grade of the sillimanite zone in part. The volcanic rocks (Greenstone formation) are in the amphibolite facies. The argillite and impure quartz-feldspar sandstone on Utik Lake (Utik Lake formation) has reached the grade of the garnet zone. Cordierite is present in part of the Merritt and Utik Lake formations. The area is characterized by deficient shearing stress during the regional metamorphism.

CHAPTER 1

INTRODUCTION

Forward

The material for this thesis was gathered during the summer of 1953. The writer was co-chief with M. D. Moorhouse of a geological field party engaged in mapping the California Lake Area in Northern Manitoba for the Manitoba Mines Branch. The results of this survey will be published as the Manitoba Mines Branch Report 53-3 (1954) with the title "Geology of the California Lake Area, Northern Manitoba."

This thesis is a study of the northern volcanic-sedimentary belt. M. D. Moorhouse's thesis is a study of the southern volcanic-sedimentary belt and the granitic rocks.

Location and Access

The California Lake Area lies across the east-west boundary between the Cross Lake and Oxford Lake Mining Divisions. The map-area comprises approximately 230 square miles, and lies between 55° 00' and 55° 20' north latitude and between 95° 30' and 95° 45' west longitude.

The most convenient mode of entry into the area is by air from Norway House (approximately 120 miles), or Ilford on the Hudson's Bay Railway (approximately 60 miles).

The best canoe route originates at Oxford House. From Semple (Sucker) Bay on Oxford Lake, the route follows the Semple River with three short portages to Semple Lake, in the extreme southern portion of the area. Continuing into the central portion, from the north shore of Semple Lake the route follows a stream with two short portages to Powstick Lake, a one mile portage leads to California Lake, and from the north shore of California Lake a three-quarter mile portage terminates at the south shore of Bear Lake, Access to the northern part of the area is gained by following the Bigstone River from its point of origin on the north shore of Bear Lake over one short portage to Bigstone Lake. Utik Lake, in the extreme northwest corner of the map-area, may be reached by a one-half mile portage from the north shore of Bigstone Lake.

General Character of the Area

The topography of the area is dominated by monotonous stretches of muskeg and swamp which are separated by broad gently sloping belts of glacial clays whose long axes lie in a northeasterly direction.

Throughout the area to the east of Bear Lake, and from there south to Semple Lake, there are many glacial ridges of greater height composed of sand and boulders. These ridges are thickly covered with second-growth jack pine and in some places spruce. They differ from the lower ground which, where previously burned, is sparsely dotted with spruce. In general, good rock exposures are not associated with this sort of topography. Over most of the area outcrops are concentrated on the shores of the larger lakes. The area of most extensive outcrops and also of greatest relief (up to 100 feet), lies between the Bigstone River and the eastern portion of Bear Lake.

In the past, fires have destroyed much of the timber in the area. Many of the burned trees still stand in a tangle of second-growth spruce and jack pine. The most recent burn is located on the south shore of Bear Lake at the mouth of the creek flowing from Dobbs Lake. The average diameter of the living trees is from four to six inches and only rarely were any found having a diameter over ten inches. Timber for mining operations or extensive construction can not be found in quantity in the area.

Previous Geological Work

Prior to 1951, little work had been done in the area. Wright (1925) examined the Oxford and Knee Lakes area, and in the same year, Merritt made a track survey of the Bigstone and Fox rivers. The latter survey crossed the present map-area from south to north.

Present Geological Work

Field mapping was conducted in the California Lake area during the summer of 1953. Traverses were run, where feasible, at intervals of 1500 to 2000 feet. Outcrops were located by pace and compass and on vertical aerial photographs. A base map on a scale of two inches to one mile was compiled by the Manitoba Surveys Branch from vertical aerial photographs, using slotted template and sketchmaster.

This work is part of a mapping project which covers a volcanic-sedimentary belt extending from near the Nelson River to the present map-area.

General Geology of the California Lake Area

All consolidated rocks in the area are of Precambrian age. The oldest rocks consist of two belts of metamorphosed sediments and volcanics. The northern belt is called the Bigstone Lake group and the southern belt is called the Semple Lake series. The Bigstone Lake group is more highly metamorphosed than the Semple Lake series. Andesites and basalts are the dominant rocks of these belts. Some sedimentary and minor acid volcanic rocks are associated with the intermediate and basic lavas. Granitic rocks, which extend over the major part of the area, include alaskite, a northern granodiorite, pink massive quartz monzonite, porphyritic granodiorite, and grey to buff quartz monzonites, granodiorites, and quartz diorites. The age relationships of these granitic rocks are not clearly established.

A persistent diabase dyke, the youngest rock type in the region, extends for several miles in a northeasterly direction across the northern part of the area.

Faulting is common throughout the area. One major fault extending across the southwest part of the map-area is believed to be an extension of the Bear Lake fault mapped by Milligan (1954) to the west. Most of the faulting is on a small scale. Some of these faults are recent enough to have displaced the diabase dykes.

Table of Formations

The rock types of the map-area and their postulated relative ages are summarized in the following table of formations.

TABLE OF FORMATIONS

Recent and Pleistocene	Swamp and muskeg Glacial deposits: clay, sand, gravel, and boulders
PRECAMBRIAN	Basic dykes
	Alaskite Northern granodiorite and quartz monzonite and gneissic marginal phase Porphyritic granodiorite Pink massive quartz monzonite Grey and buff quartz monzonite, granodiorite, and quartz diorite
	Intrusive contact
	Bigstone Lake group and Semple Lake Series Greywacke, impure quartzite, and conglomerate. Derived schists and gneisses Plagioclase amphibolite derived from andesites and basalts; acidic volcanics and tuffs. Derived schists

Geology of the Bigstone Lake Group

The Bigstone Lake group is made up of three distinct formations, two of them being sedimentary and the third volcanic. Structural criteria show that the top of these formations is to the south and therefore the oldest formation is the most northerly one. The oldest formation is a small area of sediment which will be called the Utik Lake formation for the purpose of description. A belt of lavas called the Greenstone formation overlies the Utik Lake formation. The lavas are approximately one mile thick. The youngest formation is a band of sediments outcropping on Bigstone Lake south of the Greenstone. This band of sediments will be called the Merritt formation. The Calcareous member forms one small part of the Merritt formation.

CHAPTER 11

SEDIMENTARY ROCKS

Introduction

The sedimentary rocks have been studied with the object of determining their metamorphic history and original composition. Samples were collected wherever possible and thin sections were made so that any variation along or across strike could be detected.

The Merritt formation constitutes the main bulk of the sedimentary rocks so is discussed first. The Calcareous member is excluded from the discussion of the Merritt formation and is described next. The Utik Lake formation is described last.

A. MERRITT FORMATION

The Merritt formation is highly metamorphosed so that original textures and much of the original mineral content is changed. The best exposures are on the shoreline of the islands and south shore of Bigstone Lake at its western end.

Character

In all areas the Merritt formation has been intruded by large amounts of grey granodiorite. Some outcrops consist mainly of granodiorite containing large contorted xenoliths of the sediment. Fine and coarse lit-par-lit injections are present. The intrusions greatly increase the width of the sedimentary band.

The unweathered sedimentary outcrops are dark colored, and where fine grained resemble the fine part of the Greenstone formation. However most outcrops are weathered to a rusty brown so that the sedimentary character is apparent even though the grains are 1 mm. or less in diameter.

Composition

Quartz, plagioclase, and biotite are the predominant minerals together making up 95 to 99 per cent of the volume. The sediments do not contain potash feldspar as shown by the staining and miscroscopic examination of four of the thin sections. The metamorphic minerals, cordierite, sillimanite, and garnet, are present in certain areas in amounts less than 5 per cent. Hornblende makes up 13 per cent of one sample. The accessory minerals, not present in every sample, are magnetite, apatite, zircon, sphene, and rutile.

Rosiwal analysis of several thin sections were made to obtain the amounts of quartz, plagioclase, and biotite. In the garnetiferous bearing area these minerals are present in close to equal amounts, a typical analysis showing 30 per cent quartz, 35 per cent plagioclase, and 30 per cent biotite. The more highly metamorphosed rocks containing cordierite and sillimanite have quartz and plagioclase present in roughly equal amounts though the biotite is lower. A typical analysis has 45 per cent quartz, 35 per cent plagioclase, and 15 per cent biotite. The rosiwal analyses of the sample containing hornblende shows it to be quite different from the rest. It contains 14 per cent quartz, 58 per cent plagioclase, 14 per cent biotite, and 13 per cent hornblende.

The minerals have a similar appearance in each thin section. The quartz grains are clear and rounded. A few grains occur that are up to 3 mm. in diameter but most of them are .5 mm. or less. The plagioclase grains are rarely twinned and as they are only slightly sericitized they closely resemble the quartz grains unless stained in the laboratory. Biotite is a very strongly pleochroic brown variety. Cordierite forms irregular grains 1.5 mm. or less in diameter and contains small quartz inclusions. Sparcely distributed sillimanite forms tiny patches of needles in the cordierite, quartz, and biotite.

Metamorphism

The metamorphism is a regional type ranging from medium to high grade. The stress factor has been much reduced in part by the lubricating action of the abundant magma injections. The metamorphism is shown by:-

(1) Structure. This sediment has been intruded by large amounts of granodiorite in the form of pods or dykes usually parallel to the regional schistosity. Fine lit-par-lit injections are also present (Fig. 1). The foliation, or possibly relic bedding, is highly con-

torted. Harker (1939, p.303), concerning lit-par-lit injections, says,

> "Injection of so intimate a kind demands suitbale conditions, including high pressure as well as high temperature. It may be found locally as part of an aureole of purely thermal metamorphism bordering a granite batholith but such effects are possible upon an extensive scale only when the country rocks invaded had already been raised to a high temperature prior to the intrusion. It is then an incident of regional metamorphism; and, as already remarked, the igneous intrusion, while closely related to the metamorphism, is not to be regarded as its sole and sufficient cause."

(2) Texture. The common texture is a granoblastic aggregate of quartz, plagioclase and biotite (Fig.2) with the biotite flakes neither especially elongated nor aligned. Where the metamorphism has been less intense the biotite flakes are aligned in one plane (Fig. 3). The granoblastic texture is formed in high grade regionally metamorphosed rocks.

(3) Metamorphic Minerals. (a) The western portion of this sediment contains numerous, very small garnets (Fig. 4). Garnets can occur in sedimentary rocks under conditions of thermal metamorphism but such a sediment must contain manganese or abundant lime. The minerals associated with garnet in the Merritt formation show that lime is not abundant. A qualitative test for manganese in the garnets showed this element was not present and therefore the garnets are not due to thermal metamorphism. Manganese garnets can form before biotite in regional metamorphism but when the biotite develops the garnet loses its manganese and becomes almandine. The garnet in the Bigstone Lake must therefore be the normal garnet formed during regional metamorphism. This is almandine, which has a strong preponderance of iron in the

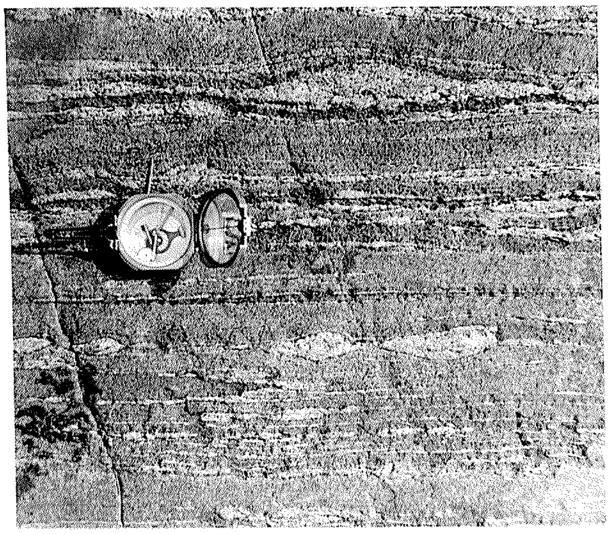

Fig. 1

Lit-par-lit gneiss

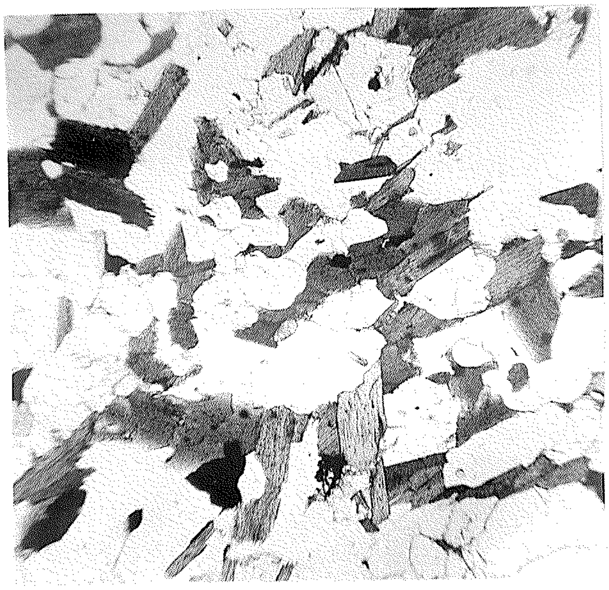

Fig. 2 Granoblastic texture X 25

Quartz, plagioclase, biotite,

magnetite, and apatite.

