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DEPARTMENT OF ENERGY, MINES AND RESOURCES

MEMOIR 361

GEOLOGY OF BENJAMIN LAKE MAP-AREA, DISTRICT OF MACKENZIE

(75 M/2)

W. W. Heywood and A. Davidson

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By

W. W. Heywood and A. Davidson

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ENERGY, MINES AND RESOURCES
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PREFACE

As this area is underlain by sedimentary and volcanic rocks similar to the Yellowknife Group of Archean age, it has attracted the attention of prospectors for several decades. Despite intensive prospecting no major base metal deposit has been found but several showings have been located.

The authors present a detailed description of the bedrock, discuss its geological structure, and describe the metamorphism that has affected the rocks. They conclude that most of the rocks are correlative with the Yellowknife Group, that they were metamorphosed before the intrusion of granodiorite plutons found in the area, and that the intrusion of the granodiorite rather than causing the metamorphism is merely one effect of the tectonism that caused the deformation and metamorphism of the area.

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

OTTAWA, October 18, 1967

MEMOIR 361 — Geologie des Kartenblatts Benjamin Lake (Mackenzie-Distrikt)

Von W. W. Heywood und A. Davidson

Die Verfasser geben eine detaillierte Beschreibung der Gesteine des Kartenblatts, erörtern ihren geologischen Aufbau und beschreiben den Metamorphismus, der die Gesteine umgewandelt hat.

МЕМУАР 361 — Геология планшета Веньямин Лейк, район Макензи.

В. В. Хейвуд и А. Давидсон.

Авторы этого отчета дают детальное описание коренных пород изученного района, обсуждают его геологическую структуру и описывают метаморфические изменения его горных пород.

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GEOLOGY OF BENJAMIN LAKE MAP-AREA, DISTRICT OF MACKENZIE

Abstract

This area, which is underlain by Archean rocks, lies within the Slave Structural Province and comprises a northerly trending belt of deformed and metamorphosed volcanic and sedimentary rocks bounded by granitic and migmatitic rocks. Diabase dykes of Proterozoic age are the youngest consolidated rocks in the region. Most of the rocks can be correlated with the Yellowknife Group although their wide range in metamorphic grade makes correlation difficult.

The region has been extensively prospected for base metal deposits; small showings of zinc, lead, silver, and copper have been located.

Résumé

La région du lac Benjamin, sus-jacente à des roches archéennes, est comprise dans la province structurale des Esclaves; elle comporte une zone de roches sédimentaires et volcaniques déformées et métamorphisées s'étendant vers le nord et limitée par des roches granitiques et migmatiques. Les dykes de diabase du Protérozoïque représentent les roches consolidées les plus récentes de la région. La plupart des roches peuvent être mises en corrélation avec celles du groupe de Yellowknife quoique les diverses intensités du métamorphisme rendent cette corrélation difficile.

La région a été soumise à une prospection intense et on y a trouvé de petites venues de zinc, de plomb, d'argent et de cuivre.

INTRODUCTION

Location and Access

Benjamin Lake map-area covers 270 square miles between latitudes 63°00′ and 63°15′N and longitudes 110°30′ and 111°00′W within the District of Mackenzie, Northwest Territories. Its centre is 120 miles east-northeast of the town of Yellowknife and 14 miles north of McLeod Bay on Great Slave Lake.

Access to the area is best gained by aircraft from Yellowknife; tractor trains have been used in winter to bring supplies to mining exploration crews. The larger lakes, such as Benjamin, Indian Mountain, and Brislane, provide local boat access, but streams between lakes are generally shallow, necessitating portages.

Previous Work, Present Work, and Acknowledgments

The first geologic observations were made by Stockwell (1933) while en route from MacKay Lake to Great Slave Lake. He reported metasedimentary rocks on the west of Waldron River and granitic rocks on the east. The area lies within MacKay Lake map-area which Henderson (1941a; 1944) mapped in 1940 and 1941 on a scale of four miles to the inch. Since that time it has been actively prospected and several mineral showings have been trenched and drilled. An aeromagnetic map of the area was published in 1964 (*Geol. Surv. Can.,* Map 3126G).

Field work was done in the summers of 1962 and 1963. Traverses were planned in advance from airphoto information and were generally spaced between one quarter and three quarters of a mile apart, depending on the complexity of the geology. Critical areas were studied in detail. On most of the larger lakes, rubber boats were used for local access and for examination of shore outcrops and islands.

This report presents an outline of the general and economic geology. Metamorphism and its relations to structure and intrusion formed the subject of a doctorate thesis by A. Davidson at the University of British Columbia, who will treat these subjects in a separate report.

Able assistance in the field was given by P. F. Hoffman and A. W. Watts in 1962 and by E. T. Longstreet and E. B. A. Lewis in 1963. The courteous and cooperative service of Northwest Territorial Airways of Yellowknife is acknowledged with appreciation.

MS received August 10, 1967

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Physical Features

The map-area has an average surface elevation of about 1,300 feet; it lies at the southern edge of an upland plain whose relief rarely exceeds 300 feet. The highest hill (about 1,625 feet) and the lowest valley (about 1,075 feet) are in the extreme southeast corner. To the south the average elevation decreases some 800 feet within 5 miles of Great Slave Lake.

All drainage enters the Mackenzie River system via Great Slave Lake. Drainage is disorganized: some lakes form chains joined by rapid, shallow streams; others drain sluggishly through muskeg-filled valleys. Indian Mountain, Indian Hill, and Benjamin Lakes feed Waldron River, which flows southeastwards through the east half of the area, but much of the land between Indian Mountain Lake and Waldron River drains independently southwards.

Bedrock is exposed extensively in the south half of the map-area where the terrain is rugged on a small scale. It is less well exposed in the relatively low-lying north half, being covered to a great extent by water, muskeg, or glacial debris. Areas of high ground are underlain predominantly by granitic or metavolcanic rocks, the latter forming prominent ridges near Indian Mountain and Brislane Lakes. Outcrops, especially those of steeply dipping metasediments, are commonly frost-thrust and display a variety of heaved and broken forms.

The main effect of the last glaciation has been to broaden valleys and to round and polish the tops and sides of rock ridges. At the northern edge of the map-area glacial striae and the axes of drumlinoid ridges have a westerly orientation whereas to the south the orientation changes gradually to southwesterly. Glacial debris consisting mainly of poorly sorted sand and gravel mantles much of the area; the southeast part is ice-scoured. Several southwest-trending discontinuous eskers cross the area, and southerly draining meltwater channels are recognized along the southern boundary.

The area is near the northern limit of trees. Southward, low shrubs with scattered stands of stunted spruce give way to a more extensive cover of spruce mixed with tamarack and white birch.

GENERAL GEOLOGY

The map-area lies within the Slave Province of the Canadian Shield. It encompasses part of a northerly trending belt of deformed and metamorphosed volcanic and sedimentary rocks as much as 15 miles wide that extends 40 miles north from Great Slave Lake. This belt is bounded on the east and west by granitic and migmatitic rocks but has a core of relatively low grade metamorphic rocks.

Except for Proterozoic diabase dykes, bedrock is entirely of Archean age. Rocks correlated with the Yellowknife Group underlie most of the area and display a wide range in metamorphic grade. Their origins, easily recognized where metamorphic grade is low, can be traced through progressively higher grade metamorphic zones but are obscure or lost where migmatite has formed. At one place the Yellowknife rocks appear to lie on deformed granitoid rocks but elsewhere they are intruded by granitic plutons of closely related age.

Meta-tonalite (1)

Distribution and Lithology

Meta-tonalite outcrops between Brislane Lake and the south end of Indian Mountain Lake. It underlies an area 3½ miles long and 1½ miles wide and also forms most of the large island in the southeast part of Brislane Lake. Most of the rocks comprising this unit are grey or pinkish grey, leucocratic to mesocratic biotite meta-tonalite. Weak foliation is common, with a linear aspect being given by smears of biotite. The eastern part of the body contains a high proportion of strongly foliated rocks with round eyes of milky quartz, in places associated with gneiss in which layers are alternately rich and poor in both biotite and muscovite. The rocks appear to be medium grained, but careful examination reveals that many are in part granulated or recrystallized so that large grains of quartz and plagioclase lie in a fine-grained matrix of quartz, plagioclase, and biotite. In all rocks examined biotite forms aggregates of many small crystals. Most are 25 to 50 per cent quartz, 5 to 20 per cent biotite, with the remainder mainly plagioclase.

Thin sections reveal that these rocks have recrystallized, although relics of deformational comminution of grain size are still apparent in some rocks. Quartz forms round, polycrystalline eyes. In some rocks, individual quartz crystals are separated by a fine-grained quartz mosaic. Plagioclase in the oligoclase–andesine range remains as broken, complexly zoned, and partly altered grains in the less deformed rocks, but in others outlines of original plagioclase grains contain a mass of small, equant plagioclase crystals with some fine-grained biotite dispersed throughout. This fine-grained plagioclase forms much of the groundmass in severely

TABLE OF FORMATIONS

Age	Formation	Lithology
Pleistocene		Sand, gravel; peat
		Unconformity
Proterozoic		Diabase, quartz diabase
		Intrusive contact
Archean		Tonalite, granodiorite, adamellite; pegmatite; agmatite
		Intrusive contact
		Meta-diabase
		Intrusive contact
	Yellowknife Group	Division C: impure quartzite, greywacke, slaty argillite; minor intercalated tuff, calcareous greywacke, graphitic slate; phyllite, knotted schist and hornfels, layered gneiss, migmatite gneiss Division B: dacite, quartz latite, felsic agglomerate, crystal tuff, calcite-cemented breccia, limestone; quartz-feldspar porphyry; micaceous quartz-feldspar schist, siliceous calc-schist, marble Division A: massive and pillowed andesite, basalt; mafic agglomerate, minor intercalated felsic tuff; quartz-feldspar porphyry dykes and sills; greenstone, amphibolite, garnet-amphibole schist and gneiss; amphibolite dykes
		Contact relations uncertain
		Amphibolite dykes
		Intrusive contact
		Heterogeneous schist and gneiss of uncertain affinity; conglomerate (?)
		Unconformity (?)
		Foliated to gneissic meta-tonalite

deformed rocks and in some shows weak, simple, reverse zoning in the calcic oligoclase range. In the more massive rocks dark greenish brown biotite forms clots, commonly containing sphene, whose individual grains are poorly oriented. In the well-foliated rocks red-brown biotite forms strongly oriented streaks and layers and is commonly mixed with muscovite. Microcline is a minor interstitial phase. Small amounts of garnet, hornblende, cummingtonite, and cordierite were recognized. Fibrolite has partly replaced red-brown biotite in one specimen of augen gniess collected near the western margin of the body.

