GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 69-42

PRECAMBRIAN GEOLOGY OF HECLA-CARROLL LAKE MAP-AREA, MANITOBA-ONTARIO (62 P E½, 52 M W½)

(Report, 15 figures and Map 11-1969)

I. F. Ermanovics

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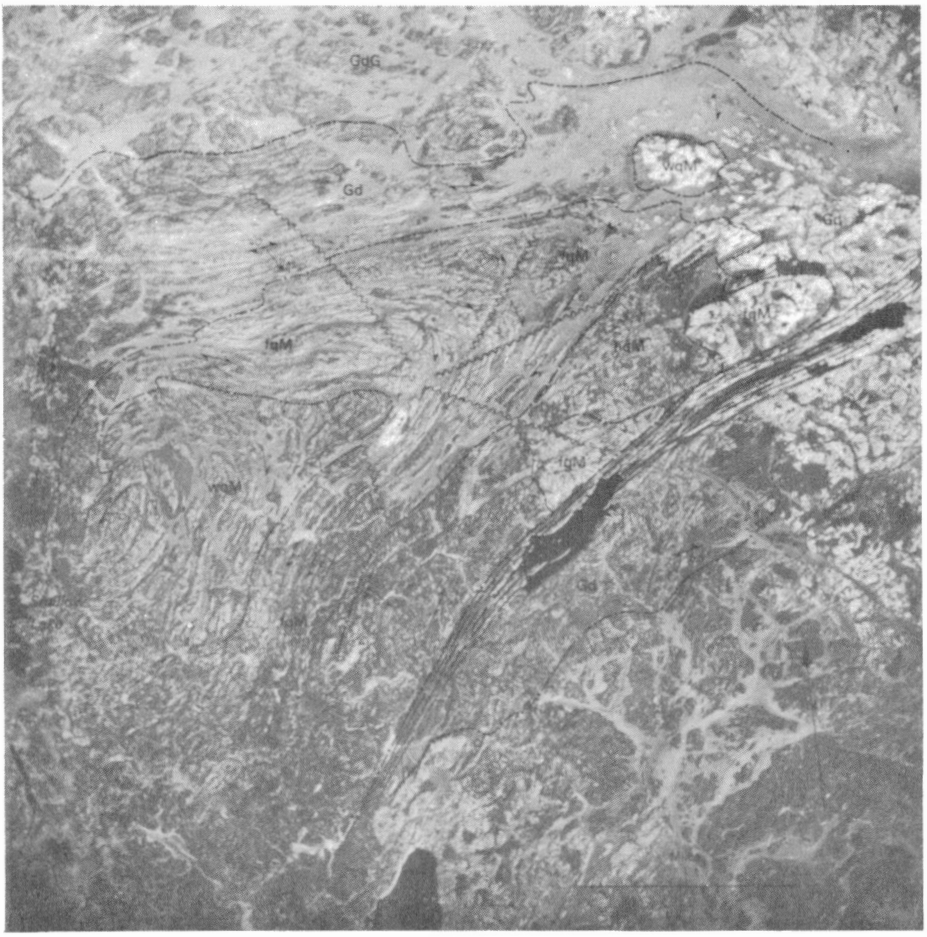
ABSTRACT

This report describes an area of Archean rocks east of Lake Winnipeg. Basic to intermediate lavas, irrupted onto a gneissic terrain, and psammitic and pelitic rocks deposited on a basement of lava, were intruded by granodiorite. Mineralization associated with quartz veins cutting the older sedimentary and volcanic rocks occurred 2,720 $\pm$ 185 m.y. ago. Later periods of intrusions resulted in other groups of igneous rocks, the youngest being massive quartz monzonite.

With the closing of San Antonio gold mine in 1968 active mining in the area ceased but claim-development work is active in most areas underlain by granodioritic rocks adjacent to metasedimentary and volcanic rocks.



Geological boundary (gradational)
Foliation (inclined, dip unknown)
Gneissosity (banding inclined, unknown)
Lineation (inclined)
Fault
Shear zone

Weakly foliated quartz monzonite . . . wqM
Foliated (biotite and quartz fabric) quartz monzonite . . . fqM
Hornblende gneiss and quartz monzonite gneiss . . . hqM
Hornblende gneiss and granodiorite gneiss . . . Gd
Banded granodiorite gneiss, mixed with granite . . . GdG

GSC

Frontispiece. Folded orthogneisses of Shallow Lake.

PRECAMBRIAN GEOLOGY OF HECLA-CARROLL LAKE MAP-AREA, MANITOBA-ONTARIO

INTRODUCTION

General Statement

The Hecla-Carroll Lake map-area (5,700 square miles), Manitoba-Ontario (95-97 degrees W, 51-52 degrees N) extends from the Ontario-Manitoba boundary on the east to Lake Winnipeg on the west and from the Rice Lake belt of metavolcanic and metasedimentary rocks in the south to the granodioritic[1] and monzonitic area of rocks in the north (Fig. 1). Most islands of Lake Winnipeg and its western shore are underlain by Paleozoic rocks.

