GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

MEMOIR 337

LEDGE LAKE AREA, MANITOBA AND SASKATCHEWAN

W. W. Heywood

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1966

Price, $1.65

LEDGE LAKE AREA, MANITOBA AND SASKATCHEWAN

2,000-1965-5379

Chief Scientific Editor
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JACQUELINE DEMERS
Printed on ANCASTER BOOK
Set in Times Roman with
20th Century captions by
CANADIAN GOVERNMENT PRINTING BUREAU
Artwork by CARTOGRAPHIC UNIT, GSC

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OF CANADA

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By
W. W. Heywood

DEPARTMENT OF
MINES AND TECHNICAL SURVEYS
CANADA

97885—2

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Available by mail from the Queen's Printer, Ottawa,
from Geological Survey of Canada, 601 Booth St.,
Ottawa,
and at the following Canadian Government bookshops:

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Price $1.65 Catalogue No. M46-337

Price subject to change without notice

ROGER DUHAMEL, F.R.S.C.
Queen's Printer and Controller of Stationery
Ottawa, Ontario
1966

PREFACE

In 1913 gold-bearing quartz veins were discovered on Amisk Lake in northwestern Manitoba, near what is now Flin Flon. This discovery was followed by a period of intensive prospecting in the region and several geological mapping projects. The results of detailed mapping done by the Geological Survey of Canada from 1954 to 1956 in this Precambrian terrain are reported on the following pages.

This report deals mainly with the petrography and petrology of the volcanic and sedimentary rocks of the Amisk and Missi Groups and associated plutonic rocks, but also presents data on and interpretations of their structure and metamorphic history. It is accompanied by a multicoloured geological map on the scale of 1 inch to 1,000 feet.

Y. O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, December 4, 1964

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MEMOIR 337 — Das Gebiet von Ledge Lake (Manitoba und Saskatchewan).

Von W. W. Heywood

Eine Beschreibung der Petrographie, der Struktur und der Metamorphose einiger präkambrischer vulkanischer Gesteine und Sedimente bei Flin Flon im nordwestlichen Manitoba.

MEMYAP 337 — Район озера Лэдж, Манитоба и Саскачеван.

В. В. Гэйвуд

Дается описание петрографии, структуры и метаморфизма некоторых докембрийских вулканических и осадочных пород вблизи Флин Флон, в северо-западной части провинции Манитоба.

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LEDGE LAKE AREA, MANITOBA AND SASKATCHEWAN

Abstract

Volcanic and sedimentary rocks of the Amisk and Missi Groups, in the Ledge Lake area near Flin Flon, Manitoba, are part of a thick Precambrian sequence. The Amisk Group is predominantly composed of andesitic and basaltic flow and pyroclastic rocks having an exposed thickness of about 17,000 feet. Diabase dykes and sills are probably genetically related to the Amisk volcanic rocks. Sedimentary rocks of the Missi Group unconformably overlie the Amisk volcanic rocks in adjacent areas, but these rocks are in fault contact in the Ledge Lake area.

Rocks ranging in composition from diorite to granodiorite have intruded the Amisk volcanic rocks and the related diabase dykes and sills. Quartz diorite and diorite near Ledge and Hook Lakes form sill-like intrusions and are probably premetamorphic. Intense folding of the Amisk volcanic rocks was accompanied by the intrusion of the Kaminis granodiorite.

Low-grade regional metamorphism of the extrusive volcanic rocks and of the diabase sills and dykes has resulted in the development of greenschist, greenstone, and meta-diabase characterized by a low-grade metamorphic mineral assemblage. A thermal metamorphic aureole, averaging about 3,500 feet wide around the Kaminis granodiorite, contains mineral assemblages that represent a medium-grade metamorphic zone and, locally near the contact, a high-grade zone.

Résumé

Les roches volcaniques et sédimentaires des groupes Amisk et Missi dans la région du lac Ledge, près de Flin Flon (Man.), font partie d'une épaisse succession précambrienne. Le groupe Amisk est surtout composé de coulées d'andésite et de basalte et de roches pyroclastiques qui affleurent sur une épaisseur d'environ 17,000 pieds. Les dykes et les filons-couches de diabase sont probablement apparentés aux roches volcaniques du groupe Amisk. Les roches sédimentaires du groupe Missi reposent en discordance sur les roches volcaniques de l'Amisk dans des aires adjacentes, mais ces roches sont en contact par faille dans la région du lac Ledge.

Des roches dont la composition varie de la diorite à la granodiorite ont fait intrusion dans les roches volcaniques de l'Amisk et dans les dykes et les filons-couches de diabase apparentés. La diorite et la diorite à quartz, près des lacs Ledge et Hook, forment des intrusions semblables à des filons-couches et sont probablement prémétamorphiques. Un intense plissement des roches volcaniques de l'Amisk s'est accompagné de l'intrusion de granodiorite du Kaminis.

Un faible métamorphisme régional des roches volcaniques intrusives et des filons-couches et des dykes de diabase a provoqué la formation de schiste vert, de roche verte et de métadiabase qui sont caractérisés par un pauvre assemblage minéral métamorphique. Une auréole thermométamorphique de quelque 3,500 pieds de largeur autour de la granodiorite du Kaminis renferme des assemblages minéraux indiquant une zone à métamorphisme moyen, et par endroits près du contact, une zone à fort métamorphisme.

Chapter I

INTRODUCTION

Location

The Ledge Lake area comprises about 30 square miles between latitudes 54°37′N and 54°43′N and longitudes 101°47′W and 101°53′W. It is centred on the Manitoba–Saskatchewan provincial boundary about 7 miles south of Flin Flon, Manitoba.

Accessibility

Flin Flon is readily accessible from the southern part of the province of Manitoba. The Canadian National Railways provides service to Winnipeg and Regina and Transair Limited schedules a daily airline service to Winnipeg. Provincial highway No. 10 provides road connections to the south. Charter air services are available at Channing on the Northwest Arm of Schist Lake, about 4 miles southeast of Flin Flon.

Although no roads extend into the Ledge Lake area, it is readily accessible by water from Channing. Most of the area can be reached from the Northwest Arm or from the West Arm of Schist Lake. The northwest part of the area is accessible from Phantom Lake, which is 3 miles by road from Flin Flon.

Vegetation

The area is forested with conifers except in those parts recently burned. A dense growth of spruce occurs where the soil is more than a few inches thick, but pine is more common where the soil cover is thin, and in the more rocky areas. Both spruce and tamarack grow in the drier muskegs.

Thick growths of birch and poplar have formed the first cover in areas recently burned. They have attained their greatest development on the east side of the Northwest Arm of Schist Lake in an area that was burned in the early 1930's.

Mosses and lichens cover most outcrops except in areas recently burned.

History and Previous Work

The inland water systems of the Saskatchewan and Churchill Rivers and their tributaries were utilized by the early explorers and traders. Descriptions of these early explorations are summarized by McInnes (1913)[1] and Bruce (1918b).

The earliest geological work was of an exploratory nature. Track surveys to map the geology and water routes in northern Manitoba and Saskatchewan were

[1]Dates in parentheses are those of *References*, p. 41.

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made by Bell, Cochrane, McConnell, Tyrrell, Low, and Dowling, all of the Geological Survey of Canada. The information on the geology derived from their work was compiled by McInnes (1913) and combined with his work in the region.

Intensive prospecting in the area commenced after the discovery, in 1913, of gold-bearing quartz veins on the northwest side of Amisk Lake. Several mineral occurrences were disclosed in the next few years, the most important being the copper and zinc sulphide bodies of the Mandy Mine on Schist Lake, and the Flin Flon Mine on Flin Flon Lake. Although prospecting continued for many years, no other commercial orebodies were discovered until 1948, when the Schist Lake Mine orebodies were found.

Systematic geological mapping was started in 1913 by E. L. Bruce of the Geological Survey of Canada. Brief descriptions of his reconnaissance surveys were published in Geological Survey of Canada Summary Reports (1915, 1916, 1917, and 1918a), and a complete report was published in Memoir 105 (1918b). Alcock (1923) mapped the Flin Flon area in more detail in 1922. Mapping, on the scale of 1 inch to 1 mile, of the Flin Flon and Schist Lake map-areas was completed in 1938 and 1939 field seasons (Tanton, 1941 a,b). The Athapapuskow and Mikanagan Lakes areas were mapped on a similar scale by Buckham (1944) and Bateman and Harrison (1945). A detailed study of the structure and metamorphism of the Missi Series north and east of Flin Flon was made by Ambrose in 1934 (Ambrose 1936a,b). Kerr (1936) mapped an area around the Flin Flon Mine in great detail. In 1944 Stockwell (1960) commenced the detailed mapping of the Flin Flon–Mandy area.

Present Work

The Ledge Lake area was mapped during the 1954, 1955, and 1956 field seasons. Most mapping was done directly on enlarged air photographs on the scale of 1 inch to 500 feet. However, in areas of dense bush, conventional pace and compass traverses at intervals of 200 to 500 feet were made between base lines cut and surveyed for that purpose; elsewhere, picket lines, previously cut by mining exploration companies, were utilized. Added control for the pace and compass traverses was obtained by spotting positions on air photographs wherever possible. All information was compiled on base maps on the scale of 1 inch to 800 feet.

Physical Features

Regional

The map-area is near the southwestern margin of the Canadian Shield. This general area of the Shield has a low relief resulting from long-continued erosion. In detail, the surface of the Shield is rugged with hills and ridges separated by rivers, streams, lakes, and swampy depressions. Many of the rivers consist of a series of rock-bound, lake-like expansions joined by fast flowing rivers that have numerous rapids and falls. Characteristic of the Shield are the many lakes, ranging from small

ponds to large bodies of water 200 miles or more in length. Irregular shorelines and numerous islands with many outcrops are typical of most lakes. Depressions that are not occupied by rivers or lakes are commonly wet muskeg swamps.

In contrast to the Precambrian terrain are the areas underlain by Palaeozoic rocks, with their low relief, few lakes, and sluggish streams. A 50- to 100-foot escarpment marks part of the northern boundary of these younger rocks. The Palaeozoic rocks with their more or less uniform low dips were deposited on a Precambrian surface of low relief, probably similar to the present surface. The few Palaeozoic outliers are restricted largely to the areas adjacent to the present Palaeozoic cover.

Local

The Ledge Lake area has the low rolling topography characteristic of the larger region of the Canadian Shield. Schist Lake, with an elevation of 957 feet, is surrounded by hills and ridges that rise to about 1,100 feet. Cliffs abruptly rise on the west side and locally on the east side of the Northwest Arm of Schist Lake. The land rises more gently on the West Arm of Schist Lake except near the northwest end where almost vertical cliffs mark a prominent fault scarp.

The topography is to a large extent controlled by structure and lithology. The larger depressions, occupied by the Northwest and West Arms of Schist Lake, are striking features that are the result of fluvial and glacial erosion along fault zones. Numerous but less conspicuous depressions are present through all of the northern and eastern part of the area; many of these mark the locations of contacts or shear and fault zones. The relief is greatest where structure is parallel or subparallel with the direction of ice movement. Low relief is a characteristic feature of the broad areas of granitic rock.

Acknowledgments

This report is part of a dissertation completed at the University of Washington. Sincere thanks are due to Professors Peter Misch, H. A. Coombs, G. E. Goodspeed, and J. Vance of the Geology Department.

The writer was assisted in the field in 1954 by D. Hunter; in 1955 by Ashiq Ali, J. L. Jaworski, and A. M. Pringle; and in 1956 by A. S. Cathcart, W. Hanuschuk, and P. Podhorodeski.

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Chapter II

GENERAL GEOLOGY

Summary of Regional Geology

The Ledge Lake area is near the southwestern boundary of the Canadian Shield. Although the main mass of the Palaeozoic rocks is farther south, outliers of Ordovician dolomite are present in and near the area. Except for these Ordovician rocks all of the consolidated rocks are of Precambrian age, probably "early Precambrian" or "Archaean."

The distribution of the major rock units is shown on the generalized compilation map (Fig. 1) and comparative stratigraphic successions are given in Table I.