Structure

Foliation near the margins of the meta-tonalite body is parallel or subparallel to the nearby contact. In the east half of the body an early foliation that strikes between north and northwest and dips easterly between 25 and 55 degrees is deformed by a later cleavage that strikes between north and northeast and dips steeply to the east. Axes of wrinkles in the early foliation and elongate biotite streaks are parallel to the intersections of these two foliations, giving a lineation that plunges gently northerly in the north part of the body and becomes subhorizontal to shallowly south-plunging in the southeast part. An apparently still later phase of deformation, noted in two places, has deformed the earlier foliations about easterly striking, near-vertical planes, and has produced minor folds and wrinkles that plunge moderately to steeply to the east and deform the intersection lineation.

The contact of the deformed meta-tonalite body with bedding or layering in the enclosing rocks is everywhere conformable and no evidence of crosscutting relations was seen. The contact dips outwards on all sides so that the body has the form of a dome. Dips are between 40 and 55 degrees on the east side and between 50 and 70 degrees on the south and west. At the north end the overlying mafic flows of division A of the Yellowknife Group (4) have northerly dips as low as 12 degrees. Division A forms the contact rock on the north, west, and south sides of the dome. A thin wedge of banded rocks (2) separates the dome from the mafic volcanic rocks along the east side. Amphibolite dykes (3) cut the meta-tonalite and are themselves involved in the deformation.

Faults are rarely exposed within the dome, but can be seen at the margins where the contact is offset. Linear valleys that lack outcrops and that are in line with known marginal offsets are assumed to be the loci of faults within the dome; several of these are shown on Map 1198A. Most faults are steep, strike northeasterly, and show right lateral offset. One prominent fault strikes northwest and offsets the west contact with left lateral movement. The meta-tonalite which underlies an island in the southwest part of Brislane Lake is probably a slice of the larger body that has been raised along faults concealed by the lake.

Age

The meta-tonalite is deformed and metamorphosed. No evidence that it intrudes the surrounding rocks was observed and there is no contact aureole. In addition, the amphibolite dykes may be feeders to the mafic Yellowknife flows (4). Geological evidence suggests, therefore, that the meta-tonalite is pre-Yellowknife in age and may be a remnant of the basement upon which unit 2 and the Yellowknife Group were deposited. It is possible, however, that meta-tonalite intruded the surrounding rocks and that later regional deformation and metamorphism have obscured the original contact relations.

A rubidium-strontium age of 2,570±90 m.y. was determined from an isochron derived from analyses of six samples of meta-tonalite. This age is similar to potassium-argon ages determined for post-Yellowknife granitic rocks in the map-area (*see* Table II, p. 20) and in other parts of the southern Slave Province (Wanless, *et al.*, 1966). This Kenoran age (Stockwell, 1964) does not refute the idea the meta-tonalite is pre-Yellowknife. It may not necessarily be the absolute age of the meta-tonalite and may represent a redistribution of the critical Rb and Sr isotopes during Kenoran deformation and metamorphism.

Layered Rocks (2)

Distribution and Lithology

On the islands and shore of the west side of the main reach of Brislane Lake is a narrow wedge of layered rocks consisting of gneisses and schists of heterogeneous composition and uncertain affinity. Many of these rocks are leucocratic, fine-grained biotite-quartz-feldspar gneisses with or without coarse porphyroblasts of cummingtonite and garnet. Others are darker and contain variable proportions of hornblende, cummingtonite, and garnet. Some outcrops have layers of medium-grained quartzo-feldspathic rock interlayered with more mafic gneiss. Several outcrops display quartzo-feldspathic lenses up to 6 inches long in a more mafic groundmass. In some rocks, adjacent lenses have different colours and textures and resemble pebbles in deformed conglomerate. In places the fine-grained leucocratic gneisses show fine layering that is possibly relict bedding, but this feature is obscured where coarse crystals of amphibole, garnet, and biotite have grown.

Structural Relations

Gneissic layering in unit 2 dips eastwards at between 40 and 50 degrees and is everywhere parallel to the exposed parts of the lower and upper contacts. The layered rocks appear to lie above deformed meta-tonalite (1), but it proved difficult in the field to distinguish meta-tonalite and the more homogeneous layers of quartzo-feldspathic gneiss. Crosscutting relations between these two units are lacking. The lower contact is offset by several northeast-trending faults and is cut by dykes and irregular masses of amphibolite (3). Unit 2 forms a wedge that

tapers to the north and south. Maximum thickness probably does not exceed 600 feet, but the upper contact with mafic volcanic rocks of division A of the Yellowknife Group (4) is not well exposed.

Origin and Age

The layered rocks of unit 2 may in part be sedimentary. They are older than the amphibolite dykes (3) that may be feeders to the mafic Yellowknife flows (4). It is not certain whether unit 2 is distinctly older than the Yellowknife Group or whether it is a facies of the lower part of the Yellowknife Group. The possibility that the underlying meta-tonalite intruded unit 2 must not be disregarded; deformation could have obscured the original contact relations and could also have produced the conglomerate-like rocks within the gneisses.

Amphibolite Dykes (3)

West of Brislane Lake, amphibolite dykes cut the meta-tonalite (1) and the layered rocks (2). The amphibolite is dense, massive, fine- to medium-grained, and black to very dark green. It is composed predominantly of equant hornblende grains with interstitial plagioclase and minor magnetite and pyrite. In places the contacts of the dykes are sheared and have recrystallized to hornblende-biotite schist. Some dykes within the meta-tonalite can be traced continuously for as much as a mile, but many are now in the form of discontinuous slivers, having been torn apart during deformation. The dykes are from 2 to 80 feet thick and strike between north and northeast. Dips are steep to vertical at rarely exposed contacts.

Lithologically similar amphibolite dykes and sills (4a) are present within division A of the Yellowknife Group (4) between Indian Mountain Lake and the north end of Brislane Lake and also on the islands and peninsulas on the west side of Brislane Lake. In many places, however, it could not be ascertained whether outcrops of massive amphibolite in division A represent dykes and sills or massive flows. Similar amphibolite dykes have not been observed to cut rocks of divisions B and C of the Yellowknife Group.

The dykes (3) are certainly younger than units 1 and 2 and older than deformation and metamorphism of the Yellowknife Group. Their relationship to the Yellowknife Group is not certain, but it is suggested that the dykes may be feeders to the mafic Yellowknife flows because units 3 and 4a are similar and because amphibolite dykes are apparently absent from divisions B and C. If they are subsequently proven to be feeders, then the age of the meta-tonalite with respect to the Yellowknife Group would be established. It is possible, however, that they are younger than the Yellowknife Group and that their apparent absence from divisions B and C is fortuitous.

Henderson (1941b) and Fortier (1947) have described swarms of amphibolite dykes in gneissic granodiorite near Ross Lake, some 70 miles west-southwest of the present occurrence. Baragar (1966), working with the Yellowknife volcanic

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rocks near Cameron River, a few miles north of Ross Lake, suggested that these dykes may be feeders to the mafic flows of the Yellowknife Group, and that the gneissic granodiorite may therefore be of pre-Yellowknife age.

Yellowknife Group (4,5,6)

Metamorphosed volcanic and sedimentary rocks constitute a large part of the Slave Province. Originally called the Point Lake–Wilson Island Group by Stockwell (1933), they are now known as the Yellowknife Group, this name having been applied first by Henderson (1938), Jolliffe (1938), and Lord (1939). Detailed work by Jolliffe (1942; 1946) led to the establishment of the stratigraphic succession near Yellowknife as a type section of the Yellowknife Group. Jolliffe distinguished three divisions, A, B, and C, broadly characterized by mafic volcanic rocks, felsic volcanic rocks, and sediments of the greywacke type respectively. A similar three-fold division is applied here as it has been used in many parts of the Slave Province but it is not invariably applicable to the Yellowknife Group.

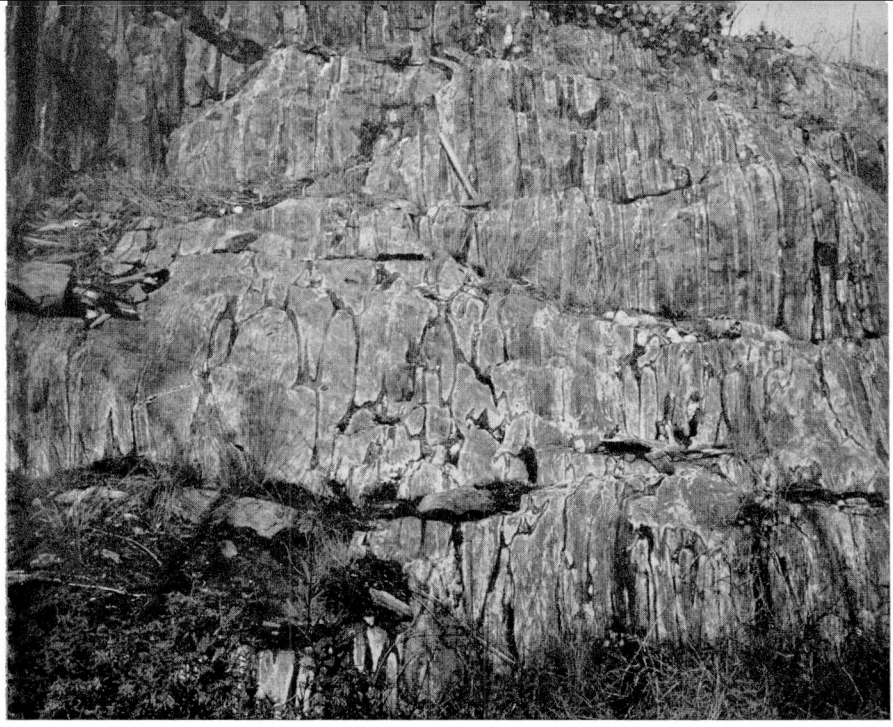
Distribution

Rocks of the Yellowknife Group underlie about 70 per cent of the map-area. Division C is the most widely distributed; divisions A and B are confined to three belts, together constituting about 8 per cent of the bedrock. The largest belt is east of Indian Mountain Lake and parallel to it. There divisions A and B form a large, complex anticline about a core of meta-tonalite (1). In the northwest corner of the map-area a narrow wedge of amphibolite assigned to division A separates division C on the east from granitic rocks to the west, and continues northwards beyond the area. The third belt is located near Susu Lake in the central-southern part of the area. It tapers northwards and extends to the south as far as Great Slave Lake (Wright, 1951). Within the map-area this belt is composed of rocks assigned to division B, but pillowed amphibolites of division A occupy its core to the south.