S-39

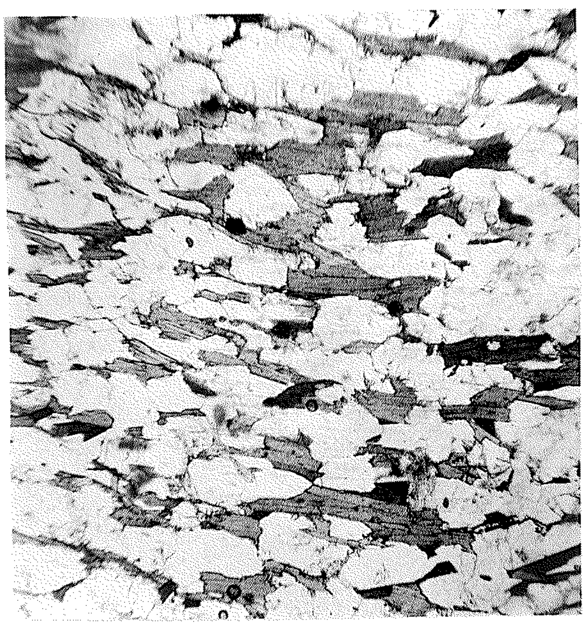

Fig. 3 Aligned biotite X 25

Biotite, quartz, and plagioclase

S-53

Fig. 4 Garnets X 25

Garnets, quartz, plagioclase,

and biotite.

S-40

dioxides and is definitely a stress mineral as well as a high pressure mineral. Its presence here shows the sediment has reached or passed the grade of the garnet zone of regional metamorphism.

(b) Sillimanite occurs in the same sedimentary band to the east of the garnetiferous bearing sediments (Figs. 5 and 6). Its presence indicates that a high grade of metamorphism has been reached there. Its scarcity, even where it does occur, is probably a reflection of the composition of the rock (high silica-low argillaceous content).

(c) Cordierite occurs along with the sillimanite (Fig. 7). Cordierite is not a good indicator of the metamorphic grade but its presence is an important indicator of the physical conditions during the metamorphism. Cordierite is a very characteristic mineral in thermal metamorphism and is definitely an anti-stress mineral. It can occur only if the influence of the stress factor is much reduced. At this locality the large amounts of granodioritic material intruding the sediment under pressure must have raised the rock to a temperature where it yielded readily to stress. Also, the granodiorite itself would alleviate the stress because it separates the sediment from a solid foundation.

(d) The potassium in the rock is apparently all in the biotite as indicated by the absence of potash feldspar. Orthoclase is a typical mineral of thermal metamorphism but its production is inhibited by stress conditions. The potash goes into biotite instead, which is abundant in these sediments.

Garnet does not occur with the sillimanite and cordierite. This may be due to the composition of the sediment but more probably

Figs. 5 and 6 Sillimanite X 80

Sillimanite and round quartz

inclusions in cordierite.

S-73

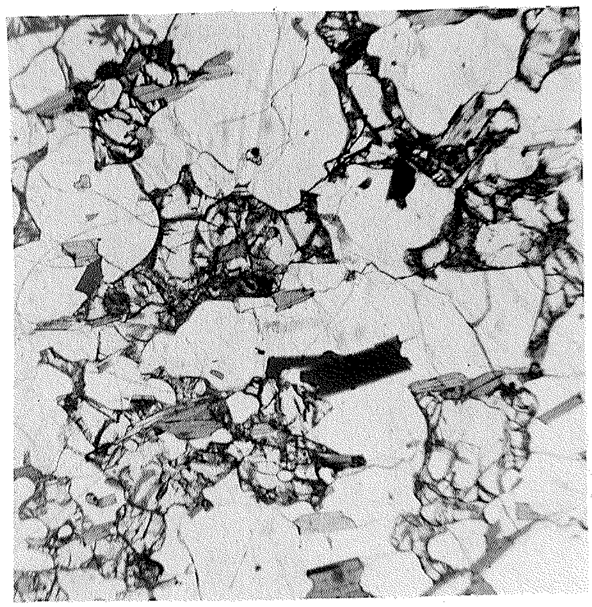

Fig. 7 Cordierite X 25

Cordierite, quartz, plagioclase, and biotite.

S-146

it is because the garnet would be the almandine variety which is a characteristic stress mineral. It would not form therefore under conditions which developed the cordierite.

Comparison with other Areas

(a) Several outcrops of an almost identical sediment occur about five miles to the east, along the shores of a narrow lake. Weathered surface, fresh surface, structure, and textures are identical. Mineral composition is similar except that sillimanite was not found. Metamorphism of the sillimanite zone has apparently not been reached although it must have been closely approached as shown by the presence of the other metamorphic minerals.

Grades of regional metamorphism have been known to range from lowest to highest over a distance of two or three miles. The two bodies of sediment in these areas reflect a very similar high grade over a distance of nine miles. The granodiorite intruding the sediment in an intimate fashion is the apparent cause of the consistent grade of metamorphism over the large area.

(b) Minor bands of greywacke occur in the Semple Lake series which lies about 15 miles to the south of the Bigstone Lake group. A sample taken from one of these bands does not resemble the samples taken from the Merritt formation due to a difference in grade of metamorphism. This Semple Lake greywacke is black on the fresh surface and weathers brownish to very dark grey. Thin sections show it to be composed of very fine scattered fragments of quartz and feldspar in a matrix containing abundant tiny flakes of biotite with some magnetite along with cryptocrystalline grains which are probably quartz and feldspar.

Regional metamorphism of the Semple Lake greywacke is less intense and has reached only the biotite zone. Fine bedding is evident in thin sections and many angular or only slightly recrystallized fragments of quartz and feldspar are well preserved (Fig. 8) which show the lack of strong metamorphic effects.

(c) J. M. Harrison (1949) made a careful study of the regional metamorphism of the sedimentary rocks of the File-Tramping Lakes area and was able to trace all grades of metamorphism in the argillaceous rocks. He noted;

> Progressive regional metamorphism is not so distinct in gneisses derived from greywacke and arkose. Biotite and garnet zones are readily desernible but minerals diagnostic of the higher grades are not so common.

He describes his metamorphosed greywackes as;

> Garnet gneisses------typically medium-grained rocks. They have a brownish grey, weathered surface speckled with small flakes of biotite or crystals of hornblende. In thin section these gneisses appear as recrystallized granular to gneissic aggregates consisting principally of quartz and fresh plagioclase (An 28-35) with subsidiary hornblende or biotite, or both, and lesser amounts of ragged, seive-textured to euhedral garnet. Accessory minerals include magnetite, apatite, zircon, epidote and pyrite. Fine needles of brownish sillimanite occur clusters in some localities. In rare places garnets are sparce or absent.

He describes more feldspathic types as being;

> ------recrystallized, rich in feldspar, and locally carrying much quartz. Biotite is the chief accessory mineral, and forms 20 per cent of the rock in some places. Amphibole is locally present in amounts up to 15 per cent. Pink to red anhedral garnets are common, but not abundant.

These descriptions closely match that of the Merritt formation.

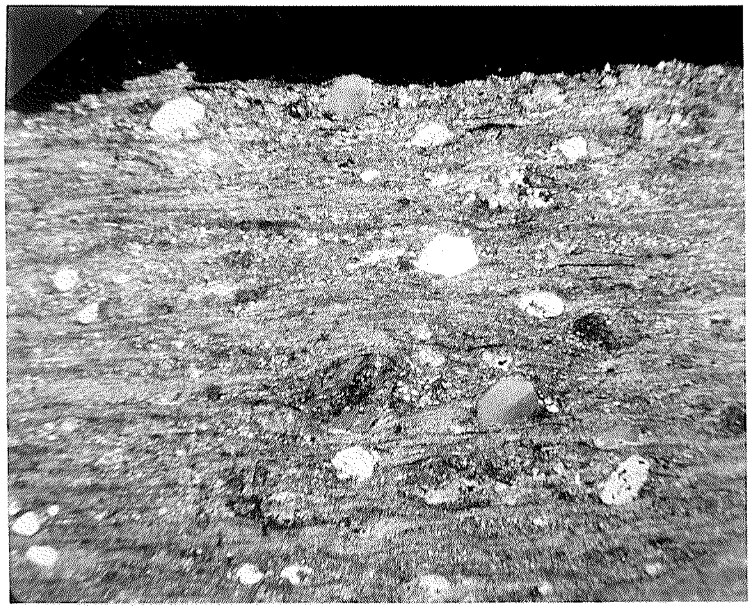

Fig. 8 Greywacke X 25

Greywacke in the grade of the biotite zone of regional metamorphism.

C-719

Harrison did not find staurolite or kyanite in the greywacke. These are also absent from the Merritt formation. He found that sillimanite did not form as quickly at the same grade of metamorphism in greywacke as in argillite. Apparently diffusion is not so rapid, because the materials necessary for the formation of sillimanite are more widely separated than in purely argillaceous rocks. Thus if the temperature is not held at the proper point long enough the minerals diagnostic of the highest grades will not occur. It is possible that the sediment of the Merritt formation carrying minerals characteristic of the garnet (almandine) zone has reached a higher grade and that the sediment to the east, which has no sillimanite, may have reached the conditions prevailing in the sillimanite zone of argillaceous rocks.

Composition of Original Sediment

The Merritt formation is recrystallized so completely that its original character is not easily determined. A detailed examination has been completed and from this an attempt has been made to establish the original composition. The following table is compiled from an examination of twelve thin sections and gives the important minerals, their amounts, and the number of samples in which they occur. The location of the samples is marked on the geological map in the back of this thesis.

Table 1

Minerals of the Merritt Formation

Mineral	Amount	Number of samples in which they occur out of a possible twelve.
Quartz	14 - 45 %	12
Plagioclase	32 - 58 %	12
Biotite	10 - 35 %	12
Garnet	0 - 4 %	4
Cordierite	0 - 5 %	3
Sillimanite	0 - 1 %	2
Hornblende	13 %	1

Quartzite does not have a composition which would metamorphose to contain the above minerals as it is too high in silica and low in argillaceous impurities. If the rock contains abundant feldspar the minerals simply recrystallize and potash feldspar always accompanies plagioclase.

Argillite contains very high alumina, magnesium, iron, and low lime. If an argillite is metamorphosed so that garnets, cordierite, and sillimanite can form, these minerals develop in large amounts. They would be present to a much greater extent than they are in the Merritt formation. The rock was therefore not an argillite.

Arkose and greywacke are somewhat similar. Both contain high alumina, lime, soda, and potash, but greywackes differ in that they contain high magnesia and iron. That is, the greywacke contains argillaceous material and the arkose does not. Pettijohn (1943) says,

> The composition of a greywacke can be approximated by averaging about two parts shale and one part arkose.

The sillimanite, cordierite, garnet, and abundant biotite show that most of the Merritt formation originally contained argillaceous material and is therefore not an arkose where these minerals occur. A minor part contains only quartz, plagioclase, and biotite, so it may be closer to an arkose than a greywacke.

A greywacke, whith its moderate content of argillaceous material would metamorphose to form the mineral assemblage described in the Merritt formation. F. J. Pettijohn (1943) says,

> Greywacke forms the great bulk of the Archean sedimentary record,

and he has a complete discussion of the composition and textures of this greywacke. As the Merritt formation has been completely recrystallized it is impossible to compare its texture with the texture of unmetamorphosed greywackes discussed by Pettijohn but it is possible to compare the composition. He describes greywackes as composed essentially of,

> -----quartz and feldspar set in a paste which in many instances equals or exceeds the volume of the larger detrital grains, consisting mainly of a microcrystalline aggregate of quartz, feldspar, chlorite and sericite. Present also are rock fragments, in some cases very abundant, mainly chert, slate, or phyllite.