The Amisk Group, named by Bruce (1914) from its type locality on Amisk Lake, is considered to be the oldest rock-unit in the area. It consists of a thick assemblage of mafic[1] volcanic rocks with minor amounts of felsic volcanic rocks and some interbedded sedimentary rocks. Tanton (1941a,b), however, mapped some narrow bands of folded and schistose sediments as the oldest rocks in the area. Where these rocks were examined by the writer, they appeared to be fine-grained tuffaceous rocks interbedded with volcanic flow rocks, and, therefore, should be included in the Amisk Group. Stockwell (1960) apparently came to the same conclusion, as he also designates them Amisk pyroclastic rocks on his preliminary map. Tanton (1941a,b) regarded the greenstone assemblage (Amisk) as of mainly intrusive origin and stated "At many places the fine-grained greenstones pass gradationally into porphyritic and coarser-textured rocks." However, he did note that other geologists considered the greenstones to be volcanic rocks, chiefly lavas. Buckham (1944) described the oldest rocks as a metamorphosed assemblage of andesite and basalt flows and pyroclastic rocks interbedded with minor amounts of acid volcanic rocks, argillite, and greywacke. In the Mikanagan area, Bateman and Harrison (1945) mapped quartz-oligoclase gneiss and hornblende schist as the basal units, but they noted that the boundary between these rocks and the greenstone complex (Amisk) is indefinite. It is therefore probable that the gneiss and schist are regionally metamorphosed equivalents of the Amisk volcanic rocks. Diabase, gabbro, and diorite associated with the Amisk volcanic rocks have been described by the above mentioned workers, but the extrusive and intrusive rocks have not generally been separated. Within the Ledge Lake area these intrusive rocks are of essentially the same age as the Amisk (volcanic) Group. The age of the Amisk Group has not definitely been established, although most geologists classify

[1]Mafic rocks, as used in this report, include andesite and basalt, and their metamorphic derivatives.

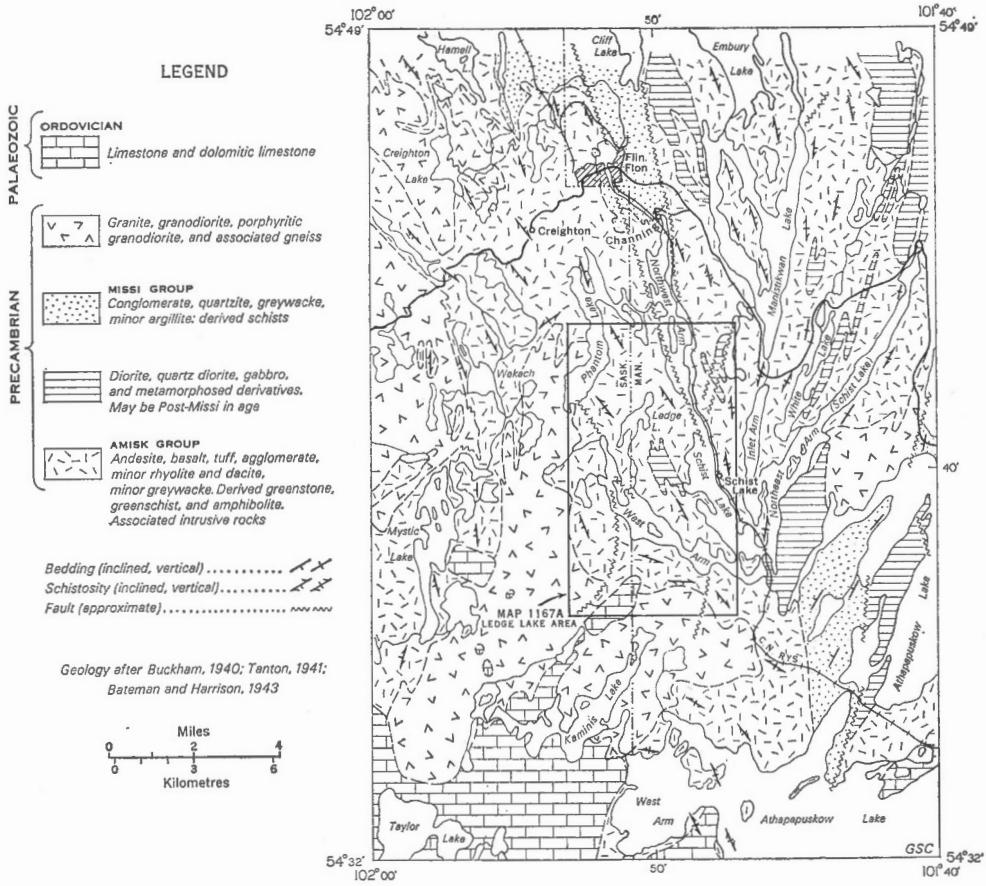

FIGURE 1. Generalized geology around the Ledge Lake area.

it as Archaean. The total thickness of the sequence is unknown as neither the base nor the top has been recognized. In the Snow Lake area, 70 miles east of Ledge Lake, Harrison (1949) estimated the Amisk volcanic rocks to be at least 30,000 feet thick. Byers and Dahlstrom (1954) calculated a thickness of 21,000 feet in the Amisk–Wildnest Lakes area west of Ledge Lake.

Conglomerate, greywacke, quartzite, and argillite of the Missi Group, and schists and gneisses derived from them, overlie the Amisk Group in several isolated areas. This unit was also named by Bruce (1914) from its type area on Missi Island in Amisk Lake, Saskatchewan. A fault or angular unconformity marks the contact in most areas, although locally the contact is conformable. Like the Amisk Group, the Missi is considered to be of Archaean age (Harrison, 1951), although some Geological Survey of Canada maps show these two units as Archaean and Proterozoic respectively. Harrison has tentatively classified the Missi Group as Archaean on the basis of structure and metamorphism, as most known Proterozoic

Table I

Comparative Stratigraphic Sections (in part after Harrison 1951)

Bruce (1918b)	Tanton (1941a,b)	Buckham (1944); Bateman and Harrison (1945)	Stockwell (1960)	Heywood (this report)
Amisk-Athapapuskow Lake District	Flin Flon and Schist Lake Areas	Athapapuskow and Mikanagan Lakes Areas	Flin Flon–Mandy Area	Ledge Lake Area
Kaminis granite Granite and allied rocks	Granite and allied rocks Basic intrusions	Boundary type intrusions Granite and allied rocks Basic intrusions	Kaminis granite Boundary intrusions Granite and allied rocks Basic intrusions	Rhyolite and dacite (?) Kaminis granodiorite Basic intrusions
Intrusive contact	Intrusive contact	Intrusive contact	Intrusive contact	Intrusive contact
Upper Missi Series: conglomerate, arkose	Greenstone complex, mainly intrusive; includes Amisk of most authors	Missi: conglomerate; clastic sedimentary rocks	Missi: conglomerate, greywacke, arkose	Missi Group: conglomerate greywacke
Unconformity				
Lower Missi Series: slate, greywacke, quartzite, conglomerate	Missi: conglomerate; clastic sedimentary rocks			
Unconformity		Unconformity	Unconformity	Unconformity
Cliff Lake granite porphyry		Granite-gneiss (?) "Quartz-eye" granite	Cliff Lake granite porphyry	Diorite and quartz diorite (may be post-Missi)
Intrusive contact		Intrusive contact	Intrusive contact	Intrusive contact
Amisk Series: basic volcanic flows and pyroclastics	Schists derived from volcanic and sedimentary rocks	Basic and acidic volcanic rocks: some clastic sedimentary rocks (not named but equals Amisk, and includes part of Lower Missi of Bruce)	Amisk Group: basic and acidic flows and pyroclastic rocks	Amisk Group: basic and acidic flows and pyroclastic rocks
	Pre-Missi sedimentary rocks			

strata in the Canadian Shield have not been strongly metamorphosed and deformed. Ambrose (1936a) gives the minimum thickness of the Missi sediments in the Flin Flon area as 5,000 to 9,000 feet.

A wide variety of plutonic rocks has intruded both the Amisk and the Missi Groups, but the relative ages of most of these intrusive rocks are unknown. Boulders ranging in composition from gabbro to granite are present in the Missi conglomerate. Bruce (1918b) related quartz porphyry boulders in the conglomerate of the Missi Group to quartz porphyry on Missi Island in Amisk Lake, and Stockwell (1960) related granite porphyry boulders in the conglomerate to the granite porphyry northwest of Manistikwan Lake where it is characterized by large bluish eyes of quartz. Within the area shown on Figure 1 a few dykes intrude the Missi rocks, and in adjoining areas diorite, quartz diorite, granodiorite, granite, and gabbro are known to be intrusive into these rocks. Therefore, there have probably been at least two major episodes of tectonic deformation accompanied by plutonic intrusions.

Summary of Local Geology

The dominant rock assemblage in the Ledge Lake area is a thick sequence of volcanic and metavolcanic rocks, which includes surface flows, pyroclastic rocks, and related intrusive diabase dykes, sills, and irregularly shaped bodies. These rocks have been intruded by plutonic rocks ranging in composition from diorite to granodiorite. The granodiorite exposed on the southern and western boundaries of the area is part of the batholith shown on the maps of Bruce (1918b), Alcock (1923), Tanton (1941a,b), and Byers and Dahlstrom (1954) Fig. 1). Diorite and quartz diorite have intruded the Amisk volcanic rocks near Hook Lake. Porphyritic quartz diorite forms a sill-like mass south of Ledge Lake.

Regional metamorphism has changed most of the volcanic rocks to greenstones and greenschists, and, adjacent to the Kaminis granodiorite, thermal metamorphism has resulted in the development of amphibolite and layered amphibolite. Narrow zones of migmatite are locally present near the intrusive contact.

The contacts between the extrusive lavas and the pyroclastic rocks are conformable. The intrusive diabase and the small plutonic units are chiefly concordant, but locally discordant. Most of the contact between the metavolcanic rocks and the Kaminis granodiorite is concordant.

Amisk Group

The Amisk Group is a thick assemblage of andesite and basalt flows, flow breccias, pyroclastic rocks, and their metamorphic equivalents. Minor amounts of rhyolite and dacite are interlayered. Clastic sedimentary rocks, common in the upper part of the Amisk Group of adjoining areas, are only exposed in one outcrop near Hook Lake. Numerous dykes, sills, and irregular bodies of diabase are probably genetically related to the extrusive rocks.

An exact determination of the thickness of the Amisk rocks in the Ledge Lake area is not possible, as metamorphism has destroyed many of the primary structures essential for the determination of tops and attitudes of beds. The maximum

estimated thickness is 17,000 feet, comprising 5,000 feet of pyroclastic rocks and 12,000 feet of flows; this total is probably high owing to repetition through folding and faulting.

In the field the various volcanic rock types have been differentiated on the basis of structure, texture, contact relations, mineralogy, and colour. Pillow, amygdaloidal, and flow structures, ropy flow tops, and flow breccia serve to distinguish many of the extrusive volcanic rocks. Of these, amygdules may be present in intrusive rocks. The extrusive rocks are generally aphanitic to fine grained and massive to porphyritic. Dykes and sills are aphanitic to medium grained; some have a diabasic texture. Many dykes and sills can only be recognized by the occurrence of chilled margins and discordant relations with the enclosing rocks. Where no intrusive features are evident, the rocks are arbitrarily included with the adjacent extrusive rocks. The andesites and basalts are dark green to buff on the weathered surface, and light to dark green on the fresh surface. Acid volcanic rocks weather grey to white, commonly brown or rusty, and are light green, greyish green or, rarely, dark green on the fresh surface.

Basic Volcanic Rocks

Porphyritic and non-porphyritic andesite and basalt and their metamorphic derivatives are the major rock types in the map-area. Numerous thin beds of tuff, agglomerate, and flow breccia, too small to show on the map, are included in this unit. Individual flows range in thickness from 5 to 100 feet, with a few as thick as 500 feet. Pillow, amygdaloidal, and flow structures are commonly well preserved but are not present in all flows. Massive and structureless rocks predominate. The grain size ranges from aphanitic to medium, the latter generally occurring in the central parts of thick flows. Although the porphyritic and non-porphyritic varieties are shown separately on the geological map, they will be described together as they have similar compositions and structures and differ only in the presence or absence of phenocrysts. Within an individual flow the phenocrysts may be large or small and numerous or rare.

The metamorphism of the volcanic rocks can be traced from almost unaltered andesite and basalt containing abundant primary minerals to schistose amphibolites consisting entirely of secondary minerals; in many places, however, vestiges of primary textures and structures have been retained.

Description

Virtually unaltered andesite and basalt occur in a few small areas within the region of the greenstone and greenschist. These massive rocks weather greenish grey to moderate brown and are greyish green to dark green on fresh surfaces. Phenocrysts of original plagioclase and augite constitute as much as 30 per cent of the porphyritic rocks. Quartz and magnetite are other primary minerals. Secondary minerals include chlorite, epidote, calcite, prehnite, and albite.

Most of the volcanic rocks have been altered to greenstone and greenschist, and south and west of the West Arm of Schist Lake the greenstone and greenschist grade into massive and schistose amphibolite towards the Kaminis granodiorite.

Greenstone and greenschist derived from aphanitic to fine-grained flow rocks consist primarily of albite, chlorite, actinolite, and epidote. The matrix generally consists of a felty mass of indeterminable alteration products so that most information on the metamorphic changes in the rock is provided by the phenocrysts. Euhedral plagioclase phenocrysts are cloudy to turbid and contain secondary albite, chlorite, epidote, and calcite. The albite forms clear rims and patches in the phenocrysts as well as in some matrix plagioclase. Dissociated remnants of augite are rarely present in aggregates of chlorite. The chlorite and a minor amount of actinolite are derived from augite.