Lithology

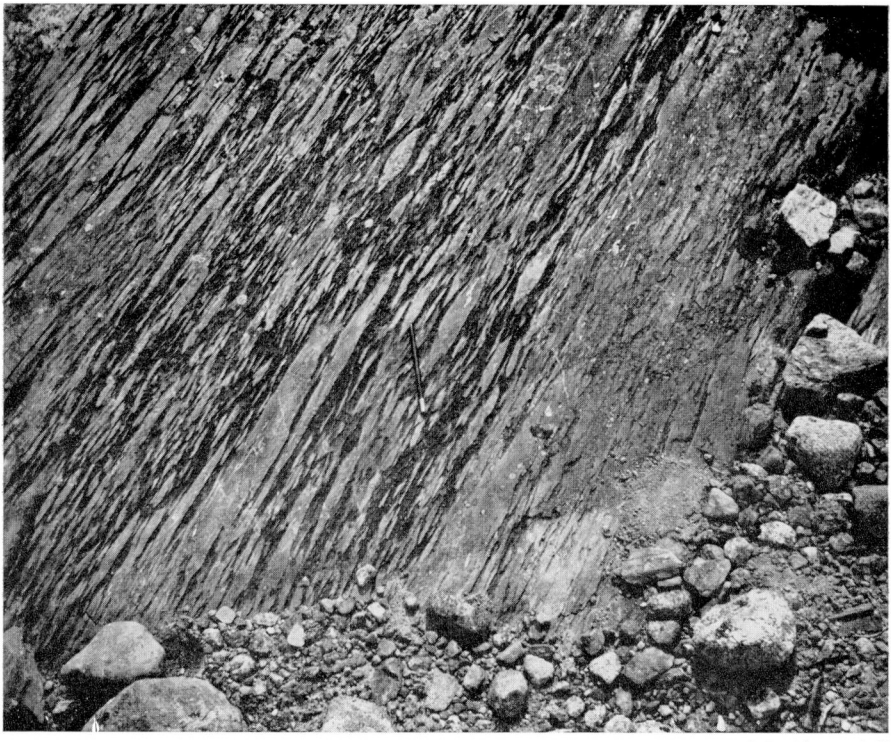
In the following descriptions the rocks are referred to in terms of their original lithologies as far as it has been possible to deduce them. Mineralogic compositions are discussed in the section on metamorphism as the mineralogy of any one rock varies from place to place according to metamorphic grade. In general it should be kept in mind that the mafic volcanic rocks of division A are now mainly amphibolites, that the rocks of division B are now platy or dense quartzo-feldspathic rocks, calc-silicate rocks, or micaceous quartz-feldspar schists, and that the metasediments of division C range through phyllites, schists, and gneisses. Preservation of primary structures has been the key to understanding the original nature of these rocks. Where this is lacking, their origins have been deduced by extrapolation or are left in doubt.

Division A (4). Mafic flow and pyroclastic rocks make up the bulk of division A. A few flows are porphyritic, with plagioclase phenocrysts, and some are amygdaloidal. Most flows have pillow structure and nearly everywhere the pillows are considerably flattened (Fig. 1). Thin layers of mafic rock that weather to give pitted



W. W. Heywood, 4-3-63

FIGURE 1. Flattened pillows in amphibolites of division A, a mile south of the west end of Brislane Lake. The hammer handle is 14 inches long.



A. Davidson, 7-9-62

FIGURE 2. Flattened mafic agglomerate of division A, 2 miles north of the north end of the body of meta-tonalite (1). Fragments are composed chiefly of fine-grained hornblende and plagioclase. Darker matrix is rich in biotite. The pencil is 6 inches long.

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or rubbly surfaces may represent flow tops. A mile south of the west end of Brislane Lake, layers and lenses of coarse breccia with leucocratic fragments are intercalated with pillowed flows. Most of the fragments are fine grained, but a few have a distinct granitic character.

Although stratigraphy within division A is not uniform, in general dark green pillowed flows make up most of the lower part of the division, giving way up-section to coarse mafic fragmental rocks intercalated with greenish grey pillowed flows whose pillows are smaller than those of the dark green flows. Mafic pyroclastic rocks are now represented by heterogeneous rocks whose fresh surfaces show vague patches of different composition, some rich in amphibole, some in biotite, and others in quartz and feldspar. On outcrop surfaces the fragments are commonly emphasized by weathering and stand in relief above the matrix (Fig. 2).

Layers of fine-grained felsic rock, with or without scattered quartz and feldspar crystals of medium grain size, are present among the mafic rocks in places. A few of these bodies cut across pillow stratification and are interpreted as dykes. Most are concordant and may be either sills or tuff beds. A few of the larger bodies are quartz-feldspar porphyry. Those that are large enough to show on the accompanying map are assigned to an intrusive phase related to division B (5c). As has already been mentioned, a few mafic dykes or sills (4a) were recognized within the pillowed flows.

The amphibolites that outcrop in the northwest corner of the map-area are fine-grained, dark green rocks. Some are massive, others are layered, and although primary volcanic structures were not recognized in the field, they are lithologically similar to the amphibolites with flattened pillows on the east side of Indian Mountain Lake and have been assigned to division A.

Three chemical analyses of amphibolites from flows near Indian Mountain Lake indicate that these rocks have compositions of iron-rich aluminous basalts (Table I). The lighter coloured pillowed flows in the upper part of division A are probably andesitic or dacitic in composition.

Division B (5). Division B has been divided into two units along the east and south sides of the volcanic belt east of Indian Mountain Lake. The lower unit (5a) contains fine-grained, grey, massive to platy rocks characterized in most places by about five per cent, but rarely by as much as 20 per cent, clear, round quartz grains between 1 mm and 4 mm in diameter. Some of these rocks contain similar sized crystals of plagioclase as well as quartz, and others contain only plagioclase. One chemical analysis of plagioclase porphyry (Table I, column 4) indicates that it is a highly aluminous rock of andesitic composition. Thin sections show that these crystals lie in a very fine grained groundmass of quartz and plagioclase with variable proportions of biotite, muscovite, and K-feldspar. Porphyroblasts of garnet and, more rarely, hornblende or cummingtonite are present in some rocks.

The upper unit of division B (5b) is characterized by coarse fragmental rocks, commonly with calcite cement, and by siliceous or pure limestone. Fragments are easily recognized in some rocks but in others have been reduced to plates or rods by deformation. Fragments range from coarse sand to boulder size and are

commonly in the range ½ inch to 3 inches. They are composed of fine-grained, grey rocks similar to those of unit (5a), but usually lack the quartz and feldspar eyes. Siliceous limestone layers are intercalated with the breccias towards the top of the unit (Fig. 3). In several places, nearly pure, layered limestone is exposed at the top of the unit and lies directly below pelites and semipelites of division C.

W. W. Heywood, 2-9-63

FIGURE 3. Crystalline limestone of the upper part of division B (unit 5b), exposed on the east side of the hill at the southeast corner of Brislane Lake. The limestone contains pods and bands of fine-grained quartzo-feldspathic rock that may represent volcanic bombs and tuff interbeds. The hammer handle is 14 inches long.

Division B is much thinner on the west side of the Indian Mountain Lake volcanic belt than on the east side. Although the same stratigraphic succession is present, it was found impracticable to separate units (5a) and (5b) for mapping purposes and they are included together in unit (5). The smaller thickness may be in part due to stratigraphic thinning, but is certainly in part due to severe shearing and mylonitization. Many of these rocks are finely layered, cherty-looking rocks with rare feldspar eyes and thin quartz lenses. Breccia has been reduced to a layered rock consisting of thin siliceous flakes in a calcite matrix.

TABLE I *Chemical analyses of metavolcanic rocks*

	1	2	3	4
SiO_2	47.7	48.5	43.5	61.5
TiO_2	1.5	1.5	2.1	0.7
Al_2O_3	18.3	17.8	16.3	21.0
Fe_2O_3 (1)	14.6	13.7	16.8	4.9
MnO	0.3	0.3	0.4	0.1
MgO	6.4	6.3	6.6	1.3
CaO	10.0	10.4	9.7	4.7
Na_2O	2.9	2.6	2.6	3.3
K_2O	0.2	0.6	0.4	0.6
H_2O (2)	1.4	1.6	2.1	—
P_2O_5	0.1	0.1	0.2	0.1
Total Wt %	103.4	103.4	100.7	98.2

(1) Total Fe as Fe_2O_3
(2) Total H_2O
1. Fine-grained amphibolite from division A
2. Medium-grained amphibolite from division A
3. Fine-grained pillowed amphibolite from division A
4. Plagioclase porphyry from flow in lower part of division B

Analyses made by the Analytical Chemistry Section, Geological Survey of Canada. Na_2O, H_2O and P_2O_5 analyzed by chemical methods; other elements analyzed by K-ray fluorescence

Dykes, sills, and irregular masses of quartz-feldspar porphyry within division A have been mapped separately (5c). They probably represent an intrusive phase related to the vulcanism that produced the felsic flow and pyroclastic rocks of division B. They may be present within division B, but if so, they are indistinguishable from the porphyritic rocks and crystal tuffs.