He notes that in normal greywacke soda is greater than potash. As has been shown, rocks of this composition would metamorphose to equivalents of the Merritt formation.

Pettijohn gives chemical analysis of greywackes which show that they contain from 61.52 per cent to 69.69 per cent SiO_2. Three activation analyses of the Merritt formation gave the following results:

#1...67% ± 2% SiO_2

#2...65% ± 2% SiO_2

#3...59% ± 2% SiO_2

The color is the same, grey to black on fresh fracture.

Pettijohn says that archean greywacke is noted for its close association with greenstone. The Merritt formation is associated with a greenstone belt.

Concerning origin of greywacke he says,

> Greywacke indicates a special tectonic environment. It is, as Fischer noted a 'poured-in' type of sediment. Very rapid deposition is implied by the muddy matrix indicative of the lack of sorting, the massive nonstratified nature of the thicker beds, the lack of cross-bedding and ripple marks (which are evidences of reworking and sorting and are possible only if sedimentation is not too rapid), the graded bedding of some phases, each graded bed representing a single years deposit, and the extraordinary thickness of the sedimentary deposits characterized by greywackes.

The fact that the Merritt formation is probably a greywacke goes a little way toward substantiating the statement, "Greywacke forms the great bulk of the Archean sedimentary record." The following table gives a list of the thin sections studied along with the important minerals they contain.

TABLE 11

MINERAL CONTENT OF 12 SPECIMENS OF THE MERRITT FORMATION AS STUDIED IN THIN SECTION

Sample No.	Quartz	Plag.	Biot.	Garnet	Cord.	Sill.	Horn.
S-73	*	*	*		*	*	
S-149	*	*	*		*	*	
S-146	*	*	*		*		
S-39	*	*	*	*			
S-40	*	*	*	*			
S-42-1	*	*	*	*			
S-44-1	*	*	*	*			
S-36	*	*	*				*
S-247	*	*	*				
S-53	*	*	*				
M-61-A	*	*	*				
M-62-A	*	*	*				

Repeated Metamorphism

Two of the samples of the Merritt formation collected 1000 feet apart show the effect of a weak dynamic metamorphism superimposed on the regional metamorphism.

The samples consist essentially of quartz, plagioclase, and biotite. The first sample has been only slightly effected. The quartz grains show strain shadows and some of the biotite flakes have been slightly bent (Fig. 9). The second sample is apparently

Fig. 9 Bent biotite X 80

Biotite, quartz, plagioclase.

M-62A

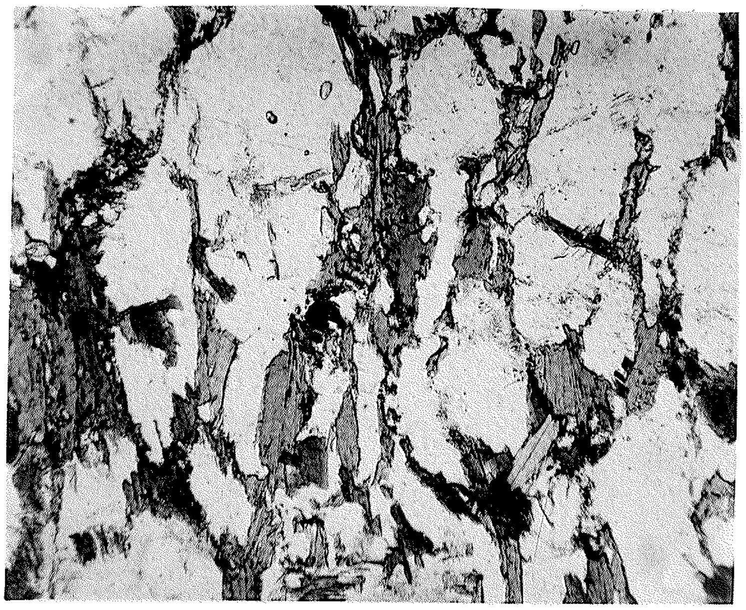

Fig. 10 Recrystallized biotite X 80

Biotite, quartz, and plagioclase.

M-61 A

closer to the shear which has caused the quartz grains to recrystallize to finer sutured aggregates and the biotite to recrystallize to fine ragged flakes which are strung out between the grains of quartz and plagioclase (Fig. 10).

Summary

The work on the Merritt formation shows that from a study of the structures, textures, and mineral content of a sedimentary rock it is possible to work out the most recent metamorphism and the probable original composition and type of sediment. The Merritt formation was, for the most part, originally a greywacke but it was regionally metamorphosed to the grade of the garnet and sillimanite zones.

B. CALCAREOUS MEMBER OF THE MERRITT FORMATION

The Calcareous member of the Merritt formation is located at the northwest corner of this main sedimentary band. Only a few outcrops were seen and these have been recrystallized to a suite of metamorphic minerals which strongly suggest that the bed was originally rich in lime.

Character

The grey to dark green outcrops are crossed by numerous dykes of pegmatitic grey granodiorite and aplite. A weak banding is strongly distorted. Stringers of epidote, due to hydrothermal action, are common.

Composition

The greywacke of the Merritt formation previously described, contains primarily quartz, plagioclase, and biotite. The Calcareous member outcrops 1000 feet to the north of this greywacke and ranges in composition from a slightly lime-bearing sediment containing quartz, plagioclase, biotite, hornblende, and microcline, with small amounts of carbonate, epidote, sphene, apatite, and magnetite (Fig.11) through a more lime-rich sediment very low in free quartz and containing pyroxene (probably diopside), hornblende, plagioclase and microcline with small amounts of sphene, zircon, calcite, epidote, apatite, and quartz (Fig. 12); to a very lime-rich variety, very poor in both quartz and plagioclase, and containing diopside, zoisite (or clinozoisite), epidote, garnet and sphene with small amounts of carbonate, magnetite, and apatite (Figs. 13 and 14).

Microscopic Appearance

Under the microscope the texture is zenomorphic and granular except in the lime poor part where the biotite and hornblende are aligned. The grains are fine, ranging mainly from .2 mm. to .5 mm. in diameter. The biotite is greenish brown, hornblende is blue-green, pyroxene is pale green, and the garnet is orange. Banding caused by narrow (1 to 5 mm.) bands composed mainly of hornblende with some

Fig. 11 Slightly lime-bearing sediment X 80
Hornblende, biotite, quartz, plagioclase,
epidote and sphene.

M-56

diopside and plagioclase alternates with bands composed of diopside with about 60 per cent plagioclase (Fig. 15).

Metamorphism

Regional metamorphism reaching the grade of the garnet zone will produce rocks having the textures and minerals just described.

Harker (1939, p. 253-4-5) describes the metamorphism of an impure non-magnesian limestone. In the low grade zones it may contain quartz, muscovite, zoisite and in places albite but in a more advanced grade (garnet-zone) grossularite and idocrase may form. The biotite gives place to diopside and muscovite to microcline. Sphene is of less common occurrence. The rock may consist entirely of lime-silicates with quartz.

Harker's description may be compared with the lime-rich sample from the Calcareous member which contains

40% zoisite
50% diopside
3% garnet
2% sphene
5% epidote

plus small amounts of calcite, quartz, apatite, magnetite, and plagioclase.

Harker says about such a rock, "The assemblage here recorded is a remarkable one. Zoisite is recognized as a stress-mineral, though not exclusively so, but grossularite and idocrase are highly characteristic minerals of simple thermal meramorphism, and the formation of diopside in preference to tremolite is significant in the same sense. It is clear that the influence of the stress-factor is here much reduced.

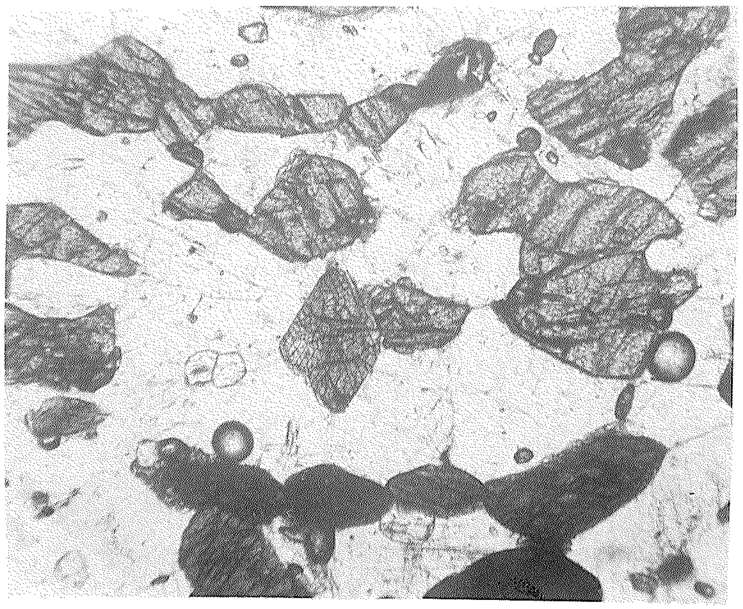

Fig. 12 Lime-rich sediment X 80

Diopside, hornblende, sphene, quartz, plagioclase, and apatite.

M-57 A

Fig. 13 Zoisite in very lime-rich sediment X 80

Zoisite, epidote, pyroxene, and sphene.

M-33

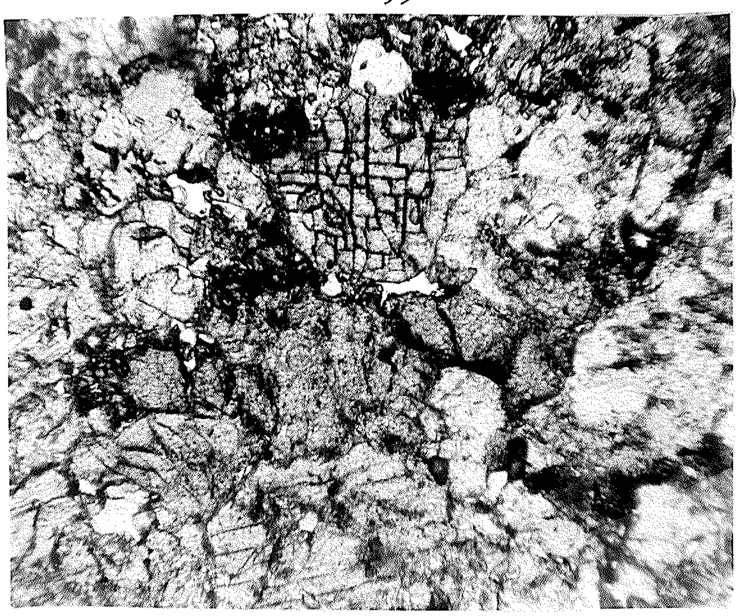

Fig. 14 Garnet and pyroxene in very

lime-rich sediment X 80

M-33

Fig. 15 Bands of hornblende and pyroxene X 25

Pyroxene, hornblende, and plagioclase.

M-57 B

Clearly pressure cannot be the determining factor, though indeed zoisite, garnet, idocrase, and diopside are all minerals favored by high pressure. The explanation is to be found in a consideration already put forward. The relatively yielding nature of a rock composed mainly of calcite makes any very high measure of shearing stress impossible. The formation of a potash-feldspar at the expense of mica in a medium grade of metamorphism is a consequence of the same principal."

The abundant intrusions of granitic material are the apparent cause of the relaxed shearing stress in this sediment as well as in the main body of greywacke.

The metamorphism is not above the garnet zone. This is shown by the green-brown biotite. Harker (1939, p. 267), in describing highly chloritic lime-bearing sediments says,

"------green-brown mica------is quite distinct from ordinary biotite, and is probably poorer in potash. Beginning well within the chlorite zone, as laid down in simple pelitic sediments, it persists into a higher grade, but apparently gives place gradually to normal brown biotite."

The common occurrence of microcline in the Calcareous member is in contrast to the complete absence of potash-feldspar in the greywacke. This is apparently due to a difference in composition. Turner and Verhoogen (1951, p. 448-9) discuss two groups of rocks containing free quartz that fall in the amphibolite facies.