There is almost a complete gradation from massive greenstones to foliated greenschists. One sample of a pillowed porphyritic rock, now consisting of secondary minerals, shows no superficial evidence of alteration. In thin section a weakly directional character is evident from subparallel arrangement of matrix chlorite, although phenocrysts and amygdules show no effects of deformation.

The greenschists have the same mineral composition as the greenstones. No primary minerals remain, and, where the intensity of the shearing increased, the plagioclase phenocrysts are smeared out; they are probably represented in thin section by aggregates of fine-grained albite and epidote.

The intensity of the metamorphism increases towards the Kaminis granodiorite. Actinolite and actinolitic hornblende replace chlorite as the major mafic mineral. The plagioclase ranges from An_{15} to An_{30} but shows no apparent systematic gradual rise in anorthite content.

Fine-grained amphibolites form a concentric band around the Kaminis granodiorite. The main features of these rocks are: the absence of chlorite; a marked increase in the abundance of both actinolitic hornblende and hornblende, except near the granodiorite where only the hornblende increases; a decrease in the amount of plagioclase; and a general increase in the anorthite content of the plagioclase. Porphyritic textures are well preserved in some of the massive rocks, and somewhat elongated plagioclase-rich pods probably represent plagioclase phenocrysts in the sheared rocks. No relics of pyroxene were noted. In general, crystalloblastic textures prevail and the newly formed minerals have largely cleared themselves of impurities.

In hand specimen the massive rocks are greenish black to black on both fresh and weathered surfaces, but some that contain pyrite weather various shades of brown. Pillows are locally preserved. Amygdules are numerous in some flows but absent in others.

Schistose amphibolites are greenish black on fresh surfaces, dark green to brown or orange on weathered surfaces. The mineral composition is basically the same as that of the massive amphibolites except that hornblende is the mafic mineral present; actinolitic hornblende is absent. The shearing apparently promoted a more complete chemical exchange during recrystallization.

Primary Structures in the Basic Lavas

Pillow structures, amygdules, and ropy and brecciated flow tops are the primary structures preserved in the volcanic rocks. Amygdules are widely distrib-

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uted in the extrusive volcanic rocks and are most numerous in the aphanitic and fine-grained types; they are rare or absent in medium-grained rocks. The size generally ranges from $\frac{1}{16}$ to $\frac{1}{2}$ inch in diameter, but a few are as much as 1 inch. The amygdules are composed of quartz or, rarely, calcite or chlorite.

Ropy flow tops and flow breccias were formed in the uppermost part, a few inches to a few feet, of some of the flows. The flow tops, in general even, in detail sinuous, can only be traced for a few hundred feet before they are lost in overburden or are cut off by faults. Where present, they afford excellent criteria for top and attitude determinations.

Pillow structures are clearly displayed in many clean outcrops and all details of the pillows are preserved. Individual pillows range from 6 inches to 7 feet in length. The larger pillows are of irregular shape and are mixed with pillows of all sizes. Most pillows have a rim that is finer grained and darker coloured than the central part. These chilled selvedges are $\frac{1}{2}$ to 1 inch wide. Amygdules are distributed throughout the pillows but are most abundant near the margins.

Not uncommonly, the pillows are deformed so that the ratio of length to height is increased as much as 20 to 1. In the low-grade metamorphic rocks these deformed pillows appear as narrow moderately schistose layers, 4 to 12 inches wide, separated by narrower more schistose layers, 1 inch to 2 inches wide. These deformed pillow lavas are not unlike non-pillowed lavas or fine-grained pyroclastic rocks that have numerous, widely spaced shear zones. It is only after prolonged weathering that the minor differences in the texture and colour of the rock become apparent, and only then can deformed pillows be recognized with reasonable assurance.

Pillow structures in the amphibolites are well exposed to within a few hundred feet of the Kaminis granodiorite. Some of the pillows, averaging about 18 inches in length, have not been deformed. Dark, fine-grained selvedges and numerous, quartz-filled amygdules are present in this rock. Microscopic examination reveals that the rock has a predominant hornfelsic texture, but a weak preferred orientation is marked by part of the hornblende.

Most pillows are deformed so that they are lengthened parallel with the schistosity. Almost all degrees of deformation, from a weakly deformed pillow to an intensely sheared-out pillow, can be observed. The latter type has been traced along strike into moderately deformed pillow lavas. The deformed pillows assist in determining the upper sides of the beds and all indicate that these metamorphic rocks are derived from pillowed extrusive lavas.

Porphyritic Andesite Flow Breccia

Porphyritic andesite flow breccia[1] outcrops extensively between Hook Lake and the Northwest Arm of Schist Lake; elsewhere it is rare and does not form mappable units. The flow breccia, which may be either andesite or basalt, has undergone low-grade regional metamorphism.

[1]*Flow breccia* is a type of lava flow in which fragments of solidified lava, produced by explosion or flowage, have become welded together by the still fluid parts of the same flow (after Holmes, 1920).

The flow breccia comprises up to 60 per cent angular to subrounded andesite fragments in an andesite matrix. Locally the fragments are present throughout the flow, but most commonly they occur in irregular masses within a flow unit. In part the flow rocks are pillowed, some pillows containing breccia fragments.

The andesite forming the matrix of the breccia weathers greyish green to dusky green, and is dark greenish grey to dusky green on fresh surfaces. The fragments are slightly darker than the matrix on both fresh and weathered surfaces. The matrix weathers readily and little of the glacially polished surface remains. The fragments, on the other hand, have retained their highly polished surfaces and only the amygdules were weathered out. The differences in colour and weathering reflect the differences in texture between the two elements that constitute the rock.

The andesite fragments, ½ inch to 18 inches in diameter, are aphanitic and contain a few tiny plagioclase phenocrysts. The matrix andesite in which these fragments are contained is finely phanerocrystalline and contains many plagioclase and amphibole phenocrysts. Quartz amygdules are most abundant in the fragments where they constitute as much as 25 per cent of the rock.

In thin section the matrix andesite is seen to consist of plagioclase, colourless to pale green actinolite, chlorite, epidote, and magnetite. Some plagioclase phenocrysts are saussuritized, others are cloudy and have relict albite twinning. The secondary minerals in the plagioclase, where determinable, are epidote and chlorite; calcite is segregated in some parts by the crystals. The composition of a few clear plagioclase areas, determined by comparing the index with quartz or balsam, is albite or albite-oligoclase. The amphibole is actinolite, which forms xenoblasts and fibrous aggregates. A few actinolite grains have almost perfect crystal form and appear to be pseudomorphic after primary hornblende. Chlorite and epidote are abundant throughout the rock.

Comparison of Flow Breccia and Pyroclastic Rocks

Massive flow breccia, pyroclastic breccia, and agglomerate occur in the area mapped; they are similar in gross aspect but differ in detail. They can be distinguished by a comparison of texture, structure, composition of the fragments, and, particularly, of the matrix. The flow breccia consists of rounded to subangular fragments of andesite in a matrix of andesite. Pyroclastic breccia and agglomerate are composed of rhyolitic to basaltic, angular or rounded fragments in a matrix of tuff, lapilli, or both. Where strongly sheared, flow breccia, pyroclastic breccia, and agglomerate are difficult or impossible to distinguish. The shearing first destroys the primary features of the matrix, then deforms the fragments. However, the two main types can be differentiated on the basis of the composition of the fragments; if all are the same composition, the rock was probably a flow breccia; if they are of various compositions, the rock was probably either a pyroclastic breccia or an agglomerate.

Pyroclastic Rocks

Pyroclastic rocks of the Amisk Group are widely distributed throughout the area. Tuffs, breccias, agglomerates, and their metamorphic derivatives, are massive

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to well bedded, and occur as irregularly shaped bodies, or, more commonly, as extensive, persistent layers. Tuffs, breccias, and agglomerates are interlayered to such an extent that they can seldom be separately mapped. Furthermore individual beds can be traced over one outcrop, but cannot be correlated with certainty along the strike. The thickest accumulations, attaining about 2,500 feet, are on the east side of the Northwest Arm of Schist Lake. Interlayered with these pyroclastic rocks are minor amounts of andesitic and basaltic flows. Between the two arms of Schist Lake, agglomerate and tuffs are interlayered with flows, and both have been intruded by diabase dykes and sills. Pyroclastic rocks are also present near the western and southwestern shores of the West Arm. Near the Kaminis granodiorite the pyroclastic rocks are not mappable units as their primary characteristics have been largely destroyed and they cannot be differentiated from sheared flow rocks.

The fragmental nature of bedded and massive pyroclastic rocks can best be studied on weathered surfaces; the fine-grained pyroclastic rocks are difficult to distinguish from flow rocks on freshly broken surfaces.

Tuffs

Bedded tuffs occur in layers that range from a foot to several tens of feet in thickness. Individual beds within these layers range from ⅛ inch to 3 feet, averaging about 2 inches. Graded bedding is common. Crossbedding, channel scour, and local unconformities indicate some transport. Massive tuff layers, with little or no bedding, range from a few feet to more than a hundred feet in thickness. The tuffs weather light to dark green and are olive green to greenish black on fresh surfaces.

In thin sections of the coarser tuffs subangular to subrounded particles are seen in an indeterminable matrix. Both coarse- and fine-grained tuffaceous rocks are composed almost entirely of a felty mass of secondary minerals; those minerals large enough to be identified are chlorite, epidote, calcite, fragments of quartz, and saussuritized plagioclase.

'Porphyritic' or 'crystal' tuffs are composed of angular fragments and subhedral crystals of plagioclase embedded in a tuffaceous matrix. This rock, where fine grained, has the appearance of a porphyritic lava. It may be differentiated with certainty only where it can be traced into coarser grained rock in which the fragmental nature can be observed on the weathered surface. Bedding planes and graded bedding are additional evidence of the sedimentary nature of this 'porphyritic' rock. Broken plagioclase crystals and tuff particles are evident in some thin sections.

Agglomerates

Agglomerates and breccia layers weather grey to greenish black and are olive green to greenish black on fresh surfaces. The weathering colour of the fragments is in places lighter than that of the matrix. Layers range from 1 foot to more than 400 feet in thickness. Cobble- and boulder-sized fragments range from 1¼ inches to 3 feet in diameter, averaging about 6 inches, and are set in a matrix of tuff and lapilli.

The bombs and breccia fragments vary considerably in composition and texture, although not too widely in the same bed. Two or more rock types are commonly present in the same layer. Most bombs and fragments are aphanitic with darker coloured rims that probably represent a chilled or glassy shell; others are finely phanerocrystalline, with a chilled shell. Plagioclase phenocrysts in the bombs are rare to abundant. Common rock types are porphyritic or non-porphyritic andesite, basalt, dacite, and rhyolite; almost all are amygdaloidal, but the size and concentration of the amygdules is variable. A poorly developed graded bedding is locally present, but lateral variations in grain size, if present, could not be determined.

Deformation and Metamorphism of the Pyroclastic Rocks

As the layers of fine-grained pyroclastic rocks are less competent than the volcanic flow rocks with which they alternate, they are commonly strongly sheared and folded, whereas the associated flow rocks have remained massive or, at best, been only slightly sheared near the contact with pyroclastic rocks. With greater intensity of shearing and metamorphism, amphibolites derived from the fine-grained pyroclastic rocks become indistinguishable from those derived from flow rocks.

The coarse-grained pyroclastic rocks, including agglomerate and breccia, are also deformed. Not uncommonly the matrix is schistose, but the bombs and fragments, although deformed and stretched, still retain primary textural features.

The metamorphism and the metamorphic minerals present in the pyroclastic rocks are similar to those in the associated flow rocks.

In the low-grade zone of regional metamorphism the characteristic minerals developed in the pyroclastic rocks are albite, epidote, and chlorite. Tuffs could not be positively identified in the medium-grade zone. It is probable that tuffaceous rocks were present but deformation and recrystallization have resulted in the development of textures and structures identical to those in the metamorphic flow rocks. Agglomerates, on the other hand, can be recognized. They occur to within a few hundred feet of the Kaminis granodiorite. Fragments are deformed and the rocks are now schistose amphibolites. The mineral assemblages are similar to those in the associated metamorphosed flow rocks; that is, they are characterized by the presence of andesine, hornblende, and epidote.

Clastic Sedimentary Rocks

Clastic sedimentary rocks of the Amisk Group are present only near the northwest end of Hook Lake. There a massive pebble-conglomerate lens, 15 feet thick, making an outcrop belt 50 feet wide, is interlayered with volcanic flow rocks. The conglomerate is dark greyish green on the fresh surface and lighter green on the weathered surface. In thin section subrounded fragments of basalt, porphyritic basalt, and minor dacite are seen to form about 50 per cent of the rock. The pebbles reach 10 mm and average 4 mm in diameter. The matrix consists of about 10 per cent of subrounded to subangular quartz and oligoclase-andesine grains set in an aphanitic felty mass in which chlorite is the only determinable mineral.