The area has been mapped previously at four miles to the inch and parts at one mile to the inch. The purpose of this report is to compile and interpret the information of previous workers and to correlate with new data obtained during the 1968 field season. With the exception of the Paleozoic rocks the author and five assistants covered all of the area in reconnaissance fashion during the summer of 1968.

Pace-and-compass methods of traversing were utilized in selected parts of the area; systematic helicopter traverses (90 hours) were used to cover other parts. Typical of large areas of granitic terrains, lithofacies changes are gradual and hence difficult to establish during one summer's work. On the other hand, the 'birds-eye view' obtained over large distances from helicopter surveys enabled the author to formulate and alter working hypotheses from day to day.

One hundred and fifty thin sections were examined petrographically. Many sialic rock specimens were stained in order to estimate alkali feldspar content. In addition to visual estimates under the microscope of plagioclase-alkali feldspar ratios, a 1/4-inch grid on acetate paper fitted over the cut surface of the rock specimen gave another estimate of the feldspar ratio in 'granitic' rocks. Plagioclase compositions quoted in this report were estimated optically from curves plotting $X, Z_{\Lambda}(001)$ and $X, Y_{\Lambda}(010)$ against composition.

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[1] The igneous rock nomenclature in this report follows the usage of I. C. Brown (1967).

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Location, Industry, Access and Physical Features

The southern margin of the area lies 80 miles northeast of Winnipeg. The settlements of Manigotagan, Bissett and Wallace Lake are accessible by road. The remainder of the area is largely uninhabited except for a sparse population along the shore of Lake Winnipeg. The eastern shore of Lake Winnipeg is accessible by winter roads and is serviced also by fixed-wing aircraft and a lake-boat operated by Marine Transport Limited. Fishing and hunting lodges are scattered around inland lakes; these are serviced by aircraft. Commercial fishing on inland lakes is prohibited, except for a two-month season on Lake Winnipeg.

Wild rice is harvested from canoes by Cree and Saulteaux Indians and by automated rice-harvesters for export markets. Forest and wild-life management is well established. Forestry towers are located on Viking Lake, Sasaginnigak Lake, Bloodvein Indian Reserve, Bissett, Manigotagan settlement and on a lake just north of Gammon Lake. Although timber has not been cut from the area recently plans are underway for pulp exploitation.

The elevation of Lake Winnipeg is 712 feet; the highest point inland is 1,150 feet. Although the relief is low the area is rugged and difficult to traverse. All large rivers originate in Ontario and flow westward into Lake Winnipeg. The gentle slope toward the lake submerges the uneven surface forming strings of islands and shoals making navigation along the east shore treacherous. Rock outcrop is plentiful, but intervening areas are underlain by swamp lands.

The following rivers are readily navigable although with numerous portages: Pigeon, Bloodvein, and Gammon. Other rivers in the area, navigable with small canoe are: Leyond, Beaver Creek, Rice, Manigotagan and Wanipigow.

Previous Work

All rocks exposed along the east shore of Lake Winnipeg and eastward are Precambrian. The rocks were described early by Tyrrell in 1890 and 1891 by Dowling in 1895, and compiled by Dowling in 1898 (Tyrrell, 1898). The schists and metasediments were recognized by Tyrrell as the oldest rocks and classified as Huronian. Inland to the east, exploring the Bloodvein River as far as Sasaginnigak Lake, he mapped massive granitoid bodies which, near the shore of Lake Winnipeg, he reported as grading to 'granitite' gneiss. Here and there he refers to such irregularly foliated gneisses as 'typical Laurentian gneisses' and he recognized in them 'Huronian' rock inclusions. Along the shore of Lake Winnipeg, Tyrrell describes the contact between Huronian schists and younger gneisses as, "generally conformable", with gneiss apophyses intruding the schists at a large angle.

Moore (1912), working in Wanipigow, Manigotagan and Oiseau River areas and along the eastern shore of Lake Winnipeg, recognized three Precambrian units, the youngest being granite and gneiss. Tyrrell's Huronian rocks were divided into the younger Wanipigow Series (Huronian?) composed of conglomerate, arkose, greywacke, chert, jasper, gneiss and schist and unconformably below this the Rice Lake Series (Keewatin) consisting of greenstone quartz porphyry, rhyolite, trachyte, felsite and schist.

Subsequent work by Cooke (1921) and Wright (1932) showed no marked unconformity between Moore's sedimentary and volcanic divisions although here and there thin beds of conglomerate are present at the base of the sedimentary group. Both series were combined by these authors to form the Rice Lake Series which was divided into three phases on the basis of local lithologies. These were, from oldest to youngest (Wright, 1932, p. 12), the Manigotagan Lake phase (quartzose and clayey sediments), the Beresford phase (lavas, tuffs, iron-formation and chert), and the Wanipigow phase (intercalated flows and bedded deposits). Thus Moore's Wanipigow Series became partly older and partly younger than the lavas. Attempts to find the provenance of granitic boulders in sediments proved unsuccessful.