The first of these groups contains K_2O in sufficient quantity to prevent entirely the appearance of andalusite, cordierite, almandene or anthophyllite. In other words, K_2O is present in excess, and and microcline can crystallize. Two of the possible mineral assemblages in this first group are, (a) Biotite-hornblende-plagioclase-microcline-quartz, and (b) Diopside-hornblende-plagioclase-microcline-quartz. Both of these mineral assemblages have been duplicated exactly in part of the Calcareous member just described.

In Turner and Verhoogen's second group, potash is deficient and potash feldspar should not be present. However a vacant field occurs in the ACF diagram of rocks deficient in K_2O. If rocks are sufficiently rich in lime and poor in alumina to fall within this area the total potash is held in potash feldspar, and all such rocks must therefore be classed as having potash in excess. Of the five samples containing microcline three do not contain biotite so must fall in this second group.

A possible, but less likely reason for the occurrence of microcline might be that it is an original constituent of the sediment and has not yet broken down and lost its potash to biotite. This could be the answer for four of the samples that contain microcline as three of these do not contain biotite and the other contains only 2 per cent. A fifth sample contains 15 per cent green-brown biotite but in this case the sample contains over 80 per cent quartz and plagioclase, with minor epidote, sphene, apatite, and magnetite. Harker (1939) says that in regional metamorphism of a fairly pure feldspathic sandstone microcline can occur along with quartz, plagioclase, biotite, muscovite, magnetite, apatite, and zircon.

Summary of the Calcareous Member

This member ranges in composition from a slightly calcareous sandstone or greywacke to a highly calcareous sandstone or greywacke much lower in silica. K_2O is an abundant constituent probably coming from an original abundance of sericite. The metamorphism is in the grade of the garnet zone.

C. UTIK LAKE FORMATION

This metamorphosed sedimentary formation which is separate from the two formations previously described, has been called the Utik Lake formation. It is the only sediment outcroping on Utik Lake in the present map area.

Distribution

The Utik Lake formation outcrops in small exposures over an area about 600 feet by 100 feet at the eastern end of Utik Lake on the south side, in contact with the Greenstone. It extends for about 12 miles to the west of the present map-area.

Character

This Utik Lake formation has been entirely recrystallized. The metamorphism has not been intense enough to destroy the pronounced bedding but it has distorted it slightly and developed a schistosity. Regional metamorphism over such a small area would be of the same grade throughout so it is possible to see the effect of the metamorphism on beds containing different quantities of impurities. The metamorphic minerals indicate that the metamorphism is not a simple type.

Composition

In part this formation is high in silica, containing mainly quartz and plagioclase, and in part it is lower in silica containing minerals produced from an original high argillaceous content.

A sample from a siliceous band contains:-

50% plagioclase
40% quartz
10% biotite
apatite
magnetite
zircon

A sample from an impure band contains:-

44% quartz
25% plagioclase
10% biotite
apatite
magnetite
zircon

A sample from a band which was apparently highly argillaceous contains:-

40% cordierite
25% biotite
15% quartz
15% plagioclase
5% garnet
apatite

magnetite

zircon

A study of the thin sections shows that most of the grains average about .3 mm. in diameter. The quartz is present as clear, irregularly rounded grains and as minute inclusions in the cordierite and garnet. The plagioclase forms irregularly rounded grains, some of which are twinned. It resembles the quartz. Biotite is a strongly pleochroic brown variety. In the main part of the rock it occurs as flakes about .5 mm. long which are approximately parallel and give the rock its schistosity. The biotite flakes included in the cordierite are randomly oriented and are only about .1 mm. long (Fig. 16). The cordierite forms rounded crystals as large as 3/8 inch in diameter, containing abundant inclusions of quartz, biotite, magnetite, and possibly plagioclase. These large grains distort the schistosity. Red garnets as large as 1/2 inch in diameter were seen on the outcrop. Thin sections show these to be irregular in shape with inclusions of quartz and magnetite. A thin section stained in the laboratory shows that potash is not present.

Metamorphism

The siliceous beds do not reflect the metamorphism well. The schistose texture shows that regional metamorphism has operated but the grade is uncertain. The biotite indicates that the biotite zone has been reached but index minerals diagnostic of higher grades are

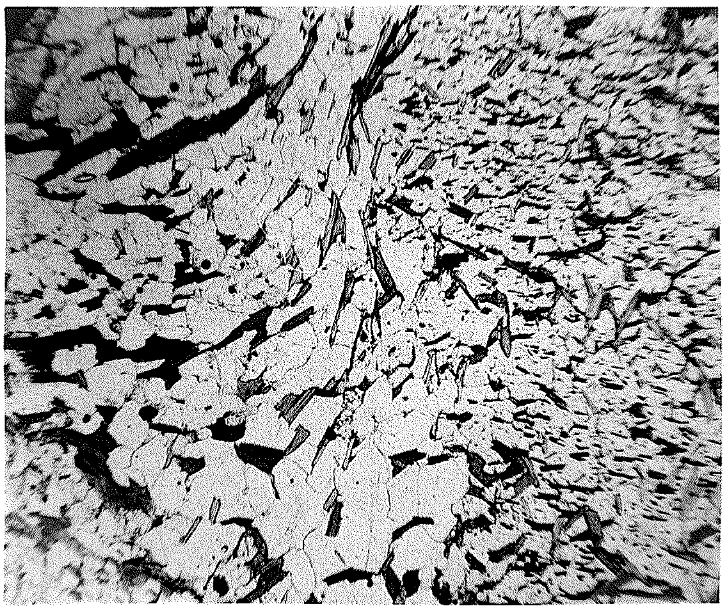

Fig. 16 Cordierite and biotite X 25

Cordierite (right half), biotite,

quartz, and plagioclase.

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not present.

The more argillaceous part contains a little cordierite which is a characteristic anti-stress mineral. This is the first suggestion that the metamorphism, if it is of a regional type, has not entirely followed its usual course. Cordierite can form during the highest grade regional metamorphism but the schistose texture shows that this grade has not been reached.

The most argillaceous band gives a better understanding of the metamorphic history. Both cordierite and garnet have been abundantly produced in this band. Garnet is a typical stress mineral. It was noted in the greywacke of Bigstone Lake the cordierite and garnet did not occur in the same rock.

Harker (1939, p. 235) says, "These garnet-cordierite-gneisses must therefore represent, with respect to the physical conditions governing their production, an intermediate case between that of simple cordierite-gneisses and that of ordinary garnetiferous gneisses. Cordierite, so commonly found in contact-aureoles and conspicuously absent from normal crystalline schists, is clearly marked as an anti-stress mineral; and its occurrence here can be attributed only to a decided relaxation of shearing stress during the metamorphism which gave birth to it."

The area has apparently been downfolded into the crust and heated to a temperature of the garnet zone. This rise in temperature has been accompanied by a normal maximum of shearing stress at this temperature which has produced the garnetiferous schist. With the temperature still elevated, though not necessarily very high, the forces causing the shearing stress have relaxed so that the stress-factor dropped below the value possible at the given temperature. This has allowed cordierite to form.

It is possible that the stress factor has never been at the maximum necessary for the usual formation of almandine.

Turner and Verhoogen (1951, p. 449) say, "------if the FeO/MgO ratio in the bulk composition of the rock exceeds a certain value, MgO and FeO must be considered as separate components, and almandine and cordierite may crystallize side by side."

This sediment extends to the west for about 12 miles and in most outcrops the cordierite is not accompanied by garnet. The composition is very likely the controlling factor there, i.e. the FeO/MgO ratio is not right for the formation of garnet along with the cordierite.

Original Composition

One type of band is made up largely of cordierite, biotite, and plagioclase. These minerals show that this sediment is rich in alumina, magnesium and iron and low in lime. A chloritic argillaceous rock has this composition. The other bands are poorer in argillaceous material and approach an impure quartz-feldspar sandstone or greywacke in composition.

Summary of the Utik Lake Formation

The Utik Lake formation is a bedded type. Some of these beds are very siliceous and others contain much more argillaceous material. It is this impure part which gives the best picture of the metamorphic history. It shows that there has been deficient shearing stress while the rocks were raised to the temperature and pressure of the garnet zone.

CHAPTER 111

VOLCANIC ROCKS

Introduction

The two belts of volcanic rocks which occur in the area were mentioned under the General Geology of the Area. They were described as being part of the Bigstone Lake group and the Semple Lake series. The lavas of the Bigstone Lake group have been called the Greenstone formation. It is this formation, consisting almost entirely of lavas, which is discussed here with the object of determining its metamorphic history.

A. GREENSTONE FORMATION

Distribution

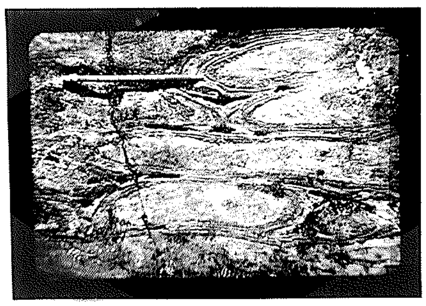
The Greenstone formation extends in an east-west direction from the eastern end of Utik Lake, across Bigstone Lake to at least the eastern boundary of the map sheet. It is a continuation of the volcanic belt mapped by Milligan (1954) although it has been separated from this belt by a body of alaskite at the western edge of the area. The belt is about one mile thick. The best exposures are at the eastern end of Utik Lake.

Character

Major folding or faulting of the lavas has not been recognized although the formation has been tilted on edge to expose the flows in cross section. Schistosity is generally weak and unsheared massive greenstone is common although some places are schistose. Pillow structures are abundant. The pillows are from 1 to 3 feet long and fairly flat. They may have been elongated by the metamorphism, but rounded pillows were also seen (Figs. 17 and 18). Interbedded tuffs or sediments were not recognized although one outcrop of tuff was seen at the extreme southeast corner of the lavas.

Composition

Dark green (faintly bluish) hornblende and plagioclase make up 95 to almost 100 per cent of the volume of the greenstone. Magnetite is consistently present in small amounts. Biotite and clinozoisite are rarely seen. Colorless, acicular amphibole accompanied by brown biotite occurs in one coarse-grained sample. Three separate determinations of 2V and optic sign of this amphibole indicate that it is cummingtonite. An X-ray defraction picture did not distinguish between tremolite and cummingtonite (Fig. 19). Apatite, often described as an accessory mineral in the lavas of other areas was not found here. The composition of the plagioclase, as shown in the following section, suggests these rocks are basalts, some of them very basic. An activation analysis of one sample showed it to contain only 44 per cent SiO_2.



Figs. 17 & 18 Pillow lavas

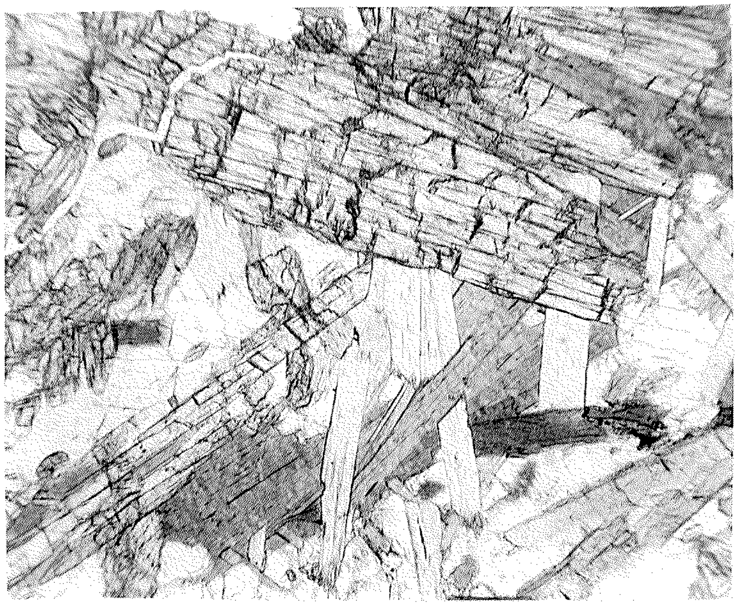


Fig. 19 Cummingtonite X 80

Cummingtonite, biotite and plagioclase.