Rhyolite and Related Rocks

Rhyolite and related silicic rocks are similar in gross aspect but differ in texture, structure and, to a lesser extent, composition. They occur as dykes, sills, and sheet-like intrusions ranging from less than 1 foot to 1,400 feet wide and are as much as 7,500 feet long. These rocks are massive to layered, aphanitic to fine grained, and commonly contain phenocrysts of quartz and/or feldspar. Shearing has locally resulted in the formation of crush breccia, mylonite, and quartz-sericite schist.

Layering, contorted layering, and concentrically layered elliptical structures are present in many localities in the Ledge Lake area. In unsheared rocks these structures appear to be primary flow features that have been enlarged and exaggerated by weathering. The layering manifests itself by differences in texture, composition, and concentration of phenocrysts. The layers, as much as an inch thick, resemble bedding but are not fragmental and die out along strike.

Description of Rhyolite and Related Rocks

A grey to reddish brown weathering porphyritic rhyolite forms a 50- to 75-foot cliff at the northwestern end of the West Arm of Schist Lake. This rock is exposed for a distance of 7,500 feet, and its outcrop has a maximum width of 1,400 feet. A similar rhyolite occurs on the peninsula 2,000 feet south of this main outcrop, and is probably a continuation of the same unit. The rock is aphanitic, with sparse to abundant phenocrysts of quartz, plagioclase, and hornblende. No primary structures are preserved, but some poorly defined elliptical to concentric structures are present near the south end of the main mass. Most of this rock is strongly sheared, and some is mylonitized. Where the shearing has been most intense the rock is thinly layered; however, this structure is obvious only on clean, weathered surfaces. Individual layers do not extend for more than a few tens of feet, and, when not brought out by weathering, they can be traced for only a few inches.

In thin section the rhyolite is seen to consist of quartz, plagioclase, and hornblende phenocrysts in a phanerocrystalline matrix of the same minerals.

Where the rock has been mylonitized the original features of the rhyolites are obliterated except for sheared-out quartz phenocrysts; however, there is little doubt about the continuity between the relatively more massive to less extremely sheared rhyolites and the mylonitized varieties. The cataclastic nature of this rock is evident in thin section. Biotite and hornblende phenocrysts are drawn out parallel with the schistosity and are altered to chlorite with minor epidote and magnetite. Quartz eyes, 1 to 4 mm long, consisting of a strained sutured quartz mosaic, are crushed quartz phenocrysts. In their central part, the grains average 0.7 mm in diameter, and, in their marginal parts, 0.1 mm. Irregular to lensoid, fine-grained, quartz patches up to 6 mm long are probably of the same origin. The delicate foliation, as seen in thin section, is irregular and discontinuous, and is formed by concentrations of dark and light coloured minerals, respectively. These folia flow around the crushed quartz phenocrysts.

Rhyolite and porphyritic rhyolite dykes, sills, and irregularly shaped bodies are exposed northwest of Ledge Lake. The porphyritic rhyolite is an olive-grey, pink weathering, fine-grained to aphanitic rock containing phenocrysts of quartz, plagioclase, and minor orthoclase. The matrix is a fine-grained to microcrystalline aggregate of quartz, feldspar, and chlorite derived from biotite. Minor hornblende is also present. Planar flow structures, in part contorted, are locally bevelled to produce surfaces exhibiting concentric structures up to 5 feet in diameter. The flow structure has been emphasized by differential weathering that first concentrated along mafic-rich layers and then the marginal portions of the adjacent felsic layers.

Fine-grained rhyolite containing a few small widely scattered phenocrysts occurs on the southwestern side of the above described porphyritic rhyolite. The groundmass has a crystalloblastic texture, possibly formed by recrystallization of an original glassy matrix. Layering and elliptical structures are similar to those described above.

Many small sills and dykes occur between the West Arm and the Kaminis granodiorite. Most of the wider sills and dykes have discontinuous flow structures and an elliptical structure is present in one dyke.

Quartz-sericite Schist

Quartz-sericite schist outcrops on the two peninsulas on the west side of the Northwest Arm of Schist Lake, on one of the islands between these peninsulas, and on the peninsula near the south end of the West Arm. The original textures and structures are almost completely destroyed but the primary character of the rock is displayed in a few crushed, angular to subrounded fragments of porphyritic rhyolite in the quartz-sericite schist.

The quartz-sericite schist is a fine-grained, pinkish grey rock that contains round quartz grains as large as 2 mm. Sericite plates are conspicuous on fresh surfaces. In thin section this rock is seen to consist of round to lenticular aggregates of fine-grained quartz in a strongly schistose matrix composed of quartz, untwinned plagioclase, sericite, minor chlorite, and calcite. The plagioclase is clear to slightly cloudy; its composition, determined by comparing the index of refraction with quartz and balsam, is albite. Xenoblastic sericite and chlorite are oriented parallel with the schistosity.

Deformation of the Rhyolitic Rocks

Field examination and thin section study show the stages of crushing of the fine-grained porphyritic rhyolite. First, the rock was fractured, and a breccia of angular fragments of all sizes resulted. During this stage mortar structure was formed around the fragment. As deformation became more intense, closely spaced shear zones were developed and increased in width at the expense of the unsheared material. The final product is a mylonite, containing eye-shaped quartz aggregates; feldspar has survived this intense deformation only as thin lensoid streaks.

Some recrystallization and small scale metamorphic differentiation have occurred in the mylonites. The layers are 1 to 10 mm thick, and are characterized

by abundant light or dark minerals. These are probably remnants of an original layering in the rock as they are not present everywhere. Recrystallization of the quartz-rich layers is shown by coarser and sutured crystalloblastic textures. These cataclastic layers have textures similar to those of the quartz porphyroclasts, which have coarser grained cores and finer grained borders. Chlorite, biotite, and hornblende are aligned parallel with the layering.

Petrogenesis of the Rhyolitic Rocks

The petrogenesis of the rhyolite primarily involves determining whether the rock is extrusive or intrusive. Conclusions regarding this problem are based on field evidence supplemented by thin section examination.

Some of the small tabular bodies have discordant contacts with the metavolcanic rocks and are therefore considered dykes. Concordant tabular plutons of composition identical to that of the dykes are probably sills. The large sill-like plutons on the northwestern side of the West Arm of Schist Lake and between Ledge and Phantom Lakes are more difficult to classify because their contacts with the mafic metavolcanic rocks are either poorly exposed or sheared, and primary textures and structures, if ever present, do not show.

The internal structure of these large sill-like plutons, like the contact relationships, fail to provide any positive evidence as to their origin. A few layers, more fine-grained than most, are present, but die out along strike and therefore are not considered contacts, hence they have no petrographic significance. The elliptical structures have previously been shown to be flow phenomena due to differential rates of movement in a confined space such as that occupied by a dyke or sill. None of the distinguishing primary structures of tuffs, ignimbrites, or volcanic flow rocks are present. Such structures could not have been destroyed by metamorphism in these localities because the bordering and older basic volcanic rocks still have well preserved primary structures and these must have undergone similar metamorphic action. The only conclusion is that the rhyolite never had any primary structures. The occurrence of some rhyolite as dykes, locally with elliptical structures, the similarity of lithology, and the absence of any primary structures common to tuffs, ignimbrites, and lavas lead to the conclusion that the large sill-like plutons are also intrusive rocks, probably derived from the same source as the small discordant dykes.

Age of the Rhyolitic Rocks

Rhyolite and related acidic rocks have been grouped with the Amisk volcanic rocks (Stockwell, 1960; Byers and Dahlstrom, 1954); however, in the Ledge Lake area there is evidence that they are of two widely separated ages. Near the western boundary of the area rhyolite dykes and sills have intruded amphibolitic rocks of the Amisk Group, but the rhyolites are not metamorphosed to the same degree as the amphibolites. This suggests that they are younger than the amphibolites and hence younger than the Kaminis granodiorite. Near the northwest corner of the area porphyritic rhyolite is intruded by porphyritic granodiorite dykes similar in texture and composition to the large mass of porphyritic granodiorite, indicating that this

rhyolite is probably older than both the porphyritic and the foliated granodiorite. For the most part there is no conclusive evidence as to the age of the rhyolitic rocks.

Diabase

Diabase dykes, sills, and irregularly shaped bodies are most common in the western half of the area. They range from a few to about 1,000 feet in thickness, and can be traced along the strike for as much as 12,000 feet. Many of the diabase bodies appear to end abruptly but their terminations are not exposed. It could not be ascertained, therefore, whether the diabase bodies lens out in a few tens of feet, whether they are continuous and offset into another horizon of the volcanic sequence, or whether they are terminated by a fault. There is no evidence of faulting.

The diabasic rocks may be of different ages but, because of their petrographic similarities, they have been mapped together. Most, if not all, are probably related to the Amisk flow rocks.

East of Phantom Lake and the West Arm of Schist Lake the diabase rocks have undergone low-grade regional metamorphism, although in places they are relatively unaltered. In the southern and western parts of the area diabases have been converted to massive and schistose amphibolites by thermal metamorphism resulting from the intrusion of the Kaminis granodiorite.

Massive, almost unaltered diabase occurs in a few areas scattered within the region of the low-grade regionally metamorphosed volcanic rocks. Primary plagioclase has been decalcified, but pyroxene has remained fresh or, at best, been somewhat chloritized at the margins. Ophitic and subophitic textures are clearly conspicuous. The original composition of the diabase, as determined by modal analyses of relict minerals whose original distribution is suggested by preserved ophitic textures, is approximately as follows: quartz, 5 per cent; plagioclase, 43 per cent; augite, 52 per cent; and a small amount of magnetite. Most of the diabase has been altered to greenstone, greenschist, or massive to schistose amphibolite.

Plutonic Rocks

Plutonic rocks, ranging in composition from diorite to granodiorite, have intruded the Amisk volcanic rocks. The textures, structures, and relation of these intrusive rocks with the Amisk volcanic rocks suggest that the intrusions occurred at different periods.

Sill-like stocks of diorite and quartz diorite southeast of Ledge Lake and on the west side of Hook Lake have been subjected to low-grade regional metamorphism, with the development of new mineral assemblages similar to those occurring in the metamorphosed Amisk volcanic rocks. These rocks are therefore classified as pre-metamorphic and, by implication, pre-tectonic; however, their relative ages are not known.

The name 'Kaminis granite' was originally used by Bruce (1918a) for the plutonic rocks occurring in the area bounded by Kaminis Lake, Mystic Lake, and

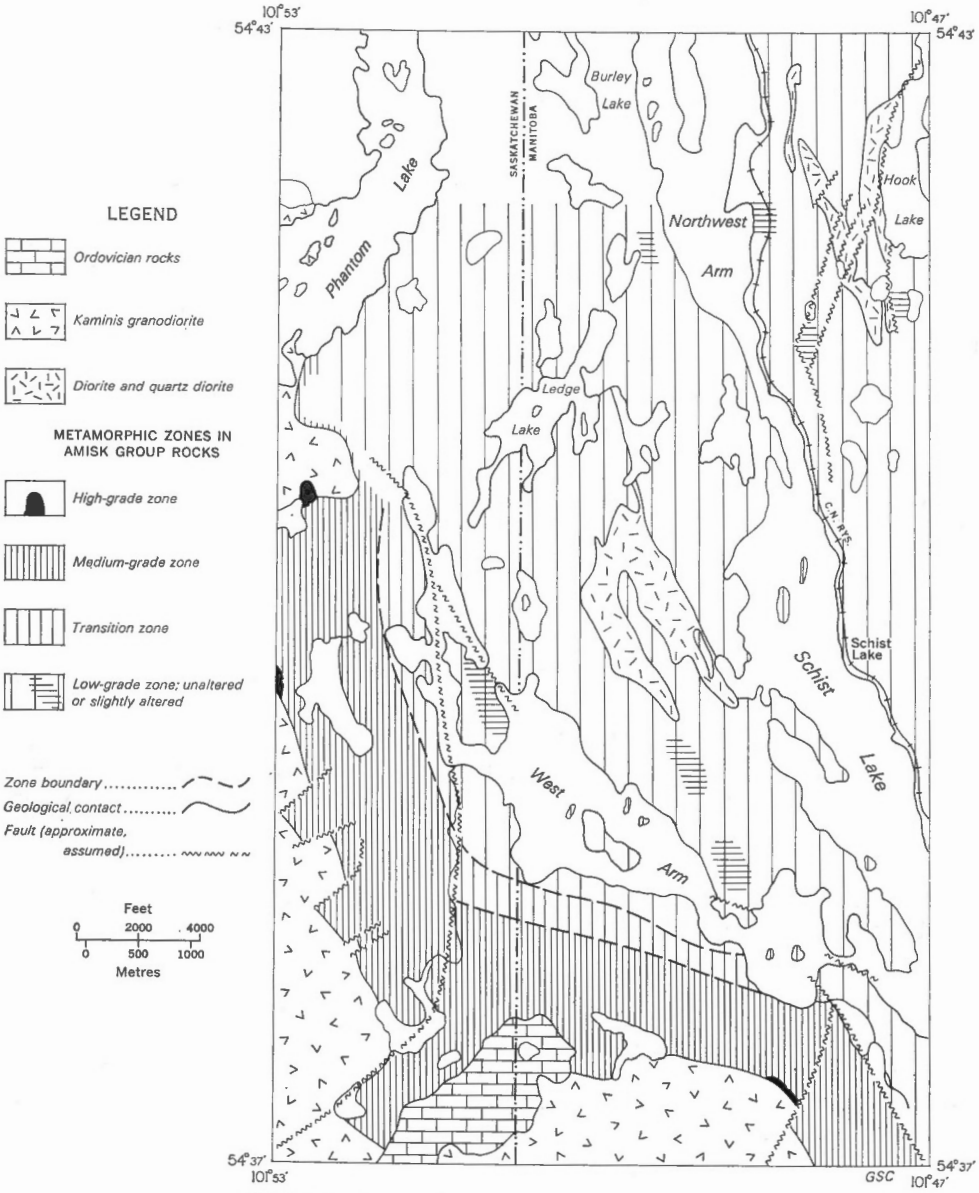

FIGURE 2. Metamorphic zones in the Ledge Lake area.