The belt of rocks (5d) mapped as division B in the south-central part of the map-area presents some problems of origin. Most of the rocks exposed there are very fine grained and equigranular, medium to light grey or pinkish grey, and show little internal structure except for faint colour banding. They are composed predominantly of quartz and feldspar with only minor amounts of biotite. In places, these rocks contain porphyroblasts of garnet and hornblende that are commonly arranged in lenticular or irregular patches and streaks. Scattered throughout the belt are discontinuous layers of coarse-grained garnet amphibolite, limestone, and felsic breccia.

Division C (*6*). Division C is a heterogeneous unit containing a variety of metamorphosed sediments. The nature of the original sediments is clear in the area of low metamorphic grade south of Indian Hill Lake. Dark grey argillite, grey greywacke, and buff-grey impure quartzite are the most common rock types. Most of the sandy sediments are fine grained and poorly sorted. Graded bedding is a

common feature of the greywackes and is useful for determining stratigraphic tops. Individual graded beds are uniform. Bed thicknesses range from a fraction of an inch to many feet and are commonly in the range of 3 to 18 inches. Units of massive, indistinctly bedded greywacke, massive to finely laminated slate and argillite, and well bedded, in part crossbedded, impure quartzite are intercalated with the graded greywackes. Present in a few places are thin units of purplish grey calcareous greywacke and black graphitic slate. In the coarser parts of the thicker graded greywackes are layers of concretions up to 6 inches in diameter. Erosive sedimentary features are preserved in places at the interfaces between graded beds and include flute casts, scour-and-fill structures, and plucked shale chips. Some argillites have convoluted laminae that are reminiscent of soft sediment deformation.

Many of the sedimentary features described above are remarkably well preserved in the equivalent metagreywackes and knotted schists at higher metamorphic grade, as illustrated by Figures 4 to 7.

Structural Relations

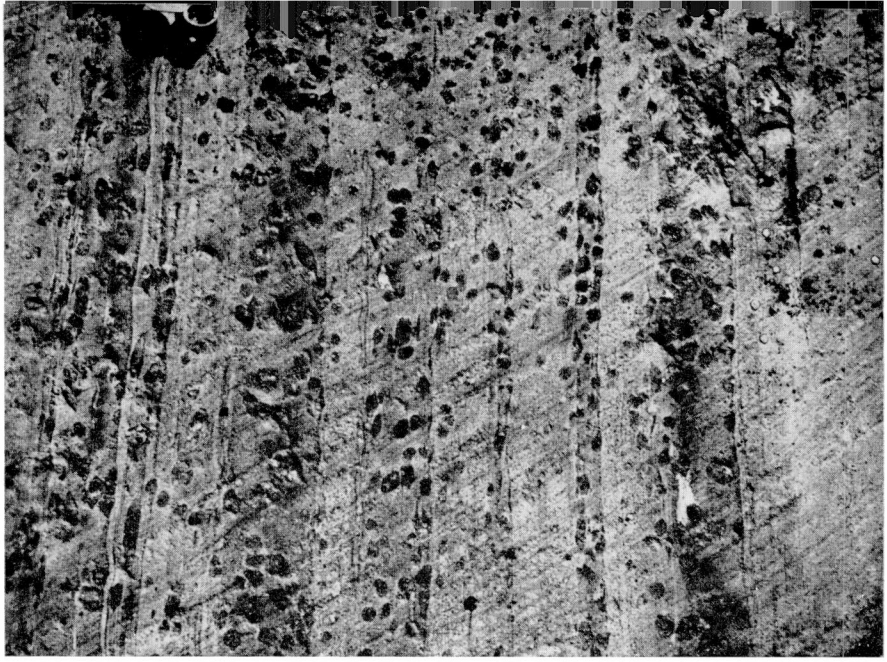
So far as is known from top determinations, divisions A, B, and C are stratigraphically conformable within the Benjamin Lake map-area. The contact between divisions A and B, although gradational, is fairly well defined except west and northwest of the north end of Brislane Lake. There quartzo-feldspathic rocks are intertongued with mafic pyroclastic rocks and the upper contact of division A is drawn where the mafic rocks become subordinate. Top determinations on pillow structures in division A indicate that division B is the younger. The contact between divisions B and C is exposed in a few places. Detrital sediments lie conformably on top of limestone or calcite-cemented breccia. Top determinations in sediments close to the contact confirm that division C is the younger. In places, however, divisions B and C are probably in fault contact. Although units of different sedimentary rocks are definable in places within division C, it was found impracticable to separate them into lithologic units at the present scale of mapping.

Age and Correlation

The Yellowknife Group is of Archean age. In the southern part of the Slave Province it is intruded by granitic rocks for which ages of about 2.5 billion years have been determined (Stockwell, 1964).

Although not connected at the surface with the type section at Yellowknife, the volcanic and sedimentary rocks of the Benjamin Lake map-area can be confidently referred to the Yellowknife Group on the basis of similarity in both lithology and stratigraphic succession. The nearest similar successions are near Camsell Lake, 30 miles to the northwest (Henderson, 1944), and north of MacKay Lake, 65 miles to the north (Moore, 1956).

Within the map-area, the correlation of the belt of rocks of unit 5d with division B of the Yellowknife Group is in some doubt. Although limestone and

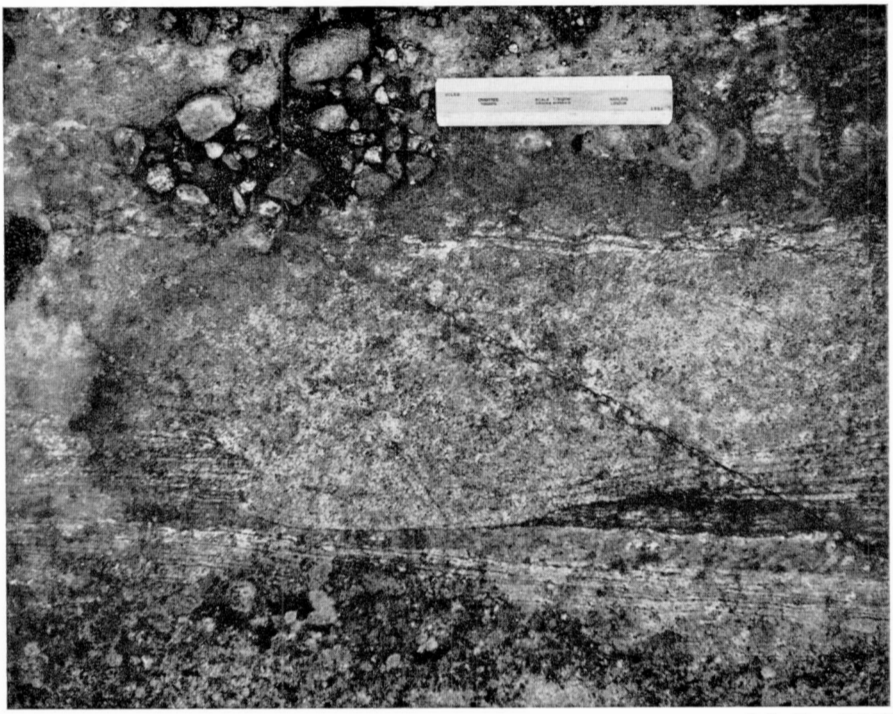


A. Davidson, 2-3-62

FIGURE 4. Cordierite knotted schist derived from thin-bedded greywackes. Graded bedding indicates that tops are to the right of the photograph. Diagonal markings are glacial striae. Location is $1\frac{3}{4}$ miles south of the southwest end of Benjamin Lake. The hand-lens is an inch in diameter.

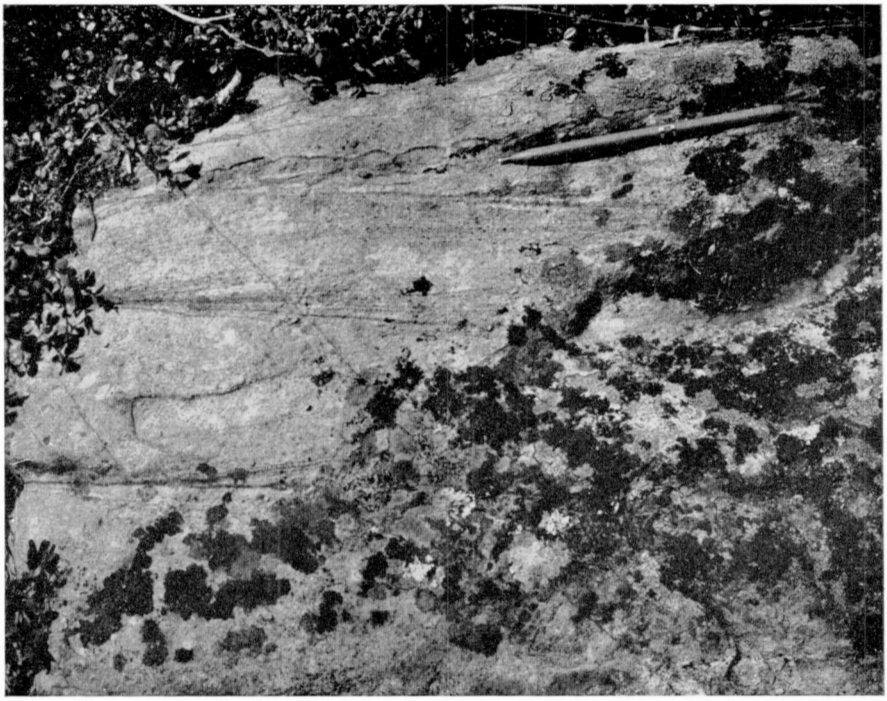
A. Davidson, 6-1-63

FIGURE 5. Cordierite-andalusite knotted hornfels derived from thin-bedded greywackes. Graded bedding is preserved and tops are towards the top of the photograph. Note that the cordierite and andalusite porphyroblasts are concentrated in the upper, originally finer grained parts of the beds. Location is 2.1 miles east-northeast of the north end of Susu Lake, and the outcrop is 300 feet from the contact of a small granodiorite stock. The scale is 6 inches long.