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Composition of Plagioclase from the Greenstone Formation

The composition of the plagioclase is an indicator of the grade of regional metamorphism reached by basic rocks so an attempt was made to obtain the composition of the plagioclase in the Greenstone formation. Several methods of doing this were tried:-

(1) Specific gravity

(2) Extinction angles on the albite twins

(3) X-ray powder photographs

(4) Refractive index by oil immersion

(1) The specific gravity is characteristic of a plagioclase of a given composition. In two outcrops five miles apart phenocrysts of plagioclase ranging from $\frac{1}{4}$ to $1\frac{1}{2}$ inches long in a finer hornblende matrix were seen. The Berman microbalance was used to obtain the composition of these pheocrysts. A value for the specific gravity of 2.73 was obtained indicating a composition of An85 (Bytownite). Further work using other methods of identification showed this to be a reasonable value. A specimen from the museum was also tested. For this specimen labled anorthite a value of 2.76 was obtained corresponding to a composition of An 100. A specific gravity of 2.68 was obtained for another specimen supposed to be in the lower labradorite region. This specific gravity of 2.68 corresponds to a composition of An 50. These three results indicate that the determination of the specific gravity by use of the Berman microbalance, is a reasonably good method of obtaining the composition of the plagioclase

but unfortunately it is necessary to use a specimen of about 2 mm. diameter. None of the recrystallized plagioclase in the lavas of the Greenstone formation is this coarse-grained so this method could not be used further.

(2) Extinction Angles on the Albite Twins

Most of the grains of recrystallized plagioclase in the Greenstone are untwinned or poorly twinned. Because of this only one or two determinations of any value could be obtained from any one thin section. More determinations than this would be necessary to be reasonably sure that the maximum extinction angle had been obtained. It was therefore not possible to use this method.

(3) Claisse (1950) developed a method of obtaining the composition of a plagioclase from its X-ray powder photograph. This method is applicable where the plagioclase grains are about .5 mm. or more in diameter so that they could be picked out from the hornblende.

Six powder photographs were taken but only two of these were sharp enough to give the accurate readings necessary. A good photograph of the phenocrysts used for the specific gravity determination was obtained. Two separate observers carefully read this photograph. The first obtained values of An 85 and An 75, using two separate pairs of lines, with the latter considered the better value. The second pair of lines was better than the first as the first pair had a third line superimposed which made exact measurements of the spacing difficult. The second observer obtained values of An 70 and An 80 with the latter considered the better value. The other good photograph was taken of fine recrystallized plagioclase in the greenstone.

This gave two separate values of An 37 and An 46. Here there was nothing in the photos to indicate which value was the better one but oil immersion work indicates the latter value is better. This value of An 46 was obtained from the pair of reflections corresponding to the pair which gave the best value for the composition of the phenocrysts. The accuracy is certainly not that claimed by Claisse.

(4) Oil immersion work on the porphyritic sample used above gave the lowest reractive index for cleavage fragments of the phenocrysts as 1.568 corresponding to a composition of An 78. On such a basic sample the accuracy is about ± 2. This value of An 78 agrees with the results of specific gravity and X-ray methods leaving no doubt that the phenocrysts are bytownite.

Most of the recrystallized plagioclase is from .05 to .3 mm. in diameter and is mixed with large amounts of hornblende in a crushed sample. Satisfactory results could not be obtained using such fine grained rocks but three samples containing grains of about .5 mm. were used. One sample was of unrecrystallized plagioclase and two were recrystallized plagioclase. The following results were obtained:-

TABLE 111

INDEX OF REFRACTION OF PLAGIOCLASE BY OIL IMMERSION

Sample	Lowest Index	Composition
1. (unrecrystallized)	1.557 ± .002	An 55 (labradorite)
2. (recrystallized)	1.550 ± .002	An 42 (andesine)
3. (recrystallized)	1.566 ±.002	An 72 (bytownite)

This method seems to be the most accurate.

Conclusions

The porphyritic lava contains phenocrysts of bytownite. This is not a common type. Wahlstrom (1947, p. 318) says,

"Miharaite is a porphyritic variety of basalt containing phenocrysts of bytownite and hypersthene in a fine-grained groundmass of labradorite."

The porhyritic lavas described may be of this type. Any original mafic minerals would be recrystallized to hornblende.

The unrecrystallized labradorite laths from sample #1 suggest that at least this one flow is a basalt.

The composition of the recrystallized plagioclase, especially sample #3 with a composition of An 72 suggests that the metamorphism is not of a normal regional type. In normal regional metamorphism with shearing stress at a maximum the plagioclase is albite in the lowest grade and increases in anorthite content as grade increases until it is medium andesine in the amphibolite facies and maybe labradorite in the pyroxene hornfels facies. Harrison (1949) found labradorite (An 55) in the most highly metamorphosed greenstones of the File-Tramping Lakes Area. The very basic plagioclase from sample # 3, even though it has been recrystallized has certainly never broken down to albite or zoiisite.

It is uncertain whether the composition of the recrystallized plagioclase (An 42) from sample #2 is original or due to the metamorphism.

Metamorphism

Grades of regional metamorphism in basic volcanic rocks, which are equivalent to those established for pelitic sedimentary rocks, are difficult to determine. The composition of basic rocks is such that diverse minerals diagnostic of different degrees of metamorphism do not form to the same extent as they do in the pelites. Harrison (1949) sutdied the metamorphism of the File-Tramping Lakes lava. He made a summary of what other workers found and says,

"Wiseman found that progressive metamorphism of basic igneous rocks in the Highlands of Scotland produced albite and pale hornblende in the chlorite and biotite zones of pelite schists, but in the garnet zone plagioclase becomes more calcic and the hornblende is typically blue-green, and andesine is characteristic of the kyanite and sillimanite zones. Turner noted that oligoclase normally appears as a product of dynamothermal metamorphism at relatively high grades such as prevail in the zones of almandine and perhaps kyanite. Ambrose found, in explaining greywackes of the Missi series near Flin Flon, that, concurrently with the appearance of garnet, the anorthite content of the associated plagioclase rose abruptly from An 6-8 to An 28-32. Greenstones exposed in the garnet zone are composed mainly of greenish blue amphibole, and plagioclase is more calcic than albite. Harker notes that chlorite soon disappears in the garnet zone, epidote diminishes, greenish hornblende becomes the dominant mineral, feldspar passes through oligoclase to andesine, and in the highest zones, pyroxene should appear. Bateman noted that, in general, the greater the intensity of metamorphism, the deeper the colour of the hornblende. From these observations it appears that blue-green hornblende, plus plagioclase at least as calcic as An 20-30, can be considered to indicate a grade of metamorphism for basic igneous rocks equivalent to the garnet zone of fine-grained sediments."

The composition of the lavas of the Greenstone formation ----green (often faintly bluish) hornblende and intermediate to calcic plagioclase----indicate a grade of metamorphism about equivalent to the garnet zone as defined for fine-grained sediments. In a rock such as this which has a composition that does not easily reveal the grade of metamorphism the facies classification would perhaps be better. The facies reached here is the amphibolite facies. The absence of epidote or pyroxene indicates it does not belong in the facies below or above this, namely the epidote amphibolite facies or the pyroxene hornfels facies respectively. The persistant composition and similarity of textures over the entire formation show that large changes in the grade of metamorphism do not occur in different parts of the formation.

The textures of the greenstone are due to the metamorphism. The hornblende grains may be equidimentional and unaligned (Fig. 20) or more elongate and aligned (Fig. 21). The grain size is a reflection of the original grain size. Pillow lavas are always very fine grained (.1mm.) but they may be in contact with massive greenstone containing mainly hornblende of about 5 mm. diameter. The coarser bands must be sills or thick flows.

The plagioclase is mainly recrystallized to fine granules but original plagioclases are also present. The plagioclase phenocrysts (An 78) described on page 47 are original. These are partially recrystallized around the edges or in fractures (Fig. 22) and may or may not be partially saussuritized. In most of the greenstone there are also occasional small (1 mm.) twinned laths of plagioclase which are distinct from most of the plagioclase which is in fine granules (Figs. 23, 24, 25). These laths must also be primary crystals.

Harker (1939) says that in low grade regional metamorphism of basic rocks the plagioclase is albite. Mason (1951, p. 240) says that anorthite breaks down to zoisite and albite. As the grade increases the zoisite disappears and the plagioclase increases in

Fig. 20 Granoblastic texture X 80

Hornblende, plagioclase, and magnetite.

M-73

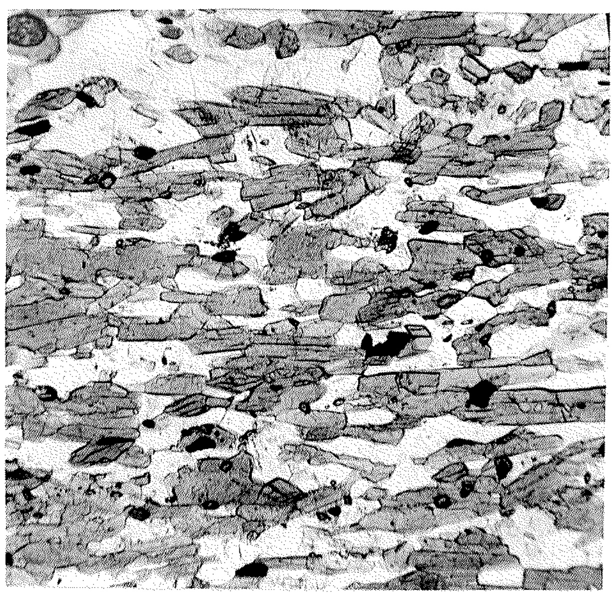


Fig. 21 Aligned hornblende X 80

Hornblende, plagioclase, and magnetite.

S-129

the anorthite molecule. Zoisite can remain up to the amphibolite facies. Also Mason (p. 217) says,

> "Anorthite is notably unstable under conditions involving stress and is practically confined to contact-altered argillaceous limestones. Plagioclase is a sensitive indicator of metamprphic grade; in the lowest grade rocks it is pure albite, and the calcium content increases as the grade increases."

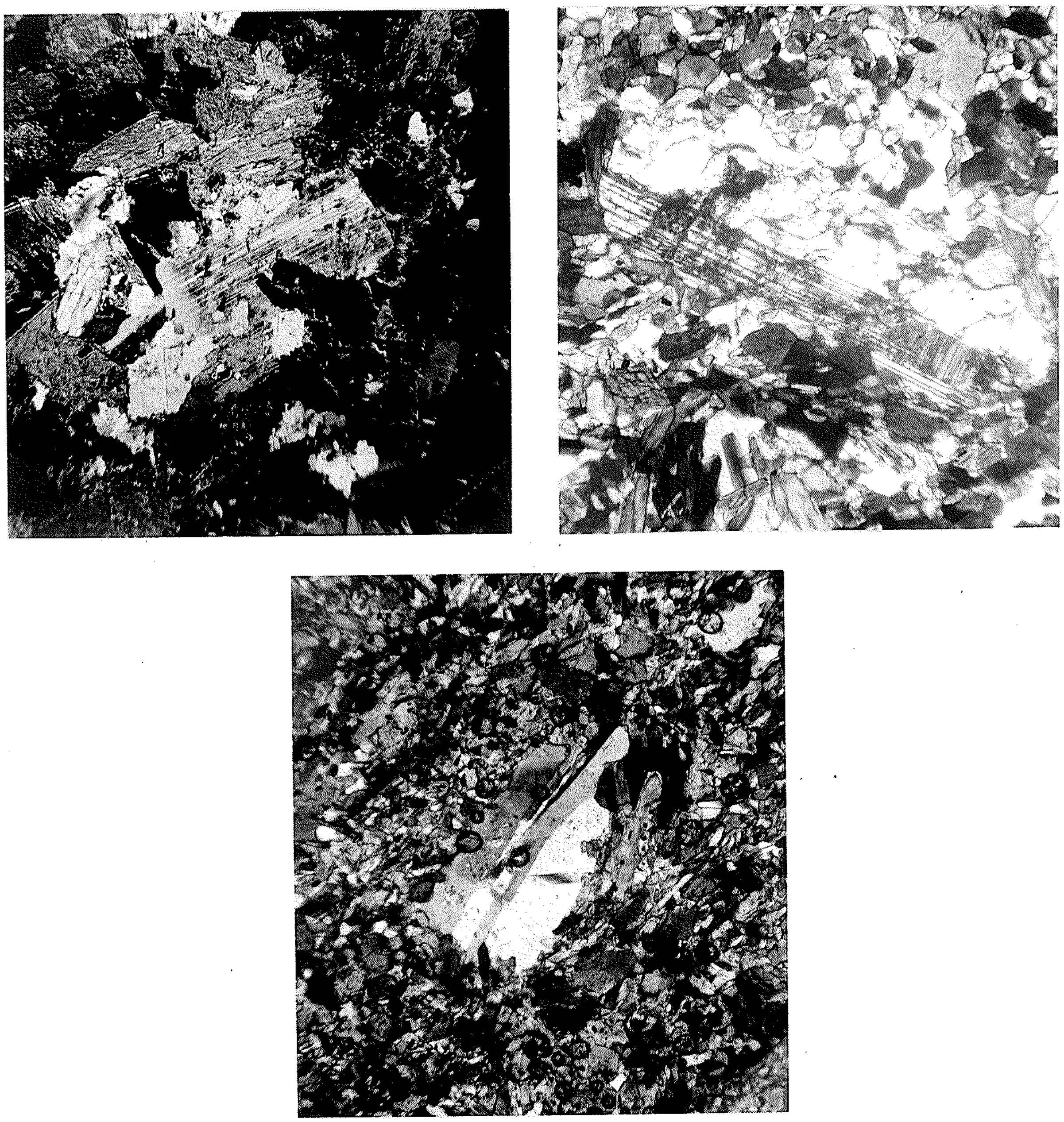
The presence of unrecrystallized plagioclase crystals in the Greenstone formation suggest that the stress-factor has not been too important in the metamorphism and that the grade is in the lower part of the amphibolite facies. The metamorphic history is apparently one where shearing stress was deficient while the temperature was somewhat elevated. The metamorphism is distinct from thermal metamorphism because it has a regional distribution and is not confined to a contact zone yet high temperature and pressure have been more important than shearing stress.