Johnston (1936a, b), dealing with the area of the present report, explored the northern 'granitic terrain' and the rocks of the Rice Lake Series. He dropped the formational names but recognized a predominantly sedimentary group overlying volcanic rocks and postulated a sequence of plutonic intrusions and development of hybrid gneisses. The earliest intrusions were interpreted as being granodiorite and quartz diorite followed by a granitic phase. It was primarily during this time that remnants of greenstone were recrystallized and incorporated into magmatic rock to form gneisses. This event was followed by the emplacement of alkali-rich magma into existing granodioritic rocks producing large areas underlain by hybrid magmatic rocks. Gneisses were of two types: predominantly paragneiss and predominantly orthogneiss with greenschist inclusions.

Stockwell (1938) found at Rice Lake that some sediments were conformable with the lavas whereas others overlay sediments and lavas with marked structural unconformity. Thus the rocks were again divided into two units. He retained the name Rice Lake Series for lavas and interbedded sediments and introduced the name San Antonio Formation to designate the younger sediments at Rice Lake. The San Antonio sediments therefore are recognized as younger than the adjacent quartz diorite and subjacent Rice Lake Series which includes porphyry dykes, sediments and lavas.

Russell (1948, 1949) and Davies (1949, 1950 and 1951) prepared five 15-minute geological maps forming the southern portion of the present area. Their map-units for the Rice Lake Group rocks are listed in Table 1; numbers in each slot refer to numbers of the map accompanying this report.

Stockwell (in Lowdon, 1961, p. 54) sampled five localities in the area for K-Ar age determination of biotites as part of the Tectonic Map of the Canadian Shield project. The indicated ages confirmed that the Aikens Lake granite (2,440 m. y.) is younger than the mafic granodiorite (2,670 m. y.) north of Wallace Lake (Russell, 1948) which is equivalent in age to granodiorite (2,670 m. y.) intruding rocks of the Rice Lake Series. Thus he agreed that 2,670 m. y. is a minimum age for the Rice Lake Series and a maximum for the San Antonio Formation. The stratigraphically upper part of the Rice Lake Series extends southward through injection paragneiss (1,700 m. y.) into a young granite inferred to be 1,700 m. y. old. Stockwell suggested that the Rice Lake and San Antonio rocks were deformed at this time. The metasedimentary rocks at Manigotagan settlement, however, yield an age on metamorphic muscovite and biotite of 2,455 m. y. and 2,435 m. y. respectively. This age is coincident with that of the Aikens Lake intrusion of 2,440 m. y.

Turek and Peterman (1968) studied the geochronology of the area using Rb-Sr. Their results appear in Table 2. The most significant change

TABLE 1

Comparative table showing stratigraphic sequence of Rice Lake Group rocks as developed by Davies, Russell and Stockwell

Legends of various workers[1]	Manigotagan-Rice River area, Davies, 1951	English Brook area, Russell, 1949	Wanipigow Lake, Davies, 1949	Wanipigow River area[2], Davies, 1950	Wallace Lake area, Russell, 1948	Definition of Rice Lake Series[2], Stockwell, 1938
7				Quartzite, slate, tuff (5)		Trachyte breccia, porphyritic dacite breccia
6				Rhyolite breccia, partly porphyritic; interbanded tuff and rhyolite flows (2)	Granitized arkose and quartzite (5)	Porphyritic andesite
5				Porphyritic andesite and dacite breccia, trachyte breccia (agglomerate) (1)	Chiefly quartzite, arkose greywacke, conglomerate (4)	Basalt
4	Arkose, tuff, quartz-sericite schist; minor conglomerate (5)		Quartz-biotite-feldspar, quartz-hornblende gneiss derived from 2; injection gneiss (7a)	Andesite porphyry, basalt, porphyry, minor breccia (1)	Chiefly volcanic flows, rhyolite, andesite and basalt (2)	Tuff, arkose conglomerate
3	Quartzite, impure quartzite, subordinate derived quartz-mica schist some with garnet and staurolite (4)	Quartzite, micaceous quartzite (some with staurolite and garnet), arkose, slate and tuff and probably some beds of greywacke (4)	Hornblende-plagioclase gneiss, chlorite schist derived from 1; injection gneiss (7b)	Arkose, conglomerate, tuff (4)	a) chiefly iron-formation b) chiefly limestone in part silicified (3)	Porphyritic basalt
2	Rhyolite, rhyolite porphyry, rhyolite breccia (2)	Tuff with some thin interbedded quartzitic layers (4a)	Quartzite, tuff, slate minor conglomerate arkose and chert (4)	Andesite, basalt, largely schistose; chlorite schist (1)	Vesicular and amgdaloidal lavas; chert; graphitic slate (1)	Rhyolite, trachyte, andesite, breccia
1	Andesite, basalt, chlorite schist (1)	Rhyolite, porphyritic rhyolite, amygdaloidal greenstone, agglomerate, andesite, basalt and gabbro and metamorphic rocks [in part (1)]	Rhyolite, dacite, andesite, basalt; porphyritic and amygdaloidal phases; agglomerate; iron-formation (1)	Rhyolite, rhyolite porphyry, trachyte; some breccia, interbedded sediments (?) (1)	Andesite, basalt; some iron-formation; slate, tuff, schist	Porphyritic andesite breccia

[1] Areas are arranged from west to east between Long. 96° 30' and Long. 95° 15'. Lithologic types in horizontally adjacent slots are not necessarily stratigraphically equivalent. Stockwell's work includes regions south of the present area. Numbers in parenthesis are those of the map-units used in this report.