A. Davidson, 7-11-63

FIGURE 6. Well-preserved flute cast in metagreywacke from which it can be determined that the beds face towards the top of the photograph. The location is three quarter mile northeast of the north end of Susu Lake.



A. Davidson, 7-2-62

FIGURE 7. Crossbedding in impure quartzites 4 miles east-southeast of the north end of Susu Lake. The pencil is 6 inches long.

felsic volcanic breccia occur in both units 5 and 5d, the gross lithologies of the two units are dissimilar. However, the presence of mafic pillowed flows in the core of this belt south of the map-area (Wright, 1951) suggests that unit 5d occupies a similar stratigraphic position to that of division B near Indian Mountain Lake. Previously mapped with the volcanic divisions (Henderson, 1944), the rocks of unit 5d are for the most part probably of sedimentary origin, perhaps derived from very fine grained limy sands and silts.

Meta-diabase (7)

Meta-diabase is exposed in several outcrops near the southwest end of Benjamin Lake. In one place it has the form of a vertical dyke at least 250 feet thick that strikes northwesterly. This dyke cannot be traced far and the pattern of outcrops of meta-diabase suggests that it has been broken into segments. Diabasic texture and fine-grained margins are preserved in places but elsewhere the rock is a medium-grained, greenish grey schist containing much pale green, fibrous amphibole. Thin sections show the meta-diabase to be composed chiefly of pale green hornblende, andesine, and minor quartz and biotite. As this mineral assemblage is compatible with the metamorphic grade of the neighbouring metasediments of division C, it is possible that the dyke was intruded prior to metamorphism. Age relations to the granitic rocks are not known directly as meta-diabase was seen in contact with the stock of granodiorite immediately to the north.

Granitic and Migmatitic Rocks (9, 8)

Distribution

About 27 per cent of the map-area is underlain by granitic rocks and about 3 per cent by migmatitic. The granitic rocks are exposed chiefly at the east and west sides of the area where they form parts of more extensive granitic terranes that border the northerly trending belt of Yellowknife rocks.

Parts of two plutons project into the map-area on the the west side of Indian Mountain Lake. The largest granitic body in the eastern part lies east of Waldron River. The Yellowknife metasediments bordering this pluton contain many small granodiorite stocks. For the most part, migmatites are local border phases of homogeneous plutons and are of the agmatite type. However, in the southwest and northeast corners, relatively wide zones of migmatitic gneiss are developed which appear to grade into foliated granitic rocks that extend beyond the limits of the map-area.

Lithology

Most of the granitic rocks are medium grained, massive, and homogeneous. Two distinctive types are pink to cream, porphyritic (microcline) biotite granodiorite to adamellite (9A), and grey to pinkish grey, equigranular biotite granodiorite (9C). The former (9A) comprises the large pluton east of Waldron River, two

smaller bodies to the north and south of this pluton, and all the granitic masses in the western part of the area except for part of one pluton west of the narrows of Indian Mountain Lake which is to grey, equigranular granodiorite. The latter (9C) is the predominant rock of the small stocks in the east half of the map-area.

The porphyritic type (9A) contains pink to cream microcline megacrysts between one half and one inch in diameter that form up to 20 per cent of the rocks. Megacrysts are not oriented and commonly include grains of other minerals arranged in zones parallel to microcline crystal faces. Pink to white plagioclase is complexly zoned and ranges in composition from An_{28} to An_{15}. Plagioclase normally constitutes between 40 and 50 per cent of the rocks and clear quartz between 20 and 35 per cent. Greenish black biotite, the only mafic mineral, occurs as scattered single crystals. Small amounts of muscovite are present near the margins of the plutons. Apatite, magnetite, sphene, and allanite are the accessory minerals; chlorite, sericite, and epidote are secondary. Medium- to fine-grained, pink, equigranular granodiorite is exposed near some contacts. Diffuse microcline megacrysts appear in the rocks a few hundred feet inside the contacts and increase in size, amount, and idiomorphism towards the central parts of the plutons. The contact facies of the porphyritic granodiorite is foliated along the southwest contact of the batholith east of Waldron River but elsewhere is massive.

Equigranular granodiorite (9C) lacks conspicuous microcline crystals but is otherwise similar in texture to the porphyritic type. Normally grey throughout the smaller stocks, it grades from grey near the margins to pinkish grey near the centres of the larger stocks. Change in colour of plagioclase is responsible for this colour zoning and is concomitant with an increase in the microcline content from about 5 per cent at the margins to as much as 15 per cent in the cores. The microcline is white and forms large, irregular, highly poikilitic crystals. In some specimens, euhedral quartz crystals embedded in microcline have the hexagonal bipyramidal habit typical of β-quartz.

A third type of granitic rock (9B) is fine- to medium-grained, equigranular, foliated, grey-white biotite-muscovite adamellite, which forms a small pluton in the southeast part of the map-area. It is associated with irregular patches of pegmatite and grades into pegmatite at its narrowing eastern extremity. The plagioclase component is albite (An_{4-10}) and it contains as much as 15 per cent muscovite. Accessory tourmaline and green apatite are abundant enough to be identified in some hand specimens. The related pegmatites (9B) are normally white, very coarse grained, and contain graphically intergrown quartz and microcline, cleavelandite, and muscovite; here and there smaller amounts of biotite, tourmaline, apatite, beryl, garnet, and columbite are found.

A fourth type of granitic rock (9D) is medium-grained, equigranular, grey to dark grey biotite granodiorite to hornblende-biotite tonalite. It forms the matrix of part of the body of agmatite in the southeast and also forms the bulk of the granitic body in the extreme northeast where it contains numerous, irregular pegmatites that comprise up to 50 per cent of some outcrops.

Agmatite is present at the margins of some of the larger plutons, is also associated with some of the small stocks, and forms an irregular mass in the southeast corner of the map-area. Included blocks of country rock are angular and range in size from a few inches to over 100 feet. Relict bedding shows that the blocks have rotated with respect to one another. In most places the included blocks appear to float in a granitic matrix similar in character to the nearby homogeneous granitic rocks. At the eastern margin of the porphyritic granodiorite pluton (9A) west of Indian Mountain Lake agmatite shows a pronounced gradation from sedimentary schists with irregular granodiorite dykes near the outer contact to porphyritic granodiorite with scattered inclusions some 1,000 feet from the contact. Some of the small granodiorite stocks (9C) are elongate in plan and their distal ends are agmatite formed by anastomosing dykes of granodiorite that are commonly fine grained and contain small plagioclase phenocrysts. One elongate stock in the southeast part of the map-area contains numerous inclusions throughout its mass. The relatively large area underlain by agmatite in the southeast corner of the map-area is divided into two types on the basis of the nature of the granitic matrix. Part of the agmatite (9A) is apparently related to a homogeneous pluton of porphyritic granodiorite to the southwest. The other part (9D) has a matrix of equigranular, grey to dark grey granodiorite or tonalite, in places containing hornblende rock that is unlike the rocks of any other pluton exposed within this part of the map-area.

In the southwest and northeast corners metasediments of the Yellowknife Group, division C, grade into banded gneisses and migmatites (8c), in which granitic bands and lenses are parallel to relict bedding and gneissic banding. In the northeast corner, the migmatites themselves grade northeastwards into foliated granodiorite (9D) that contains biotite-rich schlieren. This gradation from metasediments without granitic lenses to foliated granodiorite takes place across a surface distance of about 5,000 feet.

In the southwest part of the map-area, banded gneisses and migmatites have formed from all divisions of the Yellowknife Group. In some places the host rock can be assigned to division A, B, or C, but in most places metasomatic alteration has rendered this distinction impossible, especially between divisions B and C. Migmatites derived from division A, are commonly rich in hornblende and more easily distinguished than the other two. The change from metasediments to migmatite gneiss is gradational near the southern boundary of the map-area, and in the extreme southwest corner the rocks are medium- to coarse-grained banded gneisses with alternating quartzo-feldspathic and biotite-rich layers. Small plutons of relatively homogeneous, pink, porphyritic granodiorite (9A) are present in places.

Structural Relations

Most of the granitic plutons are internally structureless and relatively homogeneous. Plutons of unit 9A have either narrow marginal zones of slightly finer grained rocks against sharp contacts or have narrow zones of contact agmatite. The southwestern contact zone of the batholith east of Waldron River is foliated

in part and grades inwards to massive granodiorite a few hundred feet from the contact. Inclusions are rare and usually small. The larger stocks of granodiorite (9C) show a weakly developed, concentric mineralogical zoning with a slight enrichment of K-feldspar in the cores of the plutons.

Most granitic plutons have closely spaced, near-vertical joints in some parts and poorly developed, irregular joints in others. In addition, master joints with shallow to moderate dips are present in places. The pronounced curvature of topographic lineaments near the southern part of the batholith (9A) east of Waldron River is due to two sets of curved joints, one concave with shallow northwesterly dip, the other convex with moderate southeasterly dip. The two granodiorite stocks (9C) near the centre of the southern boundary of the map-area have peripheral, gently curved, concave master joints that dip southerly at very low angles. Closely spaced, vertical joints, along which the granitic rocks are reddened and altered, are parallel to northeast-trending faults.

Except for the body of granodiorite (9D) in the northeast corner, whose contact is gradational with migmatitic gneiss, observed contacts are sharp and have intrusive characteristics. The stocks (9C) have grossly concordant contacts but in detail there are small discordances. The larger stocks of unit 9C with oval plan exhibit 'wrap-around' structure, with bedding in division C (6) dividing around them. Sedimentary top determinations indicate that some of the stocks occupy cores of anticlines but that others are within one limb of a fold or perhaps have displaced several folds. Bedding turns from its northerly strike towards the southwest contact of the batholith (9A) east of Waldron River and towards the east contact of the pluton (9A) west of Indian Mountain Lake. Bedding is buckled against these contacts, in the latter case with the formation of contact agmatite. Plutons of units 9A and 9C were not seen in contact and in several places it is known that screens of sedimentary schist separate them. Where grey granodiorite stocks (9C) are close to plutons of pink, porphyritic granodiorite (9A), the former are generally foliated subparallel to the nearby contact of unit 9A.