Summary

The Greenstone formation has been subjected to a regionally distributed metamorphism but heat and pressure have been more important than shearing stress. The metamorphism is in the amphibolite facies.

Fig. 22 Partially recrystallized plagioclase phenocryst X 25

S-85-5



Figs. 23, 24, & 25 Primary plagioclase X 80

Primary plagioclase, plus recrystallized

plagioclase and hornblende.

M-16 M-216 M-73

Thermal Metamorphism due to Diabase Dyke

A diabase dyke, about 200 feet wide cuts across the Greenstone formation. The dyke's high temperature has caused metamorphic changes to take place in adjacent rocks. One sample was taken from a slab of greenstone that was partially surrounded by diabase. The plagioclase in this sample is mainly uneffected. It has the same texture as the plagioclase in the other recrystallized lavas but the hornblende does show the effect of the high temperature. About 20 per cent of the hornblende has recrystallized to augite. The hornblende that is partially replaced by the augite does not change directly from its well crystallized prisms into the good crystals of augite but becomes somewhat ragged and fibrous in the process (Fig. 26). A small amount of biotite and magnetite are also present.

Metasomatism at Granodiorite Contact

One specimen of greenstone in contact with granodiorite has been partially granitized. This extremely fine grained rock contains about 70 per cent green hornblende. In the main part of the lavas the hornblende is accompanied by plagioclase but here quartz forms 15 per cent, fine muscovite 8 per cent, epidote and clinozoisite 5 per cent with a small amount of magnetite and partially chloritized biotite.

Fig. 26 Metamorphic augite X 80

Augite, hornblende, plagioclase,

and magnetite.

M-S-83-X

Comparison of the Greenstone Formation of the Bigstone Lake Group with the Semple Lake Lavas

The main rock type of the Semple Lake series is basic lava but interbedded with these flows are minor tuffs and agglomerate, rhyolitic and dacitic flows, and greywacke, impure quartzite, and conglomerate. This series is in contrast to the lavas of the Bigstone Lake group which do not have inter-bedded tuffs, agglomerate, acid flows, or sediments.

Metamorphism is not so intense in the lavas of the Semple Lake series as in the lavas of the Bigstone Lake group. Primary textures, extensive development of fine biotite, and absence of garnets indicate a grade of regional metamorphism of about the biotite zone as defined for argillaceous rocks (epidote amphibolite facies).

B. TUFF

Distribution

Only one outcrop of tuff was seen, occurring at the extreme southeast corner of the Greenstone formation in contact with the grey granodiorite (Fig. 27).

Structure

Sharply defined beds range from a fraction of an inch to 4 inches thick but average about 1 inch. Rare volcanic bombs indicate that this rock is a tuff. The bedding is straight adjacent to these bombs on the north side but curves around them on the south side indicating the top of the beds is probably to the south. Metamorphism due to the adjacent granodiorite has recrystallized the tuff to a fine grained, hard uniform textured rock.

Thin Section Analysis

Thin sections show the rock to be entirely recrystallized with grainsless than .5 mm. in diameter.

The light colored bands are composed of about

20% hornblende

58% plagioclase

20% quartz

1 % epidote

1 % sphene

apatite - a few scattered grains

microcline - very rare grains

See Fig. 28.

The hornblende is dark colored and strongly pleochroic blue to green. The grains, although not especially elongate, mostly lie with their c-axis in the plane of the bedding. The plagioclase does not usually show twinning. The grains have a slightly dirty appearance due to a

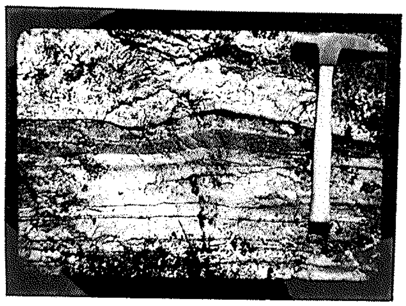


Fig. 27 Bedded tuff in contact with granodiorite.

Fig. 28 Siliceous calcareous tuff band X 80
Hornblende, sphene, epidote, plagioclase,
quartz, and apatite.

S-128-3A

little sericite and other tiny impurities. The quartz is clear and shows strain shadows in most of the grains. The grains are smaller than most of the plagioclase.

A few plagioclase crystals form vermicular intergrowths with quartz. These intergrowths, along with apatite and abundant quartz, suggest that normal sedimentary material is mixed with the tuff in the light colored bands.

The dark colored bands are composed of about:-

25% hornblende

30% pyroxene

35% plagioclase

8% epidote

2% (sphene
   (magnetite

Finer bands, richer in either hornblende or pyroxene, alternate in these dark colored bands. The magnetite is mainly in the pyroxene rich bands (Fig. 29). The hornblende and plagioclase have the same appearance as in the light colored bands. The pyroxene (probably diopside) is pale green with a slight pleochroic blue-green mottling in most of the grains. This is probably due to remnants of hornblende which the pyroxene is replacing. The grains are rimmed with epidote. Epidote also occurs as rims around the magnetite and as small patches.

The vermicular intergrowths of quartz and plagioclase, and grains of apatite and quartz are absent from the dark colored bands.

Metamorphism

Harker (1939, p. 105-6) says,

"Where basic rocks have suffered changes of the nature of weathering, calcite is a more or less abundant product; and the re-distribution of this within the rock, in virtue of its relatively free solubility, becomes an important factor influencing subsequent thermal metamorphism. Basic tuffs, owing to their original finely clastic state and consequent liability to weathering are even more readily affected in thermal metamorphism than are lavas of like nature."

This tuff contains considerable lime as shown by the lime-bearing minerals, hornblende, pyroxene, epidote, and sphene. In such a rock hornblende is of general occurrence instead of biotite. Barth (1951, p. 326) states,

"TiO_2 forms sphene in highly calcareous rocks. In other rocks it goes into ilmenite, or it does not create any new mineral but enters as a substitutive oxide into biotite, garnet, and other minerals."

Summary

The presence of pyroxene replacing the hornblende shows that the adjacent granodiorite has caused a high grade of thermal metamorphism. The tuff originally contained considerable calcareous material which probably resulted from weathering of the tuff.

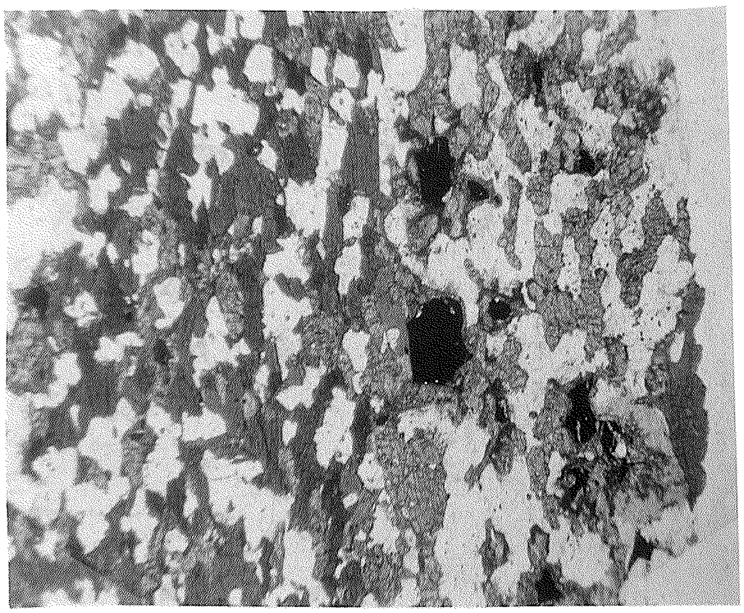


Fig. 29 Basic calcareous tuff band X 80
Diopside (right), hornblende, plagioclase,
and magnetite.

S-128-3B

CHAPTER 1V

Summary of Conclusions

1. (a) The Merritt formation has been entirely recrystallized by regional metamorphism of medium to high grade.

(b) Garnets are present in the western part of the Merritt formation and sillimanite is present in the eastern part indicating grades of regional metamorphism of the garnet and sillimanite zones respectively.

(c) Originally the main part of the Merritt formation was probably a greywacke.

2. (a) The Calcareous member of the Merritt formation was regionally metamorphosed to a grade of the garnet zone.

(b) The Calcareous member was originally a calcareous sandstone or greywacke containing considerable K_2O.

3. (a) The Utik Lake formation was regionally metamorphosed to the temperature and pressure of the garnet zone but a deficiency of shearing stress allowed cordierite to form.

(b) The Utik Lake formation originally graded in composition from an impure quartz-feldspar sandstone or greywacke to a chloritic argillite.

4. (a) The Greenstone formation is in the amphibolite facies of regional metamorphism.

(b) The Greenstone formation consists of basic lavas, probably basalts.