[2] Area in which San Antonio Formation is recognized (feldspathic quartzite, minor conglomerate).

TABLE 2

Summary of K-Ar[1] and Rb-Sr[2] geochronology of the Hecla-Carroll Lake map-area

Material dated	Location	Age (in millions of years)		Comments
		K-Ar	Rb-Sr	
Foliated quartz monzonite and granodiorite	8 determinations southeast and west of Wallace Lake and north of Rice Lake		whole-rock: 2550 ± 80	These rocks belong to a group of some of the earliest granodiorites intruding the Rice Lake Group; they are regionally lenticular, weakly to strongly foliated, occasionally porphyritic, bodies whose solid-solution mineral components and type of mafic minerals vary. Individual rock descriptions for the Rb-Sr determinations are unpublished but samples for the 8 determinations probably include compositions ranging from quartz monzonite to granodiorite.
Massive, biotite, zoned andesine granodiorite	Faraway Lake; 50° 55'00"N 95° 26'03"W	biotite: 2670 ± 125		
Foliated hornblende-biotite granodiorite	4 miles north of Wallace Lake; 51° 05'40"N, 95° 22'35"W	biotite: 2670 ± 125		
Gold-bearing quartz veins	7 determinations from veins in Rice Lake Group rocks and San Antonio Formation		sericite and fuchsite: 2720 ± 185	Quartz, gold and gangue are considered to be coeval and cogenetic; isochron defines gold mineralization.
Rice Lake Group phyllites	6 determinations from north of Rice Lake and from Long Lake		whole-rock; 2490 ± 90	Ages for the metasedimentary rocks date shearing and retrogressive upper greenschist mineral assemblages; the phyllite-shearing isochron defines a tectonic event coincident with quartz monzonite intrusion at Aikens Lake and probably at Leyond Lake. These intrusions are chemically distinguished from earlier granodiorites by virtue of their greater alkalinity.
Rice Lake Group garnet-biotite-muscovite-chlorite-quartz schist	Manigotagan settlement; 51° 06'40"N 96° 18'54"W	biotite: 2435 ± 125 muscovite: 2455 ± 125		
Massive, porphyritic quartz monzonite bearing quartz, microcline, oligoclase, biotite and muscovite	Aikens Lake; 51° 11'40"N 95° 18'00"W	biotite: 2440 ± 125		
Shear zone in San Antonio Formation	Rice Lake; 51°2'19"N 95° 43'50"W		sericite and crushed arkose: 2530 ± ?	The Rb-Sr age of 2720 m. y. of a quartz vein in the San Antonio Formation and the shearing (2530 m. y.) give minimum ages for the rocks and shearing respectively.
Micropegmatite transgressive upon biotite paragneiss and alkali-rich quartz monzonites	Tooth Lake; 50° 44'29"N 95° 20'7"W; belt extends into present map-area		whole-rock 2630 ± ?	The crystalline, hybrid gneisses here, as elsewhere, date very closely the early intrusion of granodiorite. The young K-Ar age date (1700 m. y.) of these rocks at Black Lake is probably related to remobilization of alkalies associated with a mylonite zone just north of Black Lake.
Fresh, red-brown, biotite paragneiss with granitic 'lits'	East end of Black Lake; 50° 38'45"N 95° 18'00"W	biotite: 1700 ± 90		

[1] Mica determinations from Lowdon (1961) and Lowdon et al. (1963, reprinted 1968).

[2] Whole-rock determinations from Turek and Peterman (1968); ages were calculated using the decay constant 1.39×10^{-11} yr^{-1}.

with their interpretation is that sericite and fuchsite associated with a quartz vein cutting the San Antonio Formation gives an Rb-Sr age date of 2720 ± 185 m. y. They interpret this date to be a minimum for both the Rice Lake and San Antonio rocks. They confirm that both the rocks of the Rice Lake Group and the San Antonio Formation were sheared at 2, 530 m. y. which together with the Aikens Lake quartz monzonite (2, 440 ± 125) represents a major geological event in the area.