White pegmatites (9B) occur in three swarms within the map-area. Within the body of grey granodiorite (9D) in the northeast corner, pegmatites are abundant and irregular in shape and orientation; they have a simple mineralogy and contain only graphically intergrown microcline perthite and quartz with large books of muscovite. To the southwest they have a more constant southwest strike, become smaller and less numerous, and are absent beyond about 1½ miles from the gradational contact between the granodiorite (9D) and the migmatitic gneisses. The most southwesterly pegmatites contain appreciable amounts of tourmaline, garnet, and apatite, in addition to quartz, feldspar, and muscovite. In the southeast, pegmatites are numerous close to the borders of the large porphyritic granodiorite pluton (9A) but not within it, and are generally concordant with bedding in division C (6). To the southwest they decrease in size and number and strike southwesterly across the northerly trend of the metasediments. In the southwest part of the map-area, small chiefly discordant, simple pegmatites are widely scattered but are most numerous near the gradational boundary between the metasediments and the migmatite gneisses.

Most of the larger plutons are roughly oval in plan, and are probably either dome-shaped or pipe-like. Some of the smaller stocks are narrow, elongate in plan, and have the form of short, thick dykes. It is suggested that magma was first introduced along relatively narrow zones and subsequently swelled in place to produce dome- or pipe-like plutons that accommodated themselves by pushing aside the already deformed country rocks. By this interpretation the narrow stocks represent the loci of introduction of magma that for some reason did not swell. It is possible that the narrow stocks widen at depth, or even that they are the stems of more bulbous intrusions that have since been eroded.

Gradational contacts and the formation of migmatites are probably functions of both relatively high temperature and of metasomatic activity. In the northeast corner of the map-area, the gradational nature of the contact between migmatite gneisses (8c) and granodiorite (9D) was probably brought about by metasomatism that accompanied the introduction of the granodiorite. Evidence in the southwest corner suggests that the migmatites were formed before the introduction of granodiorite magma which there formed distinct plutons. Granitoid lenses in the migmatites may have formed in situ by segregation, but the disappearance of the aluminous minerals sillimanite and cordierite is perhaps best explained by invoking the introduction of water and alkalis which reacted with these minerals to give plagioclase, biotite, and muscovite.

Age and Sequence of Emplacement

Four potassium-argon age determinations of the granitic rocks were made by the Geological Survey of Canada (Wanless, *et al.*, 1965) (*see* Table II).

TABLE II *Potassium-argon ages of granitic rocks from Benjamin Lake map-area*

Map-unit	Rock Type	Location	Mineral dated	Age (m.y.)
9A	Pink, porphyritic biotite granodiorite....	63°05′30″N 110°33′30″W	biotite	2,525 ± 80
9B	Pegmatite.....	63°13′20″N 110°33′W	muscovite	2,625 ± 80
9C	Pinkish grey, equigranular biotite granodiorite	63°09′N 110°33′W	biotite	2,455 ± 80
9C	Light grey, equigranular biotite granodiorite	63°02′25″N 110°35′W	biotite	2,525 ± 80

Age determinations of rocks this old cannot at present be expected to differentiate between plutons that are closely related in time. The results, however, indicate that these granitic rocks belong to one major intrusive episode. The ages are similar to those obtained elsewhere in the southern part of the Slave Province (Stockwell, 1964).

Although granitic rocks of different type were rarely seen in contact, the sequence of emplacement can be deduced by other means. Plutons of unit 9A are homogeneous and massive and are not cut by the large white pegmatites (9B). Pegmatites are intimately associated with the body of biotite-muscovite adamellite (9B) and cut plutons of units 9C and 9D. Plutons of unit 9C commonly are foliated close to massive plutons of unit 9A, notably in the northeast part of the area. The migmatitic gneisses that border and are parallel to the foliated granodiorite (9D) in the northeast corner are cut discordantly by the stock of massive, homogeneous, porphyritic granodiorite (9A) to the west. The stock of grey, equigranular granodiorite (9C) that occurs within the agmatite (9D) in the southeast corner is foliated and both units are cut by numerous pegmatites (9B). The same pegmatites, however, do not cut the pink, porphyritic granodiorite pluton or its associated agmatite (9A) to the southwest. In summary, the order of intrusion in the eastern half of the map-area is considered to have been as follows: 1) foliated granodiorite (9D) with formation of marginal migmatitic gneiss in the northeast corner; granodiorite and quartz diorite agmatite (9D) in the southeast corner; age relations of these two bodies are not known; 2) small stocks of grey granodiorite (9C) and associated agmatite; 3) pegmatites (9B) and the associated body of biotite-muscovite adamellite (9B), the latter probably being a forerunner of the intrusion of 4) larger plutons of massive, pink, porphyritic granodiorite to adamellite (9A).

Age relations between granitic rocks in the western part of the map-area are not clear. Small bodies of porphyritic granodiorite (9A) cut the migmatite gneisses in the southwest corner and have fine-grained border phases. There is no evidence to suggest which is the younger of the two plutons west of Indian Mountain Lake.

Diabase, Quartz Diabase (10)

Vertical dykes of brown-weathering diabase cut all other rocks within the map-area. A few dykes strike northeasterly, but the most prominent set strikes north-northwesterly and belongs to the Mackenzie dyke swarm of Fahrig, *et al.* (1965). The main dykes range from about 40 to more than 300 feet thick and can be traced for many miles. Much thinner dykes, some only a few inches thick, were observed in places.

In most dykes, dark grey basalt in the narrow chilled margins grades inwards to medium-grained, equigranular, greenish grey gabbro with pronounced diabasic texture. Most thin sections reveal the presence of interstitial quartz and micropegmatite between altered grains of plagioclase and pyroxene. Uralitic hornblende and secondary biotite and chlorite commonly have replaced pyroxene. One dyke

(10a) in the northwest corner is in part composed of normal-looking diabase and in part of a reddish granophyric diabase differentiate. Another dyke (10b) in the southeast contains altered olivine as well as plagioclase and pyroxene, and in addition has large amygdules filled with calcite, quartz, and chalcedony.

A radiometric age of 1,245±75 m.y. has been reported for the large dyke of the Mackenzie swarm at the south side of Benjamin Lake, 63°08′N and 110°14′W (not 110°41′W as previously reported in Wanless, *et al.*, 1965, p. 42).

STRUCTURE

Folds

Within the map-area, planar structures in the Yellowknife Group strike northerly except north of Benjamin Lake where they swing to the east. These structures dip away from the marginal granitic terranes, steepening towards the central part of the Yellowknife belt where they are vertical.

A major complex anticline exposes volcanic divisions A and B of the Yellowknife Group in the western part of the area. The volcanic rocks are disposed about a core of meta-tonalite (1) in the form of a dome. North of the core, the plunge of the major fold axis changes gradually from northerly through steep easterly to southerly, so that the anticline turns over along its length. Subsidiary folds are formed where the volcanic rocks bend around the north end of the meta-tonalite core (*see* Fig. 8) A corresponding syncline to the southwest is arched southwest of the meta-tonalite body so that division A is exposed at the crest of the arch whereas division C is exposed in the trough of the syncline to the northwest and southeast of the crest. Faulting and the formation of migmatites have greatly complicated this structure. The volcanic rocks have been deformed by penetrative movement which caused original structures such as pillows and fragments to become flattened. Flattening is pronounced along the east flank of the meta-tonalite dome. It is especially severe along the whole west flank of the anticline where pillowed rocks are reduced to thinly layered amphibolites and the acidic rocks of division B are mylonitized in places. In the crest of the arched syncline southwest of the dome, pillows and fragments are stretched into columns or rods, forming a prominent lineation that plunges steeply to the southeast. At the north end of the meta-tonalite body, pillows appear little deformed in flows that dip gently to the north. It seems as if they were protected by their proximity to the meta-tonalite body which, although deformed in places, probably behaved as a relatively rigid block during deformation.

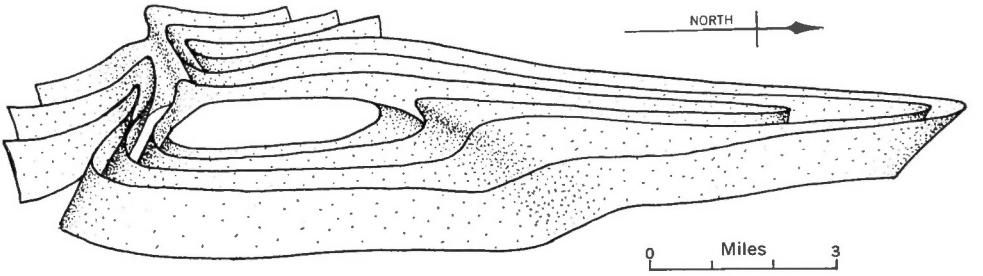


FIGURE 8. Simplified structural diagram of major anticline between Indian Mountain and Brislane Lakes.

Another major anticlinal structure exposes unit 5d, tentatively correlated with division B, in the central-southern part of the map-area. This structure probably consists of a number of closely spaced folds whose axial surfaces dip moderately to the east and whose axes plunge northeasterly.