5. One tuff outcrop in contact with granodiorite was thermally metamorphosed to a high grade.

6. The regional metamorphism of the Bigstone Lake group is characterized by deficient shearing stress.

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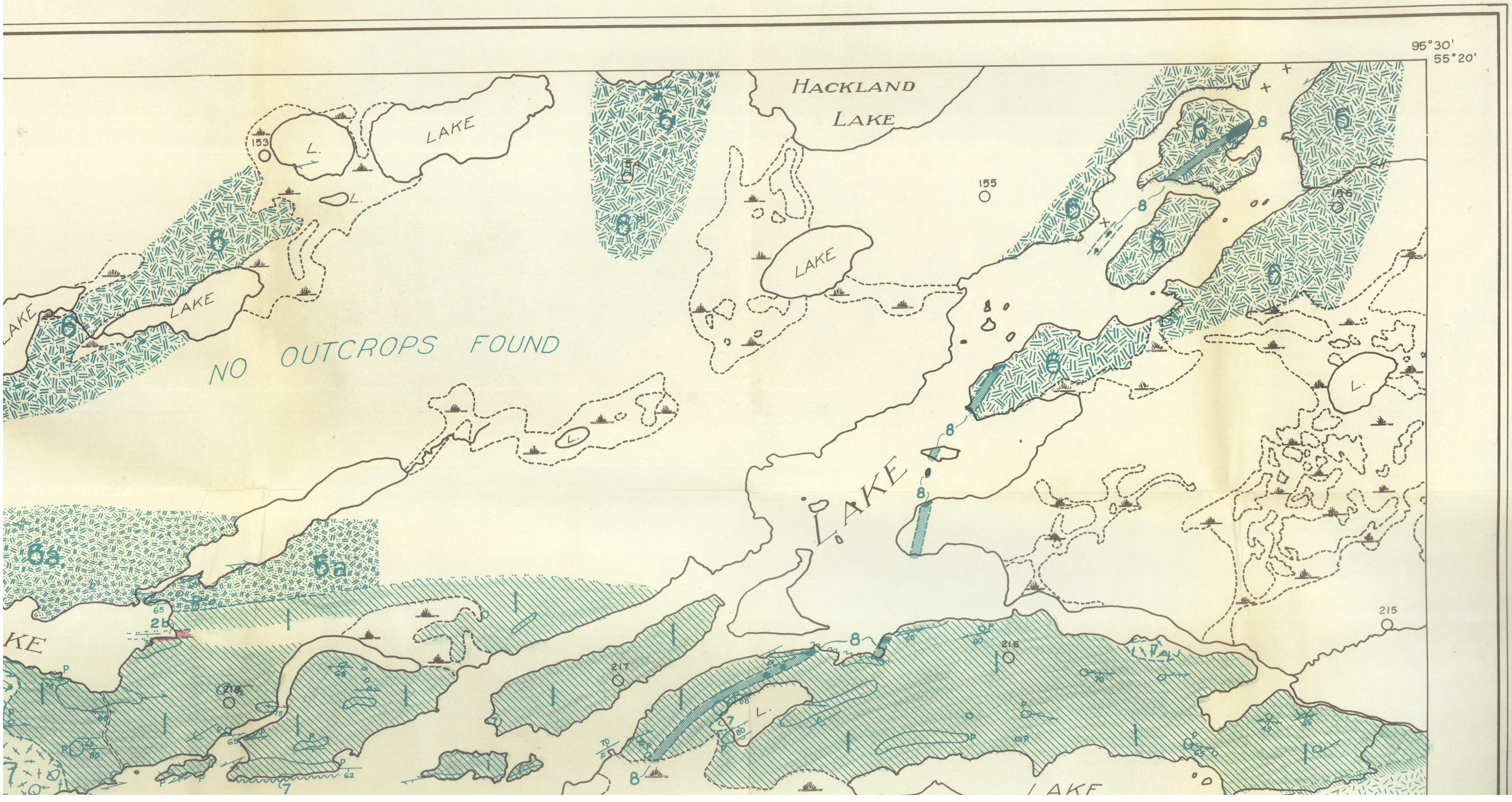

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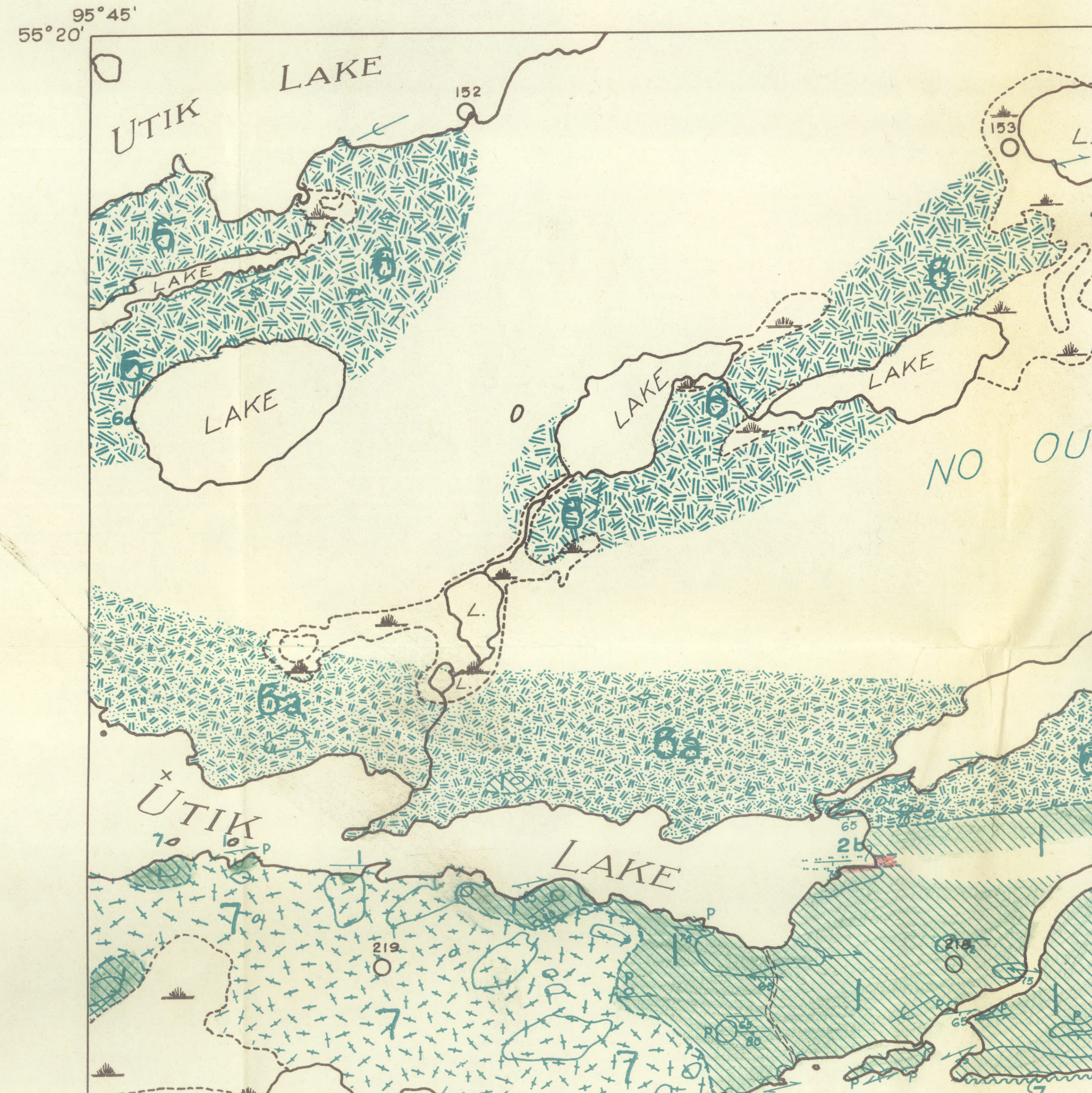
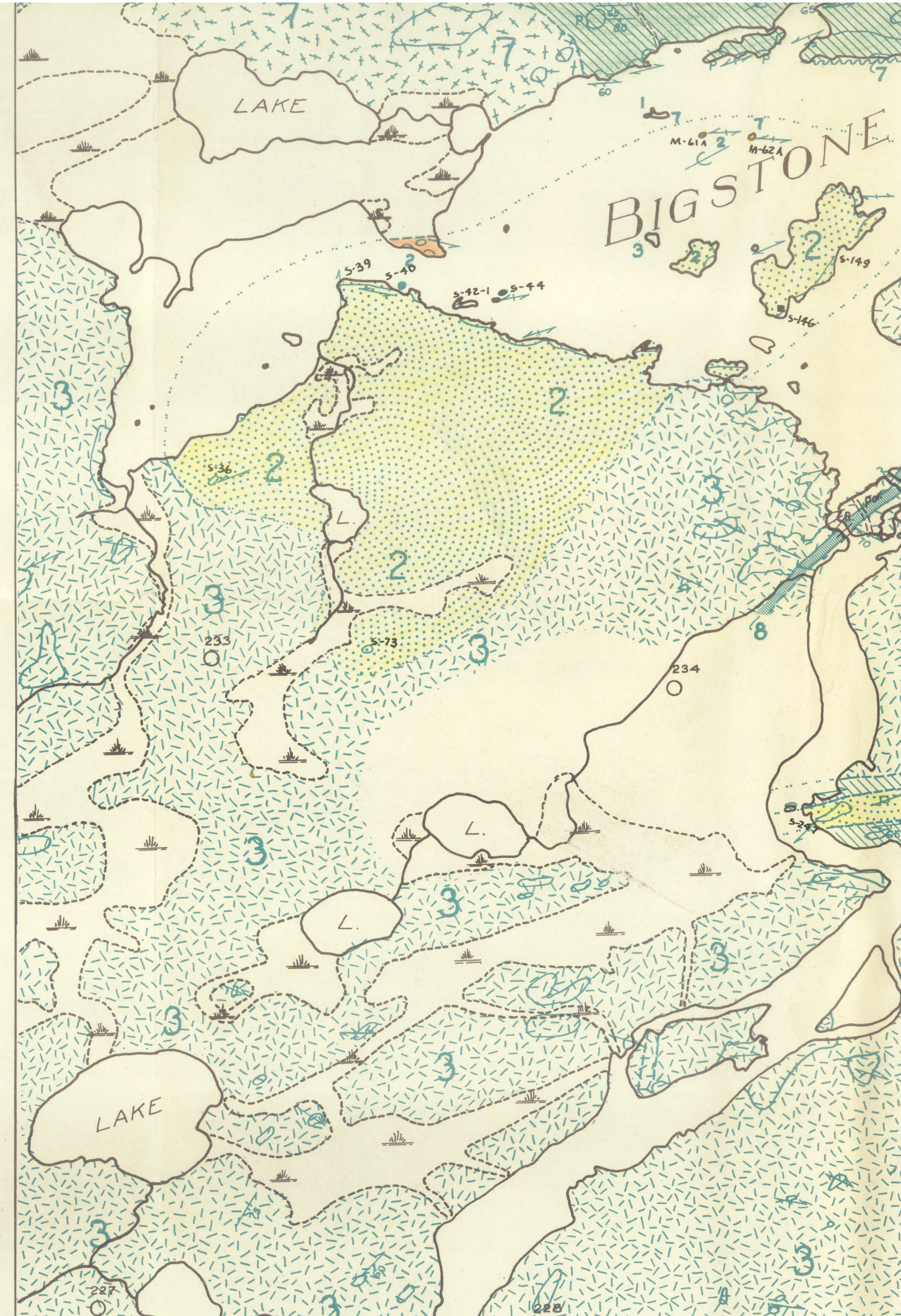
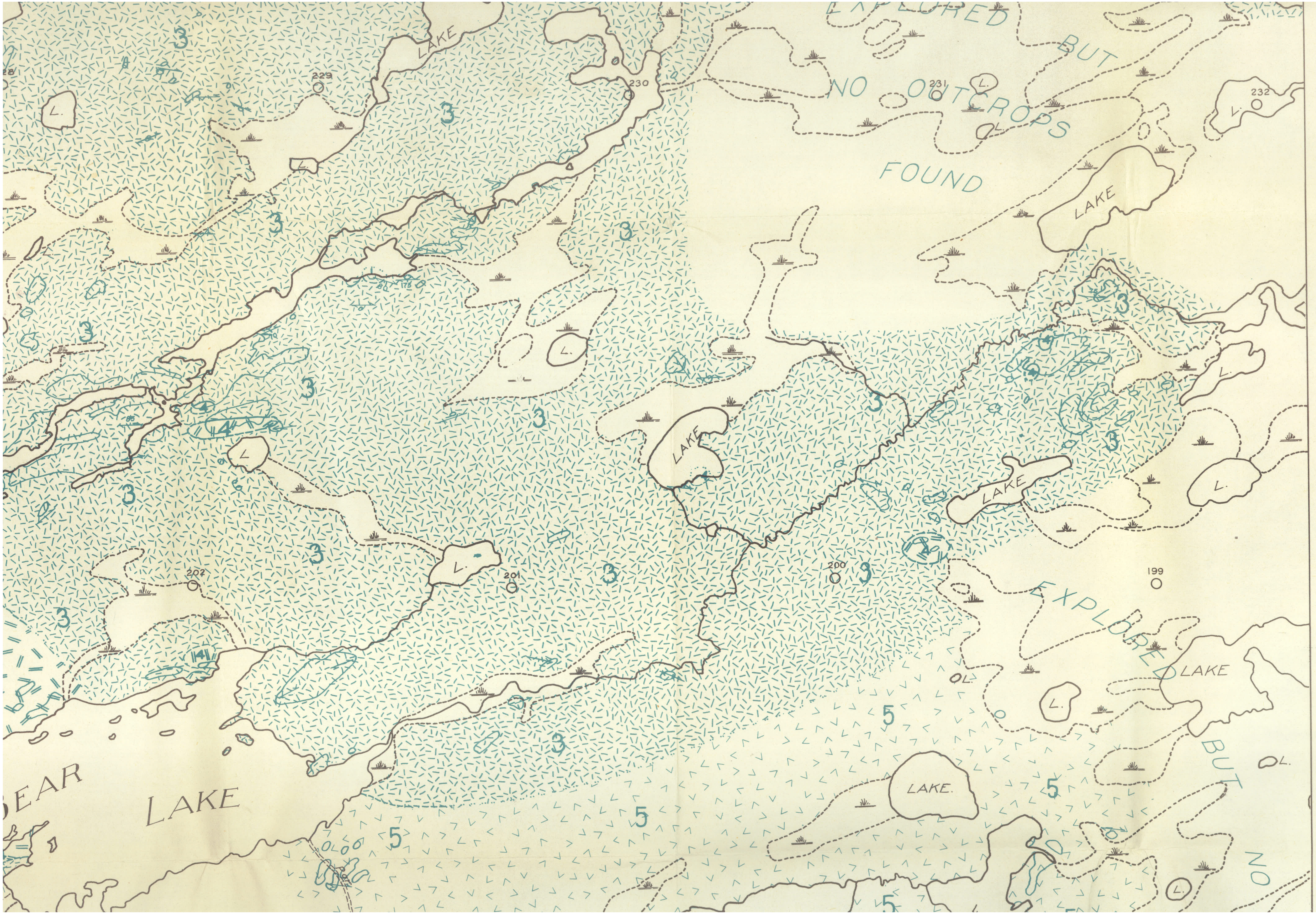