Church and Franchi (1968), remapping the Wanipigow Lake area, delineated a dacite body for the first time and recognized the main sedimentary rocks of the Rice Lake Group as the stratigraphic equivalents of the San Antonio Formation. In a written communication Church states, "The boulders in this conglomerate (tonalite boulders in feldspathic quartz wacke matrix) were derived from the tonalite-diorite complex located immediately to the north just as the San Antonio Formation in the type area 5 miles to the east, is composed mostly of the erosion products of adjacent granitic bodies". This new hypothesis in interpretation of Rice Lake Group rocks requires testing for rocks east and west of the Wanipigow area. If correct, the work of Church and Franchi would substantiate Moore's (1912) original thesis that the "Huronian rocks" comprise an upper, younger sedimentary "Wanipigow Series" and an older predominantly volcanic "Rice Lake Series". The two Series[1] would be then only locally separated by marked unconformity as at Rice Lake.

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GENERAL GEOLOGY

Description of Formations

Rice Lake Group (1-5)

The detailed lithologies of the Rice Lake Group[2] are listed in Table 1 after Davies (1949, 1950 and 1951), Russell (1948, 1949) and Stockwell (1938). Stockwell's work on the "Rice Lake Series" included regions to the south of the present area. The rocks in their respective areas are well described by

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[1] As indicated below, in a footnote, the term 'Group' has recently superseded the term 'Series' in the present map-area; the former term is used throughout the remainder of the report. However, original terms of the authors in the above historical review have been retained to prevent confusion in discussing their work.

[2] The term 'Group' rather than 'Series' is used because the Rice Lake rocks do not constitute a clearly designated time-stratigraphic interval.

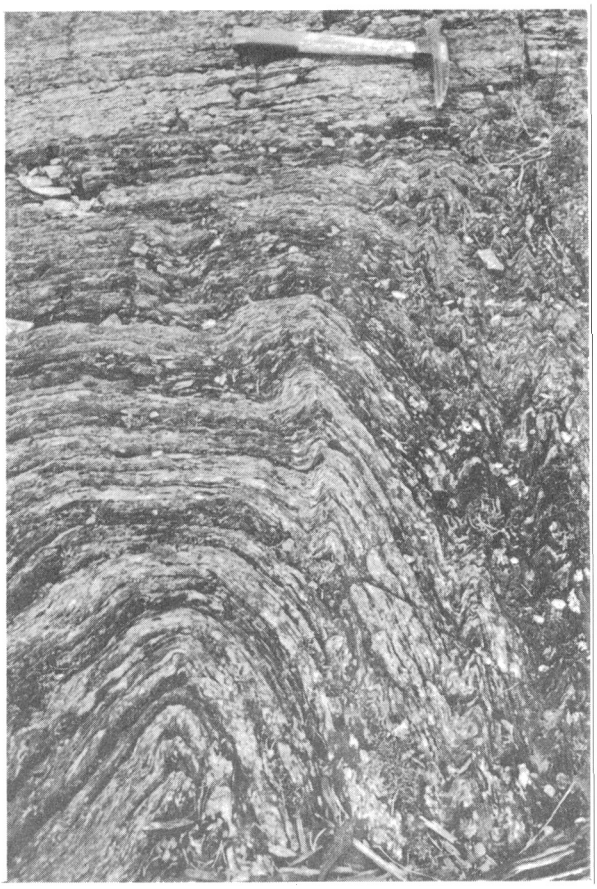


Figure 1. Fold in basic flow rocks in 'decollement' style against unfolded foliation at the top; south of Obukowin Lake in mylonite zone (146904).

these workers and only a summary discussion of them is given here for the purpose of describing the Rice Lake 'greenstone' belt as a whole.

At the base of the column are basic to intermediate flow rocks (1), here and there intercalated with pyroclastic and sedimentary rocks. They are either variously foliated or massive. Pillow-bearing lavas are common on Wallace Lake and Black Island areas. Elsewhere the rocks have been metamorphosed to prevailing greenschists (Figs. 1 and 2). Commonly basic lavas grade to gabbro. A large concentration of mafic rocks transitional from basalt to gabbro underlie a large area south and west of Wanipigow Lake. The unit (1) as defined in this report, pinches out between granodiorite (11) and sedimentary rocks (4) at Manigotagan settlement; it extends the length of the greenstone belt to east of Rice Lake where it pinches out to reappear on Wallace Lake. It is in this unit near the contact of a tuffaceous rock on Rice Lake, that a diabase dyke with gold-bearing quartz veins was the site of the last operating mine in the area - San Antonio Mines.