Phantom Lake (Fig. 2). Three phases, all granodiorite[1], have been mapped in the Ledge Lake area. Syntectonic biotite and hornblende-biotite phases occur in the southern and southwestern parts of the area. A late or post-tectonic phase occurs

[1]Called the Kaminis granodiorite in this report in recognition of their composition. They are part of the plutonic rocks named 'Kaminis granite' by Bruce (1918a).

south and west of Phantom Lake. Both phases contain similar mineral suites, but they differ in that the syntectonic phase is foliated and massive, whereas the late or post-tectonic phase is massive and porphyritic.

Quartz Diorite

Distribution and Contact Relations

Quartz diorite outcrops south of Ledge Lake and west of the Northwest Arm of Schist Lake. Related sills occur north and south of the main body of quartz diorite.

Although the original minerals are considerably altered, the rock is classified as quartz diorite because it contains more than 10 per cent quartz, and the feldspars, as far as can be determined, are plagioclase.

The contact between the quartz diorite and the Amisk volcanic rocks is poorly exposed. Near the southern end of the eastern outcrop band, pillowed flow rocks are in contact with fine-grained quartz diorite containing scattered plagioclase phenocrysts. Elsewhere the contact rocks are sheared or crushed and no primary relations can be determined. Contacts between satellitic dykes and sills and the volcanic rocks are well exposed. These contacts are sharp and only a narrow chilled selvedge is present. There is no evidence that the quartz diorite metamorphosed the enclosing volcanic rocks and, if this metamorphism was ever present, it has been completely masked by the later, low-grade, regional metamorphism. The quartz diorite contains secondary minerals, similar to those in the adjacent Amisk volcanic rocks, which are representative of low-grade regionally metamorphic rocks.

Description and Age

The quartz diorite is a grey weathering, pink to grey, medium- to fine-grained, equigranular to porphyritic rock. Diorite phases containing little or no quartz are locally present near the contact with the Amisk volcanic rocks. Quartz, plagioclase, epidote, biotite, and chlorite are the main minerals. The results of point-count analyses are given below.

Table II

Mineral Composition of the Quartz Diorite

	Volume %	
	Average	Range
Quartz	31	21–46
Plagioclase	48	26–60
Biotite and chlorite	14	9–24
Epidote	5	2–8
Accessory minerals	2	

Subhedral to euhedral plagioclase phenocrysts and anhedral grains in the matrix are partly to entirely altered with the development of calcite, epidote, sericite, and a minor amount of chlorite. The composition ranges from sodic oligoclase to andesine.

The mafic constituents are almost completely altered to aggregates of chlorite, epidote, sericite, calcite, and magnetite. Weakly birefringent patches of incompletely altered brown biotite occur in some of the chlorite masses; other masses appear to be pseudomorphic after subhedral biotite. Epidote commonly occurs as rims around, and inclusions in, the chlorite. Epidote also forms skeletal porphyroblasts with inclusions of quartz, sericite, and chlorite. Calcite occurs in and around plagioclase crystals, in the matrix, and closely associated with the chlorite derived from the mafic constituents.

Minor accessories include apatite, sphene, and a radioactive material that has formed pleochroic haloes in the chlorite.

The age of the quartz diorite near Ledge Lake is not definitely known. The degree of metamorphism suggests that it is older than the Kaminis granodiorite. The relation to the diorite and quartz diorite near Hook Lake is not known as these two units are not in contact.

Diorite and Quartz Diorite

Distribution and Contact Relations

Diorite and quartz diorite form two outcrop bands on the west side of Hook Lake virtually parallel with the trend of the Amisk metavolcanic rocks. Most of the contact is covered in a series of discontinuous linear valleys. Where exposed, the rocks in the contact area are sheared and faulted. On the east side of the stock, sheared rocks on either side of the contact are similar both texturally and mineralogically. On the western and southwestern boundaries, the diorite and quartz diorite grade into saussuritized, fine-grained porphyritic rock not unlike the metamorphosed, porphyritic, Amisk metavolcanic rocks.

The diorite and quartz diorite west of Hook Lake are considered to be premetamorphic, having intruded the Amisk volcanic rocks prior to or during their folding and metamorphism. The mineral composition of the two groups of rocks indicates that they have been subjected to the same metamorphism.

Description

The diorite and quartz diorite are mottled grey to light brown on weathered surfaces and grey to dark grey on fresh surfaces. They are generally medium grained, but locally they are either fine or coarse grained. In general, the rock is massive but in a few areas it is layered. These layers, ½ inch to 2 inches thick, are composed of alternating amphibole-rich and feldspar-rich rock. The diorite and quartz diorite were not separated in the field because much of the quartz is too fine

grained to be recognized in hand specimens. The range and average volume percentages of the major minerals are given in the following table:

Table III

Mineral Composition of the Diorite and Quartz Diorite

	Diorite (volume %)		Quartz diorite (volume %)	
	Average	Range	Average	Range
Quartz	2	0–6	11	10–12
Plagioclase	57	50–63	55	49–60
Pyroxene	1	0–3	5	0–10
Actinolite	37	28–48	26	18–34
Accessory minerals	3		3	

Grey to white weathering plagioclase occurs as anhedral to subhedral crystals. Microscopic examination reveals the alteration of the feldspar to a brownish, almost opaque mass of aphanitic to fine-grained secondary minerals. Reliable determinations of the original composition are not possible, but in three specimens extinction angles indicated an andesine composition. Considering the degree of alteration, it is probable that these are partly decalcified remnants of the original plagioclase. The present mineral composition of the rock, as well as that of the enclosing volcanic rocks, suggests that the grade of metamorphism was not high enough to produce andesine. Faint zoning and twinning are marked by changes in concentrations of the various alteration products. Although most of the alteration products are too fine grained for determination, chlorite, sericite, epidote, and calcite can be recognized.

Actinolite and actinolitic hornblende occur as poikiloblastic crystals and aggregates of smaller grains. These amphiboles are derived from pyroxene, as relics of augite are present in about half the specimens examined. Relict cleavage and fracture patterns of the pyroxene are marked by fine-grained magnetite and a dark, opaque mineral in many of the aggregates of secondary minerals.

Kaminis Granodiorite

The Kaminis granodiorite outcrops in the southern and western parts of the Ledge Lake area. It has intruded and metamorphosed the Amisk volcanic rocks and, north of the area, intruded the Missi sedimentary rocks. Within the area mapped the Kaminis granodiorite has been divided into three units: hornblende granodiorite in the southern part, biotite-hornblende granodiorite in the western part, and porphyritic granodiorite in the northwestern part. The first two units are similar in structure, mineral content, and mode of occurrence; they probably are genetically related and do not differ much in age. They differ in texture, composition, and in their contact relations with the metavolcanic rocks. The porphyritic granodiorite is generally similar in composition to the other two units, but differs in texture and structure.

Hornblende Granodiorite

Distribution and Contact Relations

The hornblende granodiorite occurs near the southern boundary of the Ledge Lake area. There the relief is low and exposures are separated by broad areas of muskeg; such outcrops as are present, however, are clean.

The contact between the hornblende granodiorite and the Amisk metavolcanic rocks is exposed only in two areas: at the southern end of a small lake on the eastern side of the provincial boundary, and near the southeastern corner of the map-area. Near the contact the granodiorite changes from pink to grey, and the amount of mafic minerals increases. The percentage of inclusions increases from less than 1 to more than 50 per cent and these inclusions display all degrees of alteration. The contact is gradational through a narrow zone of migmatitic rocks. The planar structure in the granodiorite is parallel with the schistosity in the metamorphosed volcanic rocks.

Description

The hornblende granodiorite is pinkish grey to grey on the fresh surface and pink to grey on the weathered surface. It is commonly medium grained and equigranular, although locally it is either fine or coarse grained. Quartz, grey to white plagioclase, pink microcline, and hornblende are the major constituents. Minor amounts of biotite are locally present.

Plagioclase ranges in composition from An_{10} to An_{38} but averages about An_{25}. Oscillatory and normal zoning are universally present. The zoned plagioclase has a core of altered calcic oligoclase or, rarely, andesine, and the zones usually differ less than 10 per cent in anorthite content. Clear albite or albite-oligoclase commonly forms narrow rims around the plagioclase. In many crystals the zoning has been largely destroyed, and is now marked only by zones of micro-inclusions. The twinning is best developed in peripheral parts of zoned crystals, but is present throughout some unzoned crystals. Most of the altered zoned crystals are partly twinned.

Poikilitic microcline grains, as much as 4 mm in diameter, contain all other minerals as inclusions. The matrix microcline forms discrete grains and anastomosing masses that replace plagioclase and quartz. The replacement of plagioclase occurs along cleavages and intergranular boundaries. Deeply embayed and separated remnants of optically continuous plagioclase form islands in the microcline.

Hornblende, the major mafic constituent, is chiefly subhedral but euhedral and anhedral crystals are common. Many hornblende crystals poikilitically include quartz and magnetite. Biotite locally replaces or surrounds the hornblende. In a few thin sections examined, the hornblende is partly chloritized.

Biotite is present in all specimens but exceeds 3 per cent in only one specimen examined. Brown biotite is interlaminated with a strongly pleochroic green variety, which is partly chloritized.

Table IV

Mineral Composition of the Hornblende Granodiorite and Biotite-Hornblende Granodiorite

	Hornblende granodiorite (volume %)		Biotite-hornblende granodiorite (volume %)	
	Average	Range	Average	Range
Quartz	19	10–36	19	12–26
Plagioclase	51	40–57	47	38–55
Microcline	15	8–31	13	5–20
Hornblende	12	8–21	10	3–23
Biotite	2	0–12	10	5–15
Accessory minerals	1		1	

Accessory minerals are magnetite, apatite, sphene, and zircon. Chlorite, epidote, and sericite are alteration products.

Biotite-Hornblende Granodiorite

Distribution and Contact Relations

Biotite-hornblende granodiorite occurs along the western boundary of the map-area. The contact with the metavolcanic rocks is well exposed in many areas. Locally the contact is sharp; within a few inches to a few feet of the contact the mafic content of the granodiorite is slightly higher and the grain size is finer. Rotated angular and rounded inclusions are present near these sharp contacts, but there is no marked increase in amount of inclusions. In part, the contact is a wider, inclusion-rich to migmatitic zone.

Description

Typical biotite-hornblende granodiorite is medium grained and equigranular, and pink, grey, or pinkish grey on weathered and fresh surfaces. There is no apparent pattern to the colour distribution. The texture is dominantly granoblastic, but a few specimens show some cataclasis. These partly cataclastic rocks have textures that are somewhat hypidiomorphic-granular or granitoid, but crystalloblastic minerals are common.

Anhedral quartz occurs as interstitial grains and groups of grains with sutured contacts. Subhedral to anhedral plagioclase crystals range from 0.5 to 4 mm in length, but average about 1 mm. The composition ranges from An_{10} to An_{30}, averaging about An_{25}. In some specimens the plagioclase has a cloudy to mottled core containing abundant microcrystalline sericite and minor amounts of calcite and epidote. Around these altered cores there are narrow rims of clear sodic oligoclase. Zoning is rare and, if present, generally faint. The few crystals that are well zoned have calcic cores and sodic rims.

Microcline is interstitial to the earlier formed minerals. Anhedral grains contain inclusions of plagioclase, quartz, hornblende, and magnetite. Staining of the potassium feldspar shows that it occurs as discrete grains, anastomosing masses, and replacements in the plagioclase.