The sediments of division C have been deformed into much tighter and more closely spaced folds than are present in the more competent volcanic rocks. Fold hinges are rarely exposed, although numerous folds are indicated by series of graded beds that face alternately to the east and west. Bedding is well preserved, especially in the sandy rocks, and small-scale sedimentary structures do not appear to have been deformed. Equant detrital grains in greywackes are separated by fine-grained matrix. Shale fragments are preserved in the basal parts of some graded beds. This evidence suggests that much of the movement during deformation took place along bedding and shear surfaces. It is probable that penetrative movement was confined to the argillaceous sediments. Continuous fold traces in division C can rarely be mapped, and those shown on the accompanying map have been inferred from sedimentary top determinations. Even in areas with much outcrop, tracing of folds in division C is hindered by lack of marker horizons and by the probability that many of the fold cores have been destroyed by shearing. The present disposition of bedding in many places suggests that slices of opposing fold limbs are stacked side by side. It appears that continuing compression caused initially formed flexural folds to become increasingly tightly closed until the prevailing stresses could only be accommodated by shearing of the folds with transport of fold slices upwards and out of the core of the fold belt.

The already deformed metasediments have been refolded in the vicinity of the granodiorite plutons. Steeply plunging open folds have formed where the metasediments bend around the stocks of unit 9C. Where the general trend of bedding turns towards the southwest contact of the pluton (9A) east of Waldron River, the metasediments are buckled into a series of folds whose axial planes are parallel to the contact and which become increasingly tight and more closely spaced as the contact is approached. Figure 9 shows this fold set and illustrates that both metasediments and interlayered pegmatites have been folded together. Folding about the plutons is interpreted as an accommodation feature formed during forceful intrusion of granodiorite magma.

Cleavage

The term cleavage as used here includes slaty cleavage in the low grade metasediments, schistosity in the knotted schists, mica foliation in the gneissic rocks, and platy cleavage in the metavolcanic rocks. Nearly everywhere cleavage is subparallel to bedding, or lies at a shallow angle with it. Where at an angle, the strike of cleavage is almost invariably displaced from bedding in an anticlockwise sense, regardless of the direction in which the beds face. It is therefore not an axial plane cleavage of the main folds and has a later origin. In places, however, mesoscopic folds whose axial surfaces are parallel to cleavage have developed in the limbs of the main folds. The angle between cleavage and the

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FIGURE 9. Late folding of metasediments and interlayered pegmatites attributed to intrusion of nearby granodiorite. These folds are within one limb of a pre-existing, large-scale fold within the metasediments. Most of the prominent outcrops on the far shore are of pegmatite. The location is $1\frac{1}{2}$ miles southeast of the centre of the small pluton of unit 9B in the southeast part of the map-area.

axial surfaces of the earlier folds suggests that the folds have been rotated. Cleavage was formed during the stage of deformation when the folds had attained maximum closure and when continuing deformation was accomplished by shearing.

Thin sections show that cleavage is due to the alignment of the earlier-formed metamorphic minerals, such as muscovite and chlorite in the low grade metasediments, muscovite in the knotted schists, and acicular amphibole in the mafic volcanic rocks. Biotite porphyroblasts are poorly aligned in the low grade metasediments, but the alignment of biotite improves with increasing metamorphic grade. The large porphyroblasts of andalusite and cordierite in the metasediments and of cummingtonite in the metavolcanic rocks are not oriented and commonly overprint the cleavage outlined by the earlier-formed minerals. Thus metamorphism was synkinematic at first, but did not reach its peak until essentially static conditions prevailed.

In some places, phyllites and slates in division C are crenulated. Some outcrops of knotted schists exhibit kink bands. Both crenulation planes and kink bands strike between northeast and east and dip steeply. Cleavage and biotite

porphyroblasts are bent around the hinges of crenulations. Cordierite is commonly altered along kink bands. These structures are therefore post-metamorphic and are not related to the main period of deformation.

Faults

Wherever the lithology is varied, as in the southwest, it was observed that small valleys commonly separate blocks of different rock types and that contacts are offset. In some places, blocks of the same rock type in which stratification has markedly different attitudes are separated by valleys. Although sheared rocks are rarely exposed in or at the sides of valleys, such valleys are assumed to conceal faults. Except where marked by pronounced alteration, faults can rarely be traced within the metasediments of division C or within the homogeneous granitic rocks, partly on account of uniform lithology and partly because the rocks are poorly exposed along suspected fault traces.

The most prominent set of faults strikes northeasterly and is subvertical. Where contacts are offset, displacement is dextral. One fault in the central-southern part has a dextral offset of about half a mile. Many of these faults are accompanied by alteration zones a few hundred feet wide on either side of a zone in which quartz-cemented fault breccia and silicified mylonite outcrop in places. In the outer parts of the alteration zones, biotite and cordierite in knotted schists are chloritized and plagioclase is sericitized. Towards the central parts of the fault zones the schists commonly have a bleached appearance. Granitic rocks near faults are reddened, constituent biotite has changed to chlorite, and joints are coated with epidote. In some places the altered granitic rocks are laced with milky quartz veinlets. In others, quartz appears to have been leached, leaving vuggy, friable rocks composed almost entirely of reddened feldspars with scattered grains of chlorite.

Faults that preceded intrusion of the granitic rocks have not been recognized. All observed faults are older than the diabase dykes (10).

METAMORPHISM

Metamorphic Mineral Assemblages

Increase in metamorphic grade has caused rocks of different compositions to display different sequences of mineralogic change. Although it is not possible to follow any one stratum through the complete metamorphic range, the mafic lavas of division A and the pelites and semipelites of division C are distributed widely enough and their original natures preserved well enough that their respective sequences of mineralogic change with increasing grade can be worked out. Division B, however, contains a great variety of rocks whose proportions vary, so that it has not been possible to evaluate the different metamorphic assemblages derived from any one type in this division.

In the field, the only noticeable changes in the mafic volcanic rocks accompanying rise in metamorphic grade are a general increase in grain size and the presence of garnet and cummingtonite at higher grade. The following description of mineralogic changes is based mainly on thin section examination. The lowest grade rocks are very fine grained, dark green amphibolites composed predominantly of fibrous amphibole and andesine with minor amounts of quartz, biotite, chlorite, and rare epidote. Pillow selvages are characteristically rich in biotite. With increasing grade, the amphibolites become darker and small garnets appear in some pillow selvages at about the same grade that chlorite and epidote disappear. The character of the calcic amphibole changes progressively from pale blue-green actinolite through blue-green to green hornblende and from fibrous to equant prismatic form. Plagioclase becomes more calcic with increasing grade, changing from andesine to labradorite. Cummingtonite first appears with hornblende at what seems to be a definite metamorphic grade; a cummingtonite isograd has been drawn on the accompanying map.

The lowest grade pelites and semipelites of division C are little altered slaty argillites and metagreywackes. Thin sections reveal metamorphic chlorite and muscovite in all rocks and biotite in most. In the direction of higher grade, the amount and size of biotite increase and the slaty argillites grade into biotite-spotted phyllites. The notable change from metagreywackes and phyllites to knotted schists is delineated by the cordierite isograd. Cordierite appears first in the pelitic rocks as large, ovoid poikiloblasts. Within a few hundred feet of its first appearance it is present in all rocks except the most quartzose greywackes. The appearance of cordierite is concomitant with the disappearance of fine-grained chlorite in the groundmass of the metasediments. Andalusite is rare in the pelitic rocks near the cordierite isograd, but becomes increasingly abundant in the

direction of higher grade towards the southeast part of the map-area. Staurolite was noted with andalusite in two specimens of knotted schist. Sillimanite is the next characteristic mineral to develop in the knotted schists, initially as the form fibrolite associated with red-brown biotite, and finally as patches of aligned, chunky crystals that are pseudomorphous after andalusite porphyroblasts. At higher grade than the sillimanite isograd, the schists lose their knotted character and grade into fine-grained, banded gneisses and finally into migmatitic gneisses in which cordierite and sillimanite are rare and restricted to biotite-rich layers.

The changing sequences of metamorphic minerals with increasing grade outlined above are illustrated in Figure 10. It is worthy of note that, within the metagreywackes of division C, amphibole-bearing concretions and lenses, probably once cemented with calcite or dolomite, show the same mineralogic changes as do the mafic volcanic rocks.

The acidic volcanic rocks of division B, represented mostly by quartzo-feldspathic schists and fine-grained granulites, do not change much with metamorphic grade. Less felsic members, notably the heterogeneous pyroclastic rocks, have produced (at higher grade) a variety of schists and granulites with irregularly scattered lenses, patches, and porphyroblasts of coarse hornblende, cummingtonite, biotite, and garnet. Coarse-grained cummingtonite-labradorite-biotite granulites, some with garnet, near the south end of Brislane Lake, may be the high grade equivalents of calcareous tuffs. Felsic breccias cemented with calcite show surprisingly little change with increasing metamorphic grade; scattered garnet, hornblende, calcic plagioclase, and possibly diopside grains are present in some breccias that are otherwise composed of fine-grained quartzo-feldspathic lenses in a coarse calcite matrix.

Nature of Metamorphism

Metamorphism has produced, on a regional scale, mineral assemblages that are commonly found in contact aureoles. Regional metamorphic grade ranges from upper greenschist to middle cordierite–amphibolite facies of the low pressure andalusite–sillimanite facies series (Miyashiro, 1961; Winkler, 1965). The cordierite isograd is well defined within division C, as it is elsewhere in the Slave Province (Lord, 1942; Henderson, 1941b, 1944), and is taken to mark the beginning of the cordierite–amphibolite facies. At higher grade the first appearance of sillimanite in division C separates the lower and middle subfacies of the cordierite–amphibolite facies. Within division A, the isograd denoting the first appearance of cummingtonite lies within the lower subfacies of the cordierite–amphibolite facies.