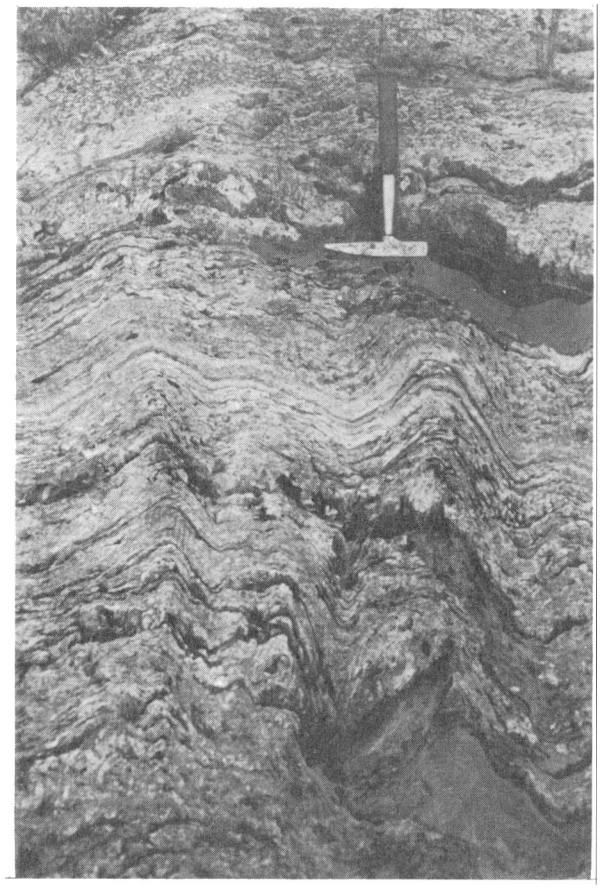


Figure 2. Crenulated basic flow rocks with axial plane cleavage; Grey Point south of Black Island on Lake Winnipeg (146900).

It should be noted that Davies (1950) reported that in the Wanipigow River area rhyolite and rhyolite porphyry flows underlie more basic flows of the Rice Lake Group. However, Stockwell (1938), mapping a stratigraphically lower portion of the same rock group farther south, reported that porphyritic andesite breccia constitutes the lowermost member of the Rice Lake rocks. None of the rock types of these intermediate to basic flow rocks are very thick or uniform in dimensions along strike. Banded cherty, magnetitic iron-formation is intercalated with basic flows on the north shore of Wanipigow Lake and Wallace Lake.

Acid to intermediate volcanic rocks (2) overlie more basic volcanic rocks in the Manigotagan-Rice River (Davies, 1951) and Wallace Lake (Russell, 1948) areas but are not differentiated from (1) in the English Brook

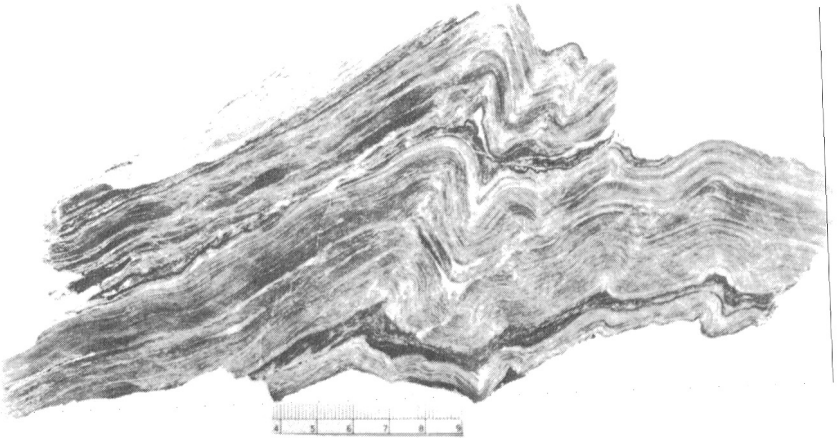


Figure 3. Folded greenschist (unit 2); Wallace Lake (200956-C).

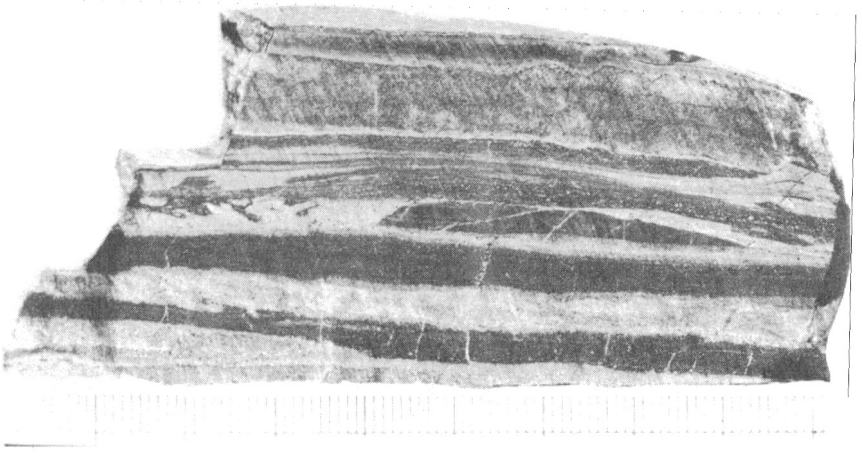


Figure 4. Banded iron-formation (unit 3); Wallace Lake (200956-G)

and Wanipigow Lake area.[1] Acid to intermediate flow rocks comprise cherty, amygdaloidal and porphyritic flows which are commonly schistose (Fig. 3). Intercalated tuffaceous and greywacke rocks are more common in this part of the section than in underlying parts. Pillow forms are rare. The designation of these rocks in the map-area is, to a certain degree, a function of their mappable thickness; areas in which these rocks are readily mapped are found in the eastern portion of the greenstone belt.