Biotite is the characteristic mineral of the crystalloblastic biotite-hornblende granodiorite. Brown and brownish yellow biotite is commonly altered to a weakly birefringent, strongly pleochroic, green biotite, which is interlaminated with the brown biotite, encloses it, or completely replaces it. Much of the green biotite is chloritized.

Anhedral green hornblende grains contain abundant round quartz inclusions, which are either randomly distributed or concentrated in irregular zones in the marginal part of the hornblende. A few hornblende crystals contain an inner zone of fine-grained magnetite and quartz; this zone encloses a paler green hornblende and relict pyroxene. In several specimens the hornblende has a pale green core bounded by a zone of magnetite grains that apparently outline former pyroxene crystals. Other hornblende grains are of uniform composition but many of them contain numerous tiny grains of magnetite and round blebs of quartz. Calcite is commonly associated with the quartz and magnetite in the pale green hornblende in the core. The calcium, silica, iron, and most, if not all, of the poikilitic hornblende may be derived from the alteration of pyroxene to hornblende. Biotite replaces the hornblende and partly to completely surrounds it. Chlorite in and around the hornblende is probably an alteration product of this biotite.

Epidote occurs as inclusions in the biotite and plagioclase, and is associated with magnetite in the intergranular parts of the rock.

Accessory minerals are magnetite, apatite, sphene, calcite, zircon, and an unidentified radioactive material.

Foliation and Lineation

Foliation is best developed in the marginal areas of the granodiorite. This structure is formed by a planar arrangement of biotite and/or hornblende, generally in a random orientation in the plane of foliation. Plagioclase laths and lensoid aggregates of quartz accentuate the foliation. Lineations are poorly developed; where present they are revealed by hornblende crystals and elongate inclusions.

Inclusions

Inclusions are present in nearly every outcrop of granodiorite. They generally constitute less than 1 per cent of the rock although they may comprise 50 per cent or more of the rock near the contact with the metavolcanic rocks. Angular and rounded inclusions occur in a few outcrops, but most of the inclusions are flattened ellipsoids, ¼ inch to 6 inches wide and ½ inch to 12 inches long. Streaks of mafic material are rare and where present appear to be plastically deformed inclusions. The flattened ellipsoidal inclusions and the streaks are oriented parallel with the planar structure of the granodiorite.

The inclusions range widely in composition, texture, and degree of alteration and assimilation. Within a single outcrop the inclusions range from sharply bordered fine-grained amphibolite fragments to almost completely assimilated shadow-like remnants.

The fine-grained inclusions are almost identical in texture and composition with the schistose amphibolites derived from the Amisk volcanic rocks. The inclusions consist of 60 to 70 per cent subidioblastic hornblende, 20 to 25 per cent xenoblastic oligoclase or andesine, and accessory minerals biotite, magnetite, epidote, sphene, and quartz. Their contact with the granodiorite is generally sharp, but locally gradational owing to assimilation. A few plagioclase crystals of the granodiorite extend into and include some of the fine-grained oriented hornblende of the inclusion.

Layered amphibolite inclusions are abundant. Microcline has replaced some of the plagioclase in the leucocratic layers where it forms 2 to 3 per cent of the rock; lesser amounts of microcline occur in the melanocratic layers.

The shadow-like remnants approach the granodiorite in composition, but still contain more mafic minerals and less microcline. They are generally finer grained and maintain a stronger schistosity than the granodiorite.

Petrogenesis of the Hornblende and Biotite-Hornblende Granodiorite

The biotite-hornblende granodiorite and the hornblende granodiorite mapped in the Ledge Lake area are part of a large concordant pluton (Fig. 1) that has a wide range in textural and structural features. Petrogenetically pertinent data may be listed as follows:

	Biotite-hornblende granodiorite	Hornblende granodiorite
(1)	Crystalloblastic textures	Hypidiomorphic textures
(2)	Xenoblastic hornblende	Subhedral hornblende
(3)	Plagioclase twinned and zoned	Plagioclase twinned, but little or no zoning
(4)	Average biotite content is 9 per cent	Average biotite content is 2 per cent
(5)	Contact with Amisk metavolcanic rocks is sharp in places, gradational elsewhere	Contact with Amisk metavolcanic rocks is gradational through a migmatitic zone
(6)	Planar structures well developed	Planar structures moderately well developed
(7)	Lineation moderately well developed	Lineation moderately well developed
(8)	Planar structures in both units are parallel with the contact between the granodiorite and the wall rocks	
(9)	Quartz and microcline are present in similar amounts in both units	
(10)	Distribution and alteration of inclusions about the same in both units	

Mineralogical and structural similarities and spatial relationships suggest a common origin for the two granodiorite phases. The planar structures in the granodiorite are parallel with the schistosity in the Amisk metavolcanic rocks. Lineations in the wall rocks and in the pluton are likewise parallel, although the data on lineations in both rocks are still sketchy. The schistosity and planar structure could have been formed by deformation before, during, or after emplacement of the granodiorite. It is most probable that the schistosity in the volcanic rocks was formed before or during the emplacement of the granodiorite. Evidence for this is found in the schistose inclusions that are aligned and rotated with regard to the planar structures in the hornblende granodiorite and in the biotite-hornblende granodiorite. The conclusion is that the two phases were intruded at the same time, and it is highly probable that they are derived from the same source.

The contrast in texture and, to a lesser extent, in mineral composition presents a greater problem. The two granodiorite phases are separated by a fault, and the dissimilarities may represent a variation in the degree of deuteric reaction with residual solutions owing to a difference in depth at which the magma cooled on opposite sides of the fault.

The hypidiomorphic-granular textures of the hornblende granodiorite suggest that there was little deuteric reaction between the granodiorite and the residual solutions; late microcline replacement is the only deuteric feature. In the granoblastic biotite-hornblende granodiorite, on the other hand, the residual solutions did not, or could not, escape so readily. The result was marked deuteric recrystallization, and a slightly greater replacement of the magmatic minerals. This probably indicates that the biotite-hornblende granodiorite cooled at a greater depth.

Porphyritic Granodiorite

Distribution and Contact Relations

Porphyritic granodiorite outcrops on the southwestern side of Phantom Lake and on several islands in the lake. Sills and dykes as wide as 60 feet have intruded the Amisk volcanic rocks in the northern half of the area, and are most numerous between Ledge and Phantom Lakes. These sills and dykes are similar in texture and composition to the main mass of porphyritic granodiorite.

The contact between the Kaminis granodiorite and the porphyritic granodiorite, where exposed, is sharp, and inclusions of Kaminis granodiorite are present in the porphyritic granodiorite. Dykes of the porphyritic granodiorite have intruded the Kaminis granodiorite in the contact area, but none are known to extend for more than 50 feet from the contact. The dykes display chilled selvedges, $\frac{1}{16}$- to $\frac{1}{8}$-inch wide. The contact with the Amisk volcanics is not exposed.

Description

Pink microcline phenocrysts, as much as 2½ inches long, comprise 15 to 20 per cent of the rock. The massive, medium-grained matrix consists of quartz, plagioclase, hornblende, biotite, and microcline. Accessory minerals are apatite,

magnetite, sphene, and epidote. Chlorite and calcite are alteration minerals. The average and range in volume per cent of the major constituents of a number of samples are given in the following table.

Table V

Mineral Composition of the Porphyritic Granodiorite

	Volume %	
	Average	Range
Quartz	19	13–24
Plagioclase	50	39–57
Microcline	23	17–35
Hornblende	2	0–9
Biotite	4	1–6
Accessory minerals	2	

Anhedral quartz grains range from 0.1 to 4.0 mm in diameter. All of the larger and many of the smaller grains show undulatory extinction. Subhedral plagioclase crystals, averaging about 3 mm in length, are calcic oligoclase, about An_{28}. Oscillatory zoning or twinning is present in most crystals; the well zoned crystals generally display poorly developed twinning. In some specimens the plagioclase is cloudy or turbid and contains numerous tiny sericite flakes. A small amount of epidote and rare calcite occurs in the most strongly altered crystals. Most of the altered grains have a distinct but discontinuous rim of clear albite. The outer border of this rim is irregular. This late albite is probably in part related to the alteration of the plagioclase.

Potassium feldspar forms irregularly shaped grains and poikilitic, subhedral to euhedral phenocrysts in the matrix. Most of the feldspar displays microcline grid twinning. The matrix microcline is interstitial to all other minerals and has irregularly replaced the plagioclase. Some plagioclase contains large microcline embayments; elsewhere the microcline occurs as tiny anhedral grains within the plagioclase, or it may entirely replace the central part of the grain. Almost all of the phenocrysts are microcline-microperthite. Although in gross appearance the phenocrysts are euhedral or subhedral, in detail their boundaries are quite irregular. Fingers of the microcline extend into the matrix and replace some plagioclase. Inclusions of quartz, plagioclase, biotite, and, rarely, hornblende in the microcline show little evidence of replacement. The plagioclase and hornblende inclusions are subhedral, the biotite anhedral, and the quartz occurs in rounded blebs.

Ragged brown biotite grains contain magnetite and quartz inclusions. In some specimens this brown biotite is partly altered to green biotite; in others it is completely altered to green biotite and chlorite.

Hornblende is uncommon, although locally it forms as much as 9 per cent of the rock. Euhedral and subhedral crystals, as long as 2 mm, are partly altered to biotite.

Migmatitic Rocks

Migmatitic rocks[1] occur locally between the Kaminis granodiorite and the metamorphosed volcanic rocks. Where present, they form a zone of mixed rocks generally 20 to 200 feet wide.

The normally grey or pink granodiorite becomes progressively darker near the contact area. Inclusions, which elsewhere form 0.5 to 1 per cent of the granodiorite increase in number until they constitute more than 50 per cent of the rock. These inclusions provide a well foliated rock, which merges with a gneissic rock that consists of narrow granitic layers and streaks and locally contains a few relatively unaltered inclusions. The gneiss is in contact with layered and schistose amphibolite.

Although the general change is as described above, the sequence is not a continuous one. Medium-grained granodiorite sills are present in both the inclusion zone and the gneiss; their contacts are not sharp, but they are abruptly gradational over a few inches. Large blocks, as much as several feet wide and several tens of feet long, of layered or schistose amphibolite occur in the gneissic zone.

No single specimen can be considered representative in the mixed zone. The two extremes in composition, granodiorite and amphibolite, do not differ from those previously described. The minerals present in the mixed zone are quartz, plagioclase, microcline, hornblende, and biotite. Accessory minerals are magnetite, sphene, and apatite, and alteration minerals are epidote, chlorite, sericite, and calcite.

Quartz constitutes 5 to 30 per cent of the rock. It is most abundant in the leucocratic layers of the gneiss, commonly within a few feet of the massive to layered amphibolites forming the wall rocks. Xenoblastic grains reach 5 mm in length and are strained.

Plagioclase forms 36 to 51 per cent of the rock. The composition ranges from An_{30} in most granitic parts, to An_{45} in some of the melanocratic layers and inclusions. Xenoblastic grains are common. Subidioblastic grains are most abundant in the mesocratic areas that contain streaks of hornblende-rich rock, and the general appearance of these plagioclases is similar to those in the granodiorite. Albite twinning is well developed, but some of the plagioclase is untwinned. Oscillatory zoned crystals are rare and those that are present are in the lighter coloured layers.

Microcline is not present in all of the migmatitic rocks, although it forms 25 per cent of it in one place. Xenoblastic grains occur in the intergranular areas and in part replace plagioclase.

Poikiloblastic and xenoblastic hornblende ranges from 0.1 to 6 mm in size. The elongate grains are oriented parallel with the planar structure except in some of

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[1]The term migmatite was introduced by Sederholm (1907) to describe rocks of mixed origin. Although it was originally restricted to a mixture of eruptive granite magma and older country rocks, it is now generally accepted as including crystalline rocks that have been altered by metasomatic emanations of no specially defined origin.

the granodiorite layers where orientation may be only weakly developed. Hornblende comprises as little as 15 per cent of the leucocratic layers and as much as 72 per cent of the amphibolitic layers.

Biotite is present in about half of the specimens examined. It is most abundant in the mesocratic parts of the rock and in one specimen it was seen to form narrow layers. Xenoblastic plates and sherds, constituting as much as 13 per cent of the rock, are oriented parallel with the planar structure. Biotite rims around hornblende are common. Alteration is to green biotite and chlorite.

Missi Group

The Missi Group, first described by Bruce (1914), is widely distributed throughout the Amisk-Athapapuskow Lakes region of Manitoba and Saskatchewan. It consists of conglomerate, arkose, and greywacke. Ambrose (1936a) gave a minimum thickness of 5,000 to 9,000 feet in the Flin Flon area. In the Ledge Lake area these rocks are confined to three small outcrop sections. Greywacke and conglomerate outcrop on the two small peninsulas near the south end of the West Arm of Schist Lake, and on a small island near the south end of the Northwest Arm. No contacts with the Amisk volcanic rocks are exposed.