The lowest grade rocks are exposed south of Indian Hill Lake. Metamorphic grade rises over a shorter distance westward than it does eastward. To the west, the cordierite isograd is approximately parallel to and within about a mile of the granodiorite pluton (9A) west of the north end of Indian Mountain Lake, and appears to be related to it. To the east, it is not obviously related to any one granitic pluton, and has the character of a regional isograd. It is between 2 and 5 miles from the nearest granitic body, with the exception of the small stock

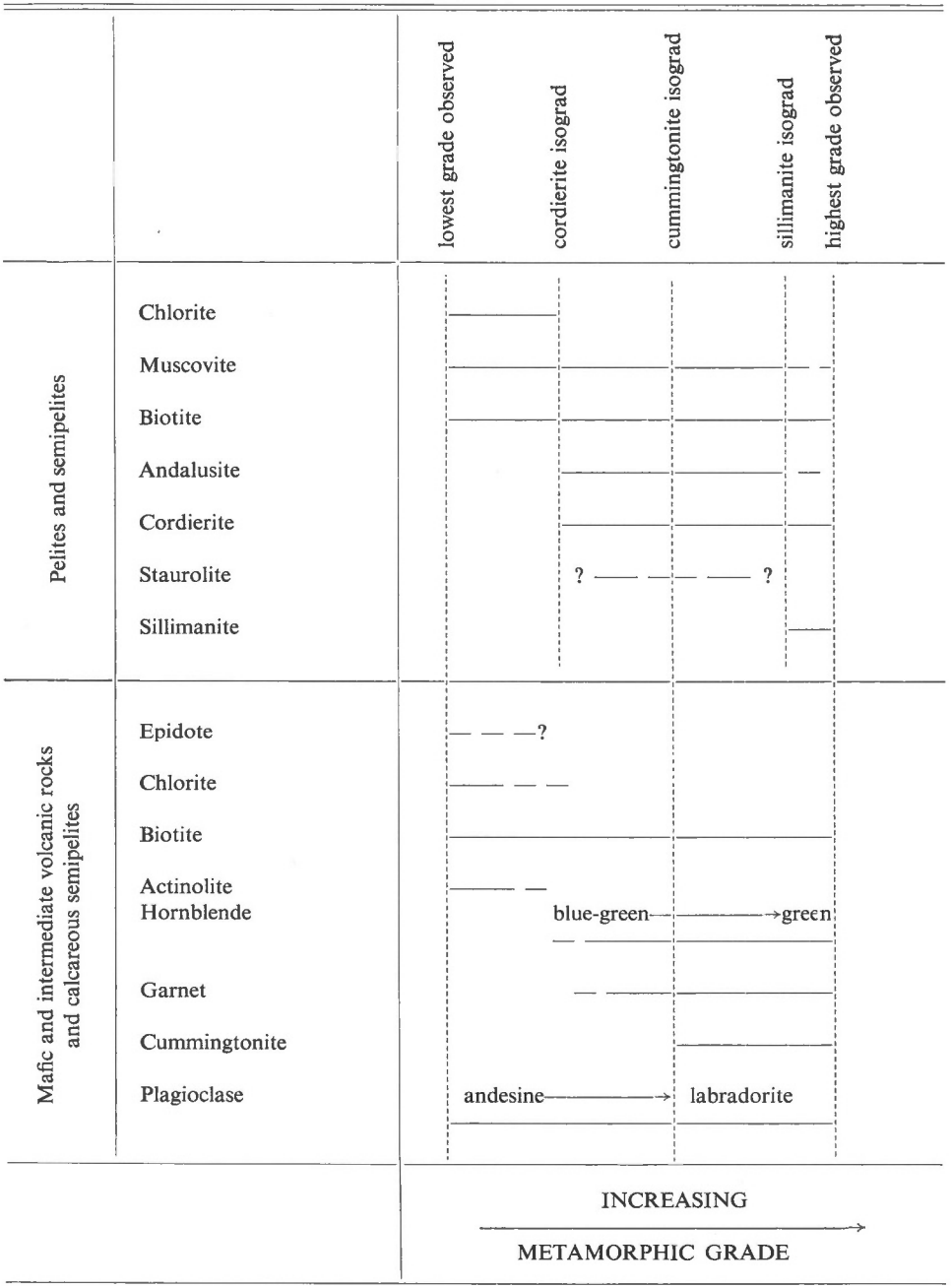

FIGURE 10. Diagram illustrating mineralogical changes with increasing metamorphic grade.

at the west end of Benjamin Lake. The western cordierite isograd, projected through the volcanic divisions parallel to and at a lower grade than the cummingtonite isograd, meets the eastern cordierite isograd near the narrows of Brislane Lake.

In the vicinity of Indian Mountain Lake the sillimanite isograd is much nearer to the neighbouring plutons than it is south of Brislane Lake where it lies about 1½ miles outside the region of migmatitic gneisses and where it is not closely related to granitic plutons. In the eastern part of the map-area, sillimanite is present in division C rocks to within a few tens of feet of the small granodiorite stocks (9C) and to within a few hundred feet of the batholith (9A) east of Waldron River. In addition to this local occurrence, it is more widely distributed in the northeast corner of the area in the rocks bordering the migmatitic gneisses and also in the southeast corner. The latter sillimanite isograd has been drawn on the accompanying map.

As noted earlier, andalusite porphyroblasts are rare in the knotted schists near the cordierite isograd, but become increasingly abundant towards the southeast. Coexisting cordierite and andalusite porphyroblasts were consistently noted during field mapping east of a line approximately parallel to and 5 miles east of the east cordierite isograd. The southeasterly increase in the amount of andalusite goes hand in hand with an increase in the biotite content and a decrease in the muscovite and cordierite contents of the schists. This change seems to be a regional metamorphic effect, and need not be attributed to compositional change of the rocks because these minerals are related by the equation:

$$\text{cordierite} + \text{muscovite} = \text{andalusite} + \text{biotite} + \text{quartz}.$$

The small granodiorite plutons (9C), within rocks of lower cordierite-amphibolite grade, have produced metamorphic aureoles within a quarter mile of their contacts. Aureole rocks are knotted schists that have different appearances to the regional knotted schists. Characteristically rich in biotite and andalusite, they either have a hornfelsic textured groundmass or are wrinkled schists of coarser grain than the regional knotted schists. The recognizable aureole along the west side of the batholith east of Waldron River is about half a mile wide and contains similar rocks except that they are rarely hornfelsic.

Distribution of isograds in the western part of the map-area seems to show a gradual change in the character of metamorphism from contact type in the north to regional type in the south. In the eastern part of the area, the regional character of metamorphism is demonstrated by the fact that the individual plutons have superimposed aureoles on previously metamorphosed rocks. It is possible that the isogradal planes, of which the metamorphic isograds are the surface expression, are steeply dipping where closely spaced and shallowly dipping where widely spaced, so that in fact the spacing of the isograds is relatively constant. According to this interpretation, the shallowly dipping isograds may not be far above a large, unexposed granitic mass of which the small stocks are cupolas. However, although there is no direct field evidence concerning the dip of the isograd

surfaces, metamorphism in the southwest part of the map-area, where the rocks change gradually from cordierite knotted schists through sillimanite-bearing schists to banded and migmatitic gneisses, certainly has a regional character. The eastern cordierite isograd appears to be too regular and too far removed from the granitic intrusions to the east to be considered as an aureole effect.

In summary, it is considered that the Yellowknife Group was regionally metamorphosed before the introduction of the granodiorite plutons. Granodioritic magma, probably generated at depth during metamorphism, worked its way to higher levels soon after regional metamorphism had reached its peak. Intrusion therefore is not the cause of metamorphism but rather is one effect of the tectonism that caused deformation, metamorphism, and intrusion in the Benjamin Lake map-area.

ECONOMIC GEOLOGY

The Benjamin Lake map-area has been intensely prospected since the discovery of base metals in the area south of Brislane Lake. Numerous test pits, trenches, and diamond drill sites attest to the interest that has been shown. Most of the work has been concentrated in the metavolcanic and metasedimentary rocks of map-units 4 and 5 that extend from Brislane Lake to Indian Hill Lake, and in the metasedimentary rocks (5d) that extend north from Susu Lake.

Quartz veins and stringers are widespread in the knotted schists and hornfels of division C but they are small, discontinuous, and not known to contain mineralization of interest.

Indian Mountain Metal Mines consist of a group of claims south of Brislane Lake, and about 8 miles north of McLeod Bay on Great Slave Lake. Zinc mineralization was discovered in 1948 and in the next two years drilling and trenching indicated 270,000 tons of ore containing 10.3% zinc, 0.85% lead and 3.45 oz silver per ton (Irwin, 1952). Mineralization, exposed intermittently for several hundred feet along strike, appears to be concentrated near the crest of a northerly plunging anticline on the southwest limb of a large southeasterly plunging syncline. The host rock is limestone or calcite cemented acid volcanic breccia, now a skarn in places, that underlies a massive quartz porphyry unit that contains clear quartz eyes. Surface trenching has exposed the ore zone which consists of disseminated to massive pyrite, sphalerite, pyrrhotite, and minor amounts of galena and chalcopyrite.

Numerous pits and diamond drill sites are located on the west side of Brislane Lake and on some of the adjacent islands. Mineralization consists of disseminated pyrite, pyrrhotite and chalcopyrite in metavolcanic rocks that are probably derived from both flows and pyroclastic rocks. Widely scattered grains of chalcopyrite are common in the meta-tonalite (1). Chalcopyrite and a small amount of secondary native copper on fracture surfaces were noted in frost heaved rubble at 63°05′30″N, 110°55′15″W. A thin lens of sphalerite, about a quarter of an inch wide, was observed in the same area.

A northerly trending belt of folded metasediments (unit 5d) extends north and south from Susu Lake. Several northeasterly trending dextral faults displace these rocks and numerous shears are parallel to the regional strike. Crystalline limestone beds and lenses ranging from a few inches to a few feet thick are interlayered with these metasedimentary rocks. Shallow pits and blast holes are evident in very fine grained quartz in the contact areas near the north end of Susu Lake, and near the northern end of the unit. These rusty, deeply weathered rocks contain disseminated pyrite and, rarely, some pyrrhotite and chalcopyrite.

A narrow vein containing small amounts of chalcopyrite and alloclasite in a quartz-siderite gangue strikes easterly within unit 5d on the southwest side of Susu Lake. Radiating steel grey needles of the rare mineral alloclasite ((Co Fe) AsS) form small rounded masses that are coated with erythrite on weathered surfaces.

Scattered hexagonal prisms of pale greenish white to cream beryl up to 4 inches long occur in pegmatite dykes at two localities in the southeastern part of the map-area. One pegmatite contains a few crystals of columbite-tantalite.

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