Iron-formation (3) as mapped by Russell (1948), includes magnetite-bearing bands interlayered with fine-grained, dense biotite-hornblende gneiss, minor silicified limestone, and chert. On Wallace Lake iron-formation lies

[1] Church and Franchi (1968) have recently distinguished dacite from basalt and both rock-types from volcanogenic sediments.

in unit 2; whereas westward and on the north shore of Wanipigow Lake it occurs in rocks of unit 1. On Wallace Lake, individual magnetite-chert bands rarely exceed 1/2 inch in thickness (Fig. 4), but intervening magnetite-bearing gneissic bands, form zones 30 feet thick. Structural interpretation of the iron-formation on Wallace Lake is ambiguous; it may lie in the trough of a syncline and hence be younger than rocks of unit 2 or, alternatively it may be intercalated in the acid flow rocks and therefore may be in part older and in part younger than rocks of unit 2.

The greatest exposed thickness of sedimentary rocks (4) occurs in the western part of the Rice Lake belt. They grade upward from rocks of unit 2 through tuff interbedded with quartzose sediments to sandstone, chert and conglomerate. Quartzite, impure quartzite and sandstone constitute the bulk of unit 4; arkose, slate, chert and greywacke are subordinate. Some thin quartzite members bear noticeable purity of 98 per cent quartz with a delicate blue-green colour. Crossbedding, graded-bedding and lenses of imbricated pebble arrangement are discernible despite superimposed schistosity. Garnet, staurolite, biotite and muscovite are common in pelitic and psammitic layers as discussed later in this report. At Manigotagan settlement the sediments are exposed continuously for four miles. Allowing for structural distribution these sediments have an estimated true thickness of 10,000 feet.

The uppermost, presumably conformable, phase of sedimentation (5) in the area was first recognized by Davies (1951) in the Manigotagan-Rice River area. These sediments are coarser and more feldspathic than those of the Manigotagan section. It is likely that the arkose, conglomerate and tuff sequence of the Wanipigow Lake area should be also included in unit 5. In Table 1, arkose, conglomerate and tuff of Davies (1950) lie midway in a symmetrical sequence of lavas but below the quartzite, slate and tuff which is akin to the Manigotagan suite of sediments. Whether the coarser, feldspathic sedimentary members are older or younger than the finer grained, quartz-rich and pelitic members is uncertain and this is discussed below.

Contact Relationships

Individual lava flows or sedimentary units are commonly difficult to distinguish from adjacent units. Outcrops are not plentiful and marker beds - except for iron-formation on Wallace Lake - are absent. 'Walking-out' beds along strike reveals the presence of many offsets and changes of lithologies; much of the rock is schistose. All these factors make detailed stratigraphic compilation difficult. In favourable areas the impression gained is that no one lithology is distinguished by thick beds. Of the three 'phases' embracing sedimentary and volcanic rocks as defined by Wright (1932) only the quartz-rich sedimentary, 'Manigotagan phase' is recognizable and then only because intercalated flows are scarce.

The sediments form the upper unit of the Rice Lake Group. The lower portion may be separated here and there from the lower volcanics by a conglomerate (Stockwell, in Lowdon, 1961, p. 54).

Contacts with igneous plutonic rocks are invariably sheared. A mylonite zone is developed at the contact south of Obukowin Lake. A fault or shear zone separates the greenschists of Black Island from stratiform

gneiss of the mainland on Lake Winnipeg. The number, size and type of altered 'greenstone' inclusions in the margins of the plutons vary. The plutonic rocks, in turn, contain zoned plagioclase (normal, continuous, and normal and reversed oscillatory types). Such basic border zones also show an increase of mafic minerals (chloritized biotite and hornblende) as compared to areas farther away from the contact. Anisotropic sedimentary-volcanic rocks bear lit-par-lit apophyses of the adjacent intrusion; competent isotropic layers bear granitoid lenses and knots. Apophyses extending from bodies of diorite, quartz diorite and granodiorite generally have a quartz monzonitic composition: such acid phases are also common in the basic to intermediate plutonic rocks. It has not yet been demonstrated what relationship these relatively potassium-rich phases have to the intrusions where they are irregularly distributed throughout. Shearing of the contacts produces epidotized plagioclase augen which may be either a primary magmatic or a cataclastic feature of the border phase. Conglomerate-like forms in greenschist in contact with stratiform gneiss or foliated igneous rocks have been observed by Tyrrell (1898) east and west of Hole River and by the author on Wallace Lake and Rice River Bay. Again, however, extreme shearing and contact metamorphism makes distinction between possible basal conglomerate and lenses produced from shear movement, unlikely, and probably impossible.