Two outcrops are present on the small island near the south end of the Northwest Arm. The northern one is a crumpled black slaty rock. The outcrop on the southwest side of the island is a dark greenish grey conglomerate that weathers light olive grey to greenish grey. This conglomerate is slightly deformed. It is composed of subrounded pebbles and cobbles of amygdaloidal volcanic rocks, subrounded to subangular slaty fragments, and quartz and chert pebbles. The matrix consists of sand-sized slate fragments, quartz grains, and clay-sized material.

Massive greywackes outcrop on the two small peninsulas at the south end of the West Arm. These are light olive grey to brownish grey weathering, dark greenish grey rocks, composed of angular to subrounded grains of quartz, feldspar, hornblende, and slate in an aphanitic matrix. A few pebbles of quartz and slate, and some larger slaty fragments, are scattered throughout the northern outcrop. Bedding is poorly defined, but from the attitudes determined, the exposed thickness of Missi sedimentary rocks is about 90 feet.

Ordovician Dolomite

An outlier of flat-lying Ordovician rocks extends over an area of about three-quarters of a square mile in the south-central part of the mapped area. The main body of Palaeozoic rocks outcrops a few miles farther south.

The Ordovician rocks are thin- to thick-bedded dolomite and dolomitic limestones that form a 50- to 100-foot escarpment. Talus covers the lower parts of the escarpment and the contact with the Precambrian rocks. Sandstone reportedly occurs below the dolomite in other areas (Bruce, 1918b; Byers and Dahlstrom, 1954), but none is exposed in the Ledge Lake area.

Bruce (1918b), on the basis of fossils collected at Cormorant Lake, 30 miles southeast of the Ledge Lake area, gave the age of the dolomite as mid-Ordovician,

probably Trenton. Kupsch (1953) agreed with Bruce's age determination. He correlated the dolomite with the Red River Formation and the sandstone with the Winnipeg Formation.

Pleistocene and Recent

During Pleistocene time valleys were widened and deepened, debris was deposited, and drainage completely disorganized. Further evidences of the continental glaciation are smoothed, polished, and striated outcrops and rounded hills. Glacial striae and grooves strike about S20°W. Glacial polish has been largely destroyed by weathering, but striae are commonly preserved on the more resistant minerals, primarily quartz. In areas underlain by granitic rocks, these resistant minerals have weathered in relief, and many retain either fine striae or a polished surface. Similarly, quartz amygdules in the volcanic rocks have locally preserved the glacially polished surfaces. Rounded outcrops, separated by areas of muskeg, are common in the regions underlain by granitic rocks. In the greenstone areas, the shaping of the hills is controlled to a greater degree by structure and lithology. Ridges are elongated where the direction of the ice movement was more or less parallel with structure. Hills are more or less equidimensional where the direction of ice movement was at high angle to the structural trends.

Pleistocene deposits consist of clay, sand, gravel, and boulders. Except for a few scattered boulders, these deposits are thin along the tops of hills and ridges, or are entirely absent. Thick accumulations are present on the southern and southwestern sides of the higher ridges, that is, the lee side of the glacial advance. Outwash deposits of sand, gravel, and boulders, as much as 75 feet thick, are well exposed in gravel pits on the east side of the Northwest Arm of Schist Lake. These were probably deposited along the margin of a waning ice mass that occupied the Northwest Arm. Outwash sand plains extend from the southeastern part of the map-area at least as far as Athapapuskow Lake. Grey, friable, poorly stratified lake clays containing scattered pebbles and, rarely, cobbles are present in a few places.

Erratic boulders of Ordovician dolomite and Kisseynew gneiss are locally common. The gneiss is exposed over an extensive area to the north, but Ordovician rocks are unknown north of the Ledge Lake area. Therefore the presence of the dolomitic erratics suggests that Palaeozoic rocks extended north of the mapped area in pre-Pleistocene time, and that the erosion of Precambrian rocks by glacial action was slight.

Post-glacial weathering is negligible throughout the area. Glacial grooves, striae, and polish are preserved in many outcrops. No pre-glacial weathered surface is generally present, but there is some local evidence of pre-glacial or inter-glacial weathering. Near the southern end of the West Arm of Schist Lake, mechanical weathering of metadiabase has produced $\frac{1}{8}$- to $\frac{1}{4}$-inch fragments. These occur only on the lee side of a large outcrop area that probably protected this pre-Wisconsin (?) weathered surface. Iron-stained volcanic rocks are exposed in a 50- to 100-foot-deep railroad cut near the southern end of the Northwest Arm and in railroad cuts south of the area. These may also represent weathering of pre-Wisconsin age.

Chapter III

STRUCTURAL GEOLOGY

The Precambrian rocks in the Ledge Lake area are part of a northerly trending belt of predominantly volcanic rocks that are bordered on the west by the Kaminis granodiorite. The volcanic and plutonic rocks in the map-area trend north except in the area south of the West Arm of Schist Lake, where the trends gradually change to southeast, then east, and back to southeast. Contacts between the rock units display intricate patterns as a result of folding and faulting; therefore, the projection of contacts, without further control, is extremely hazardous. Most of the strata dip steeply or vertically; in some places they are overturned. Many of the volcanic flow rocks are massive and structureless, and, although their general trends can be determined, their exact attitudes are difficult to ascertain. In parts of the area primary structures have been destroyed. Numerous fault and shear zones are present; most of these are parallel with the regional strike, and the amount of their displacement, although probably great in many cases, cannot be determined within this area. Minor faults predominantly strike northeast; a few strike northwest or west. Because of the complexity of the structure, any structural sections that might be constructed from the data now available would be of little value.

Folds

The Amisk rocks are tightly and, at least in part, isoclinally folded. The limbs of the folds dip steeply, generally in excess of 70 degrees. Large folds occur in the northeastern quarter of the map-area; elsewhere, the available structural data are insufficient to locate fold axes. On a large scale, the Ledge Lake area can be considered part of a north-trending anticlinorium. In the western part of the area there is some evidence suggesting a synclinal axis roughly parallel with the West Arm of Schist Lake. If this is correct, the west limb of the fold must be almost completely cut out by a fault along the West Arm. Minor folds were mapped wherever possible. Some of them trend parallel with the major structures, but in some places there is no apparent relationship.

The rock units forming the Hook Lake syncline have a more or less symmetrical distribution. At the northern end of the syncline, andesite and basalt are flanked by an arcuate outcrop band of porphyritic andesite flow breccia, which is in turn flanked by diorite and quartz diorite west of Hook Lake. The outcrop pattern of these rocks is that of a north-plunging syncline. No linear elements nor minor folds are present; hence the plunge is not known. Near the southern end of Hook Lake several transverse faults complicate the structure. South of this faulted area, andesites and, still farther south, massive pyroclastic rocks are again exposed in the core of the syncline. Lineations in this southern area plunge south at 25 to 40 degrees, suggesting that the syncline plunges in the same direction. Moreover, the

adjacent Hook Lake anticline also plunges south. The double plunge of the syncline is possible due to a younger, superimposed, gentle, transverse anticline. This younger folding may be related to the Kisseynew deformation described by Kalliokoski (1952) and Harrison (1949), which produced major folds with east-west axes. Kerr (unpublished report, 1936) noted east-west flexures in the Flin Flon area.

The Hook Lake anticline is between the Northwest Arm of Schist Lake and the Hook Lake syncline. Near the northern boundary of the area, the anticline consists of rock units similar to those in the Hook Lake syncline. The southern part of the anticline plunges south. In the northern part the plunge is not known, but the attitudes of some of the flow and pyroclastic rocks suggest a southerly plunge. South of Hook Lake this anticline is cut by oblique faults, the same as the syncline to the east. The trace of the anticlinal axis cannot be mapped south of a slightly oblique fault that has apparently cut out a large part of the eastern limb of the syncline.

On the west side of the Northwest Arm, a syncline has been mapped for about 2 miles from the northern boundary of the area. This is a southern continuation of a syncline first mapped by Stockwell (1960) in the Flin Flon–Mandy map area. The core of this syncline is composed of pillowed, porphyritic lava flows, containing a few interbeds of tuff. Flanking the porphyritic lava are fine-grained to aphanitic, pillowed flow rocks, containing some pyroclastic interbeds. The southern end of the syncline could not be traced beyond the quartz diorite near Ledge Lake.

The anticline on the east side of Ledge Lake is well marked from the northern boundary of the area as far south as the Ledge Lake pluton, beyond which its continuation is postulated for at least 2 miles. The outcrop pattern of the quartz diorite near Ledge Lake and the few attitudes available in the adjacent volcanic rocks, suggest that this anticline plunges south. The quartz diorite may be a folded sill, or the intrusion may have occurred after the volcanic rocks were folded.

Almost all the volcanic rocks west of the above mentioned anticline face and dip west. A few bedding attitudes taken on the islands in the West Arm, and on the east shore of the West Arm, face east and dip steeply in that direction. However, data are insufficient to delineate individual folds. West and south of the West Arm, all attitudes face and dip west, and the Kaminis granodiorite apparently occupies a synclinal position.

Faults

Faults and shear zones are numerous in the Ledge Lake area. Many are conspicuous on air photographs and are represented by straight or curved topographic depressions, or by long, narrow lakes. Consequently, longitudinal fault and shear zones commonly are deeply buried; transverse faults, on the other hand, are generally well exposed. Many other linear features visible on air photographs could not be correlated with mappable faults and thus are not shown on the geological map.

The major longitudinal faults are probably related to the intense folding and the same may apply to some of the transverse faults. Most of the fault and shear zones have curving trends; few remain straight for more than a mile or two. Most of

the minor faults are apparently related to the major faults, although some are younger. The amount and direction of displacement cannot be determined for most faults. Where it can be determined at some minor faults, it is relatively small.

Cataclastic deformation and alteration are no indication of the magnitude of a fault. Some faults, such as the one west of the Ordovician dolomite, have relatively inconspicuous surface expression, but displacements are measurable in thousands of feet. Other fault zones are highly sheared, but displacement commonly is only a few tens of feet.

The Northwest Arm of Schist Lake is a pronounced topographical and structural feature and probably represents a southerly continuation of the Channing fault mapped by Kerr (1936, unpublished report), Ambrose (1936a), Tanton (1941a,b), and Stockwell (1960). Farther south, at the narrowest part of the lake, it is apparently joined by the southern continuation of the Ross Lake fault (Kerr, 1936; Stockwell, 1960). In the Ledge Lake area, this fault zone is largely inferred; only locally are sheared rocks exposed. Intense shearing of rhyolitic and dacitic rocks on the two south-facing peninsulas, has resulted in the formation of sericite schist. An almost vertical scarp, 50 to 150 feet high, marks the west side of the fault zone in the narrowest part of the lake. Relative movements along this fault zone are not known in the Ledge Lake area, but farther north these faults are better exposed. The Amisk rocks on the east side of the Cliff Lake fault are thrust over the Missi sedimentary rocks; however, the displacement of the fault is not known. Kerr (1936) gave the following description of the Ross Lake fault in the area north of Flin Flon:

> Along the Ross Lake fault the east side moved northward about 3,500 feet. Evidence of relative vertical movement is contradictory but it seems most likely that the west side moved up, possibly a few hundred feet at most, relative to the east side. Evidence not only of displacement but of drag folding indicates that the main displacement was nearly horizontal.

The shearing in the Ledge Lake area indicates that this is a steep fault zone, with the dips ranging from about 80 degrees east to 75 degrees west.

A fault more or less parallel with the West Arm of Schist Lake can be traced in several discontinuous segments from Phantom Lake to the southern boundary of the map-area. All the rocks in the exposed segments are strongly sheared, and, near the north end of the West Arm, porphyritic rhyolite has been mylonitized and later recrystallized. The sheared rocks dip west, generally in excess of 60 degrees. The northern part of this fault cannot be traced beyond the granodiorite, but northwest of the area a pronounced linear feature shows on air photographs. About 1 mile south of the northern end of the West Arm the main fault branches. The west branch strikes south, and near the southern boundary of the area crystalloblastic granodiorite is in fault contact with hypidiomorphic-granular granodiorite. Furthermore, the metamorphic zones around the granodiorite are displaced horizontally about 2,500 feet. The east branch of this fault continues southeast to the edge of the map-area. The displacement of this branch is not known, but it may be large, as suggested by the presence of Missi sedimentary rocks in the narrows at the southeastern end of the West Arm.

Numerous faults on the periphery of the granodiorite are more or less normal to the granodiorite contact. Some of them can be traced into the granodiorite as narrow shear zones. Others are not evident in the granodiorite. This indicates two possible periods of faulting, a first one during the emplacement of the granodiorite, and a second one after the shell was sufficiently consolidated to fracture.