BIGSTONE
LAKE
NO OUTCROPS FOUND
NO OUTCROPS FOUND
LAKE
LAKE
LAKE
LAKE
LAKE
LAKE
EXPLORED BUT

LEGEND

- 8 — Basic dyke
- 7 — Alaskite.
- 6 — Northern quartz monzonite and granodiorte. 6a — Marginal phase — gneissic granodiorite.
- 5 — Porphyritic granodiorite.
- 4 — Pink quartz monzonite.
- 3 — Grey and buff quartz monzonite, granodiorite and quartz diorite.
- 2 — Greywacke and derived schists; lit-par-lit gneiss. Merritt formation (yellow); Calcareous member (orange)
  - 2a — Conglomerate
  - 2b — Cordierite schist - Utik Lake formation
- 1 — Basic flows - now schists derived from andesites and basalts; minor interbedded greywacke, impure quartzite and tuff. Greenstone formation (green)
  - 1a — Tuff and agglomerate
  - 1b — Dacitic to rhyolitic flows




EXPLORED BUT NO OUTCROPS FOUND
LAKE
L.
229
230
231
232
3
4
5
LAKE
LAKE
LAKE
LAKE.
202
201
200
199
EXPLORED BUT NO
BEAR
LAKE

1a	Tuff and agglomerate
1b	Dacitic to rhyolitic flows

SYMBOLS

Geological boundary; defined, approximate, assumed.

Area of outcrop

Strike and dip of beds; vertical, inclined, top known, overturned.

Strike and dip of schistosity or foliation

Fault, with direction of lateral movement

Glacial striae

Mineral occurance

Area of magnetic disturbance

Pillow lavas

Drag folds with plunge of linear feature

Portage

Rapids

Cabin

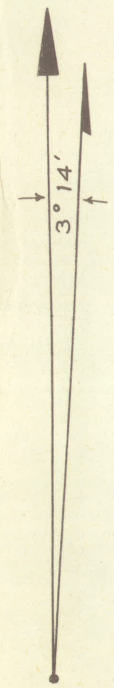
Swamp or muskeg

Adjoins Eastern Bear Lake Map 53-1

CALIFORNIA LAKE
LAKE
L.
5
4
121
122
123
124
Por.
RED BUT
FOUND
OUTCROPS FOUND
STICK
LAKE

Swamp or muskeg

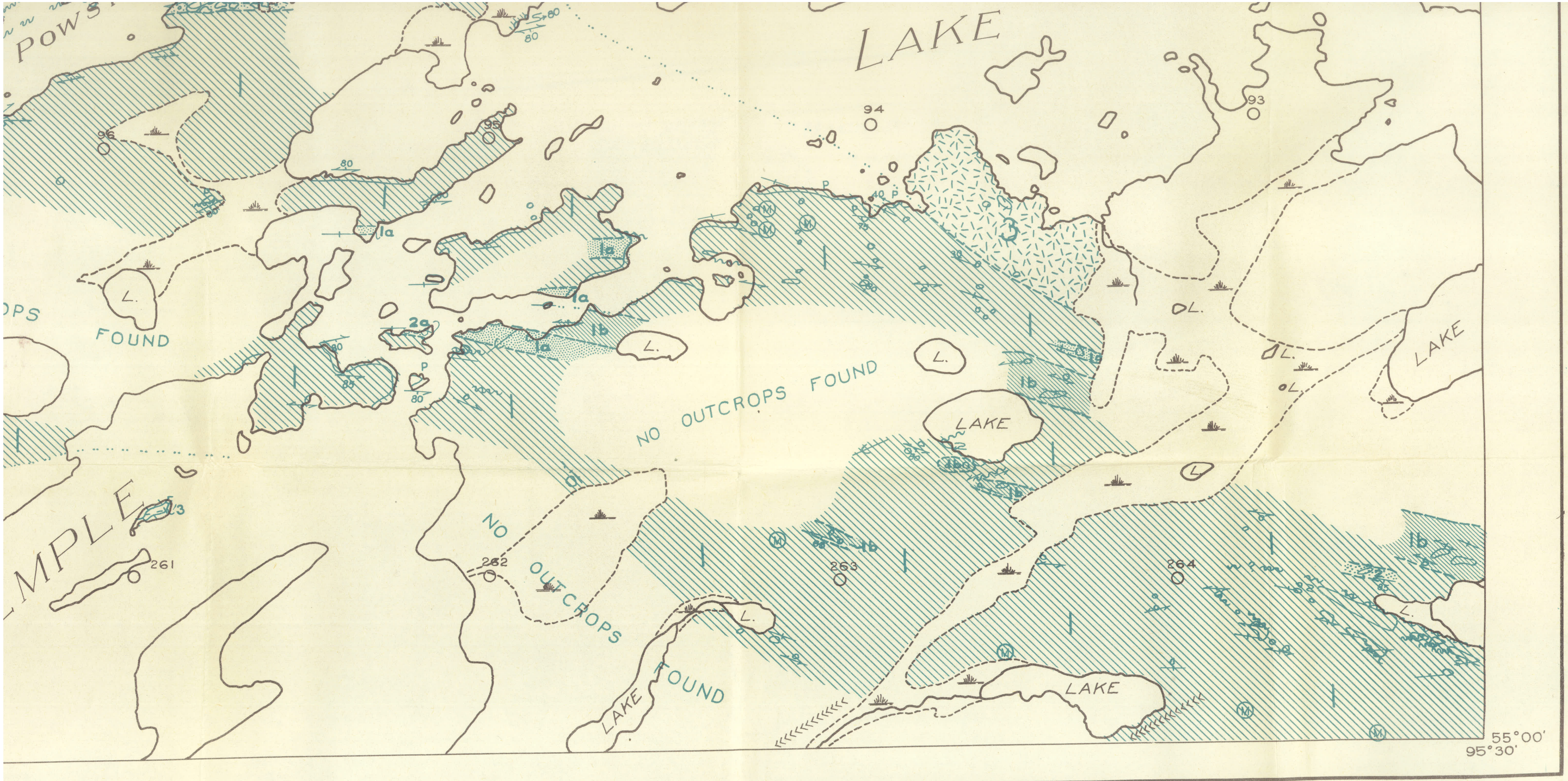
Esker



Approximate magnetic declination 3°14'E.
Decreasing 0°13' annually

Geology by M. Moorhouse and J. Shepherd

To accompany Mines Branch Publication 53-3



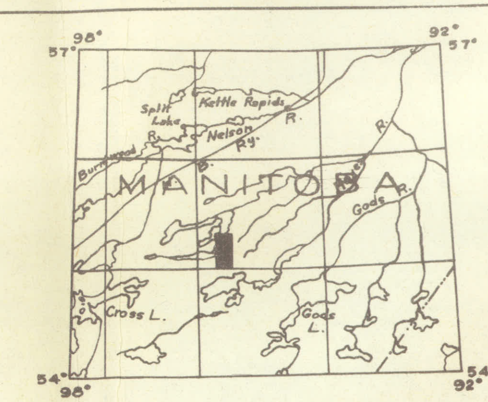
MAP 53-3

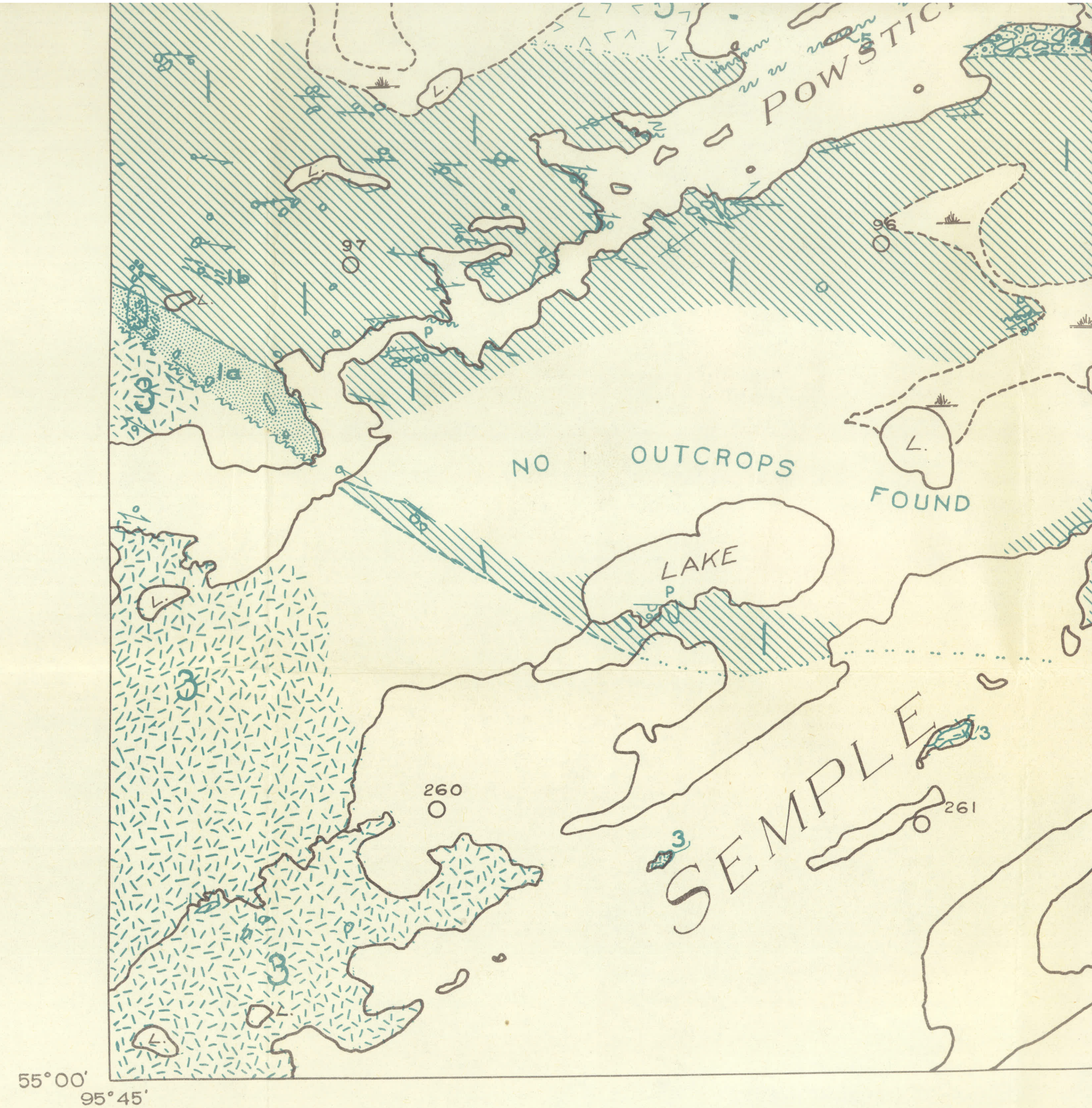
IFORNIA LAKE AREA

FORD LAKE MINING DIVISION

NORTHERN MANITOBA

Scale: 2 inches = 1 mile





Base map compiled from vertical photographs by Surveys Branch, Dep't. of Mines and Natural Resources Winnipeg, 1954

MAP 5

CALIFORNIA L

OXFORD LAKE MI

NORTHERN M