Minor faults are generally oblique to the major faults. Most of the major faults are mapped mainly from inference, as few are exposed. These faults dip steeply, generally more than 60 degrees and the movement, where determined, is predominantly horizontal. The direction of movement is about equally divided between left-lateral and right-lateral. Possibly related to these minor faults are numerous very small faults, a few inches to a few feet apart, with displacements from less than 1 inch to 2 or 3 feet. Although these individual offsets are small they may total as much as 20 feet in a strike distance of 20 feet.

Schistosity

Schistosity is present throughout most of the area. North and east of the West Arm of Schist Lake, the schistosity is best developed in the pyroclastic rocks and is locally present in the flow rocks. The strike is north, and steep westerly dips prevail. South and west of the West Arm, all rock types are schistose. The schistosity is parallel with the bedding of the metavolcanic rocks and with the contact of the metavolcanic rocks and the Kaminis granodiorite. The dips are generally steep. The development of the schistosity is related to the regional deformation and the simultaneous intrusion of the Kaminis granodiorite.

In the western part of the area massive-appearing rocks, containing apparently undeformed pillow and amygdaloidal structures and undeformed plagioclase phenocrysts, have a weak to moderately well developed schistosity. The massive rocks grade imperceptibly into schistose rocks in some areas, and are interlayered with them elsewhere. That all of the rocks were subjected to the same deformation is therefore evident. The difference now visible was in the response of the rocks to these forces. Closely spaced shear plates with submicroscopic movement would be almost impossible to detect. However, recrystallization controlled by this movement, as well as by the stress imposed on the rock, would result in the development of a weak schistosity.

Age of Orogeny

The age of the folding is probably Lower Proterozoic. Specimens of galena from the Flin Flon mine have been dated radiometrically at 1,400 to 1,550 m.y. old (Byers and Dahlstrom, 1954, p. 78). The deformation must be older, as mineralization in the Flin Flon mine was definitely post-folding (Geology Staff, Hudson Bay Mining and Smelting Company Limited, and C. H. Stockwell, 1948). In a previous section it was suggested that the Kaminis granodiorite was intruded during the last major orogeny that affected the area. At this time the Amisk volcanic rocks and the Missi sediments were tightly folded and metamorphosed. North of the Ledge Lake area the Missi sediments unconformably overlie the Amisk volcanic rocks. Byers

and Dahlstrom (1954) considered that the time interval between Amisk period of vulcanism and the deposition of younger Missi was probably relatively short with only minor folding of the Amisk rocks previous to the laying down of the Missi sediments. Kerr (unpublished report, 1936), on the other hand, stated: "The Missi or oldest late Archean rocks truncate folds in the early Precambrian that were probably as intricate before deposition of the Missi as those now common in the late Archean rocks". Stockwell (1960) also concluded that the Amisk was folded prior to the deposition of the Missi. No further information is available in the Ledge Lake area on the intensity or relative age of the pre-Missi folding.

Chapter IV

METAMORPHISM

As the metamorphic rocks in the Ledge Lake area have been described on previous pages, the present section will summarize the data on metamorphism and trace the progressive changes in the extrusive and intrusive volcanic rocks in response to regional, dynamic, and thermal metamorphic conditions. No sedimentary rocks were involved in the metamorphism of the Ledge Lake area, so that it is not possible to correlate directly the mineralogical changes in sedimentary and mafic igneous rocks.

Almost all of the rocks in the area have been subjected to low-grade regional metamorphism. In the western and southern sections of the area thermal metamorphism has further modified these rocks. Amphibolites and, locally, pyroxene hornfels, are the products of this higher grade metamorphism. Dynamic metamorphism, in shear and fault zones, has resulted in the local development of schists and mylonites containing typical, low-grade mineral assemblages. In addition, part of the Kaminis granodiorite has undergone autometamorphism, which developed crystalloblastic textures.

Low-Grade Regional Metamorphism

Regionally metamorphosed rocks are widespread in central Manitoba and Saskatchewan. Medium- and high-grade regionally metamorphic rocks do not occur in the Ledge Lake area, but they have been described in adjacent areas by Harrison (1949), Kalliokoski (1952), Robertson (1953), and Byers and Dahlstrom (1954). In the Ledge Lake area andesite and basalt flow, pyroclastic rocks, and diabase dykes and sills have been partly to completely altered by low-grade regional metamorphism.

Greenstone and greenschist grade into unmetamorphosed rocks. Fyfe, *et al.* (1958, p. 167) considered that "the outer [lower-grade] limit of the greenschist facies is defined by the first recognizable signs of metamorphism". In this report, greenstones and greenschists are defined as low-grade metamorphic rocks containing few or no primary minerals.

The gradational change in the mineral content is most apparent in the fine-grained or porphyritic flow rocks or in the medium-grained diabases. The first change noted is in the plagioclase, where the original andesine or labradorite becomes mottled and turbid, and minute alteration minerals appear along the cleavage and twin planes. This mottling is probably related to decalcification, as the mottled grains commonly contain calcite. Epidote and chlorite develop with further alteration. The final product is a cloudy or turbid plagioclase containing blebs, partial rims of albite, and few to numerous epidote, chlorite, and calcite inclusions.

The newly formed albite is commonly untwinned, but it may be pseudomorphous after relics of the primary plagioclase twins, some of which are still recognizable in the highly altered core.

The amount of plagioclase ranges from 16 to 40 per cent in the greenstones and greenschists, and from 25 to 32 per cent in the metadiabases; the average for both groups is about 28 per cent. The plagioclase content of the original diabase was about 50 per cent, as determined by modal analyses using relict textures as a guide to the original mineral composition.

Primary pyroxene has been altered to actinolite and chlorite in the low-grade zone. Chlorite is most abundant in the lower grade part of the zone, and both chlorite and actinolite occur in the higher grade part. There is no indication that the actinolite formed from the chlorite. The extrusive flow rocks contain less actinolite than the metamorphosed dykes and sills. This suggests that the rocks differed somewhat in original composition.

Some chlorite has formed in the plagioclase along cleavage and fracture planes. The constituents necessary for the development of chlorite may have been derived from the original pyroxene or from the matrix.

Most of the epidote is an alteration product of the plagioclase, but a small amount is associated with the chlorite and actinolite derived from the pyroxene.

As noted above, some of the rocks are metamorphosed, while others, a few feet away, are relatively unaltered. The following observations are pertinent to this problem: (1) the unaltered or slightly altered rocks are massive and occur as 'isolated islands' in areas of greenstone and greenschist; and (2) few or no primary minerals occur in the sheared rocks. It is probable that the selective character of the metamorphism and the preferential recrystallization of the sheared rocks indicate marginal conditions of regional metamorphism in those parts of the area concerned.

Thermal Metamorphism

The andesites, basalts, and diabases have been progressively metamorphosed in concentric zones arranged around the Kaminis granodiorite. In order to compare the progressive metamorphic changes an isochemical series of rock units is desirable, but this ideal cannot be fully attained in this area because the zonal boundaries are subparallel with the stratigraphic boundaries. However, the textural, structural, and mineralogical data available suggest that these various volcanic rocks had rather similar original compositions. The most important chemical changes brought about by the metamorphism have been the addition of water and carbon dioxide.

The transition zone rocks, between the low-grade regionally metamorphosed rocks and the medium-grade thermally metamorphosed rocks, show certain characteristics of both groups. The low-grade minerals have stable textural relations with the medium-grade minerals. Some chlorite developed late in the sequence of alterations, but it is restricted to widely spaced shears. Plagioclase and actinolitic hornblende or hornblende adjacent to these shears are not altered. It is unlikely that the amphibole porphyroblasts and plagioclase crystals would have remained entirely unaltered during a period of retrogression.

The rocks of the medium-grade metamorphic zone occur between the Kaminis granodiorite and the lower grade metamorphic rocks. They are composed essentially of hornblende and plagioclase. The mineralogical changes towards the granodiorite contact are slight; the plagioclase composition changes from sodic to calcic andesine, and locally to labradorite; the amphibole in the lower grade part of the medium-grade zone is actinolitic hornblende, but it is common green hornblende in the higher grade part. Epidote occurs throughout the zone, but is much less abundant in the higher grade part, where some rocks are in fact epidote-free.

The volcanic flow and pyroclastic rocks and the diabases have been changed to massive and schistose amphibolites in the medium-grade zone. No primary minerals were seen in the schistose amphibolites; apparently the shearing promoted a more complete recrystallization. The schistose amphibolite has a more or less even-grained texture, although rare plagioclase blastophenocrysts, and hornblende porphyroblasts, probably derived from pyroxene, are preserved. The clear, fine- to medium-grained xenoblastic andesine or rare labradorite grains contain few inclusions. Xenoblastic hornblende is fine grained in the amphibolite derived from the flow rocks, and is fine or medium grained in the rocks derived from diabase. In contrast with these schistose rocks are the massive amphibolites, many of which contain well preserved primary textures. Relics of pyroxene are present in the lower grade part of the medium-grade metamorphic zone, but only two specimens from the higher grade part were seen to contain primary pyroxene.

The textural and mineralogical changes resulting from metamorphism are best studied in the massive amphibolites derived from diabases. In the lower grade parts of the medium-grade metamorphic rocks, pseudomorphs of andesine derived from the original plagioclase contain many inclusions of epidote and hornblende or actinolitic hornblende. Projections of hornblende or actinolitic hornblende, commonly lighter coloured than the main hornblende crystals to which they are attached, have largely destroyed the original plagioclase boundaries. In many specimens, what appear to be original boundaries are marked by tiny inclusions among which epidote and magnetite can be identified. Similar plagioclase-hornblende relations are present in the higher grade parts of the medium-grade zone, but there are textural modifications. No megascopic change is apparent in the relic ophitic textures of some of these rocks, but microscopically a conspicuous change is apparent. Each original plagioclase lath has been, to some extent, pseudomorphosed by equidimensional plagioclase grains. Some plagioclase grains contain stubby hornblende projections whereas in others the hornblende has formed individual equidimensional grains. These are either intergranular in the aggregates formed from the original plagioclase laths, or in optical continuity with the adjacent hornblendes. However, some of these hornblendes may owe their smaller size to shearing, although such shearing is not demonstrable because the original ophitic texture has not been destroyed. The original texture in the rocks in the higher grade parts of the medium-grade zone and in the high-grade metamorphic zone are almost destroyed. The rocks have an even granular texture, but concentrations of hornblende or plagioclase crystals suggest a relic ophitic texture.

Cause of Metamorphism

Most of the volcanic rocks in the Ledge Lake area have undergone low-grade regional metamorphism. These rocks pass into rocks showing medium-grade metamorphism that forms a belt of more or less constant width around the Kaminis granodiorite. This relationship suggests that the intrusive mass caused the increase in the metamorphic grade. The schistose and massive rocks in the low- and medium-grade metamorphic zones have somewhat similar distribution patterns; therefore, both rock types were probably subjected to the same low-grade regional metamorphism, which closely preceded, or possibly overlapped a period of static thermal metamorphism.

In the Ledge Lake area there is little relation between the degree of deformation and the metamorphic grade. Massive and schistose rocks exposed in the same outcrop are characterized by the same mineral assemblages, and differ mainly in texture. The conclusion is that heat supplied by the Kaminis granodiorite was the dominant factor causing the higher grade metamorphism.

Chapter V

SUMMARY OF GEOLOGICAL HISTORY

The Amisk Group, a thick sequence of mafic volcanic flow rocks, was deposited in an early Precambrian geosyncline. The diabase dykes and sills probably originated during this early period of volcanic activity. Folding and erosion followed the deposition of the volcanic rocks. The quartz diorite near Ledge Lake and the diorite and quartz diorite near Hook Lake may have been intruded during this early period of deformation. Unconformably overlying the Amisk volcanic rocks in adjacent map areas are the clastic sedimentary rocks of the Missi Group, which were largely derived from the underlying Amisk volcanic rocks. Intense folding of both the Amisk and Missi rocks, accompanied by the intrusion of the Kaminis granodiorite, resulted in the regional metamorphism of the sedimentary and volcanic rocks and the thermal metamorphism of the volcanic rocks around the Kaminis granodiorite. The regional metamorphism is probably related to this main period of folding, but the possibility of regional metamorphism during the earlier deformation, which followed the formation of the Amisk Group, cannot be discounted. Transitions from almost unaltered rocks to greenstones and greenschists occur in the area now underlain by regionally metamorphosed rocks. These rocks have been changed to medium- and high-grade amphibolites in a concentric aureole around the Kaminis granodiorite. During the early stages of the main (or second period of) deformation some of the rocks were strongly sheared and major faults developed. Recrystallization of the thermally metamorphosed rocks outlasted the deformation, as is shown by the development of transverse hornblende porphyroblasts. The directionless porphyritic granodiorite was emplaced late in the deformation (orogenic) period. It is closely related genetically to the Kaminis granodiorite, as both contain similar minerals and are reported to have gradational contacts elsewhere.

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