San Antonio Formation (6)

Grey feldspathic quartzite and minor conglomerate (6) at Rice Lake lie unconformably against porphyritic andesite breccia of the Rice Lake Group (1 or 2) and on granodiorite and diorite (11). The formation forms tongues in fractures in granodiorite and has a coarse basal unit recognized along Gold Creek. The rocks show crossbedding at many localities (Stockwell, 1938; Davies, 1950). Laths comprise quartz grains surrounded by films of hematite as well as pebbles of rhyolite, red granite, quartzite and pale greenschist. The rocks vary from massive to schistose and west of Rice Lake have been folded into an east-trending syncline overturned to the south.

Banded Gneisses (7, 8)

Quartz-biotite-feldspar and quartz-hornblende gneiss[1] derived from sedimentary rocks, and hornblende-plagioclase gneiss and chlorite-albite-zoisite schist derived from volcanic rocks, together with injection gneiss were classified by Davies (1949) as belonging to the Rice Lake Group. It is suggested here that such rocks, except where they are intercalated with recognizable sedimentary and volcanic rocks, should not be included in the Rice Lake Group because some gneisses (e.g. magmatic flow gneiss) may be older than rocks of the Rice Lake Group. Additionally, there is danger that the group name would be applied to all banded gneisses away from the greenstone belt including hybrid orthogneisses resulting from later shear deformation.

The two gneiss units (7) and (8) are distinguished on the basis of composition and type of banding. Unit 7 is a broadly banded stratiform gneiss

[1] Mineral modifiers preceding the noun are in order of increasing abundance.

containing three subunits. Member 7a is a varicoloured quartz-biotite-feldspar, quartz-hornblende gneiss with granitic and quartz monzonitic layers. The bands vary from thin laminae to broad layers one foot thick. Intercalated with and occasionally indistinguishable from 7a is 7b, which comprises quartz-feldspar-hornblende-biotite gneiss and includes amphibolite gneiss. Rocks of subunit 7b occur primarily along the shore of Lake Winnipeg where they underlie a sheared belt 50 miles long extending from Bloodvein Bay to Hole River Bay. Locally, lenses of greenschist, chert, and blue-green quartzite are interlayered. The largest remnant of quartzite is 300 feet long and 17 feet thick. Lenses of greenschist ranging from one foot to 30 feet long, appear as giant augen in orthogneiss. Rocks of 7a probably represent a recrystallized sedimentary rock copiously injected with monzonitic materials; whereas 7b represents more closely compositions expected from recrystallized mafic (lava?) rocks less affected by processes of granitization.

Greenschist inclusions, common in rocks of subunit 7b, are composed of approximately 25 per cent epidote, 25 per cent chlorite and 10 per cent carbonate together with 40 per cent quartz and feldspar. Black, fine-grained, dense gneiss (amphibolite) associated with iron-formation contains, on the average, 65 per cent amphibole, (X=light brown, Y=olive green, Z=deep green), 10 per cent epidote, 20 per cent andesine (occasionally zoned, An_{44-34}) and 5 per cent quartz. Feldspathic varieties contain perthitic microcline, oligoclase and biotite (fawn brown to deep brown) with only 30 per cent amphibole. The amphibole is generally aligned parallel to the foliation and is serrated and poikiloblastic. All stages of textural changes from incomplete to complete recrystallization were observed. Quartz monzonitic layers vary in their oligoclase to microcline ratio between 1:2, and 2:1. The fabric is granoblastic, poikilitic with amoeboid grain outlines, and generally shows disorganized, intergrown fabric.

The third member (7c) is in part probably both older and younger than the Rice Lake Group. The rock is medium grained, granoblastic and consists of folded mafic lenses in a dominantly white granodioritic rock. Garnet-biotite-quartz-andesine and muscovite-biotite-quartz-andesine gneiss are most common. The type locality is two miles southwest of the northern cusp of Beaver Creek. The rocks are isoclinally folded (Fig. 5) with axial planes dipping southeast and axes plunging southwest. In the light-coloured fraction, plagioclase (An_{45-50}) is the most abundant phase (65 to 80 per cent) as part of a granoblastic, medium-grained fabric; alkali feldspar is generally absent, except adjacent to pegmatite veins; quartz constitutes 15 per cent, and combined biotite, muscovite and garnet, 5 to 15 per cent. Epidote, chlorite, apatite, zircon and opaques are either accessory or secondary minerals. Mafic portions differ only in their greater content of biotite; pink garnet occurs in both light and dark layers in equal amounts. Structures in the rocks bespeak mobility, folding, subsequent shear deformation, faulting, brecciation and at some stage, absorption of the mafic fractions (Figs. 5 to 12). Compositionally, the light-coloured fraction resembles granodiorite; however, it is now completely recrystallized and may represent the basement upon which the Rice Lake Group was deposited. During subsequent magmatic intrusion the overlying rocks were incorporated and both were recrystallized to produce andesine + quartz + muscovite + biotite + garnet gneiss. No igneous rocks in the area except gabbro contain as calcic a plagioclase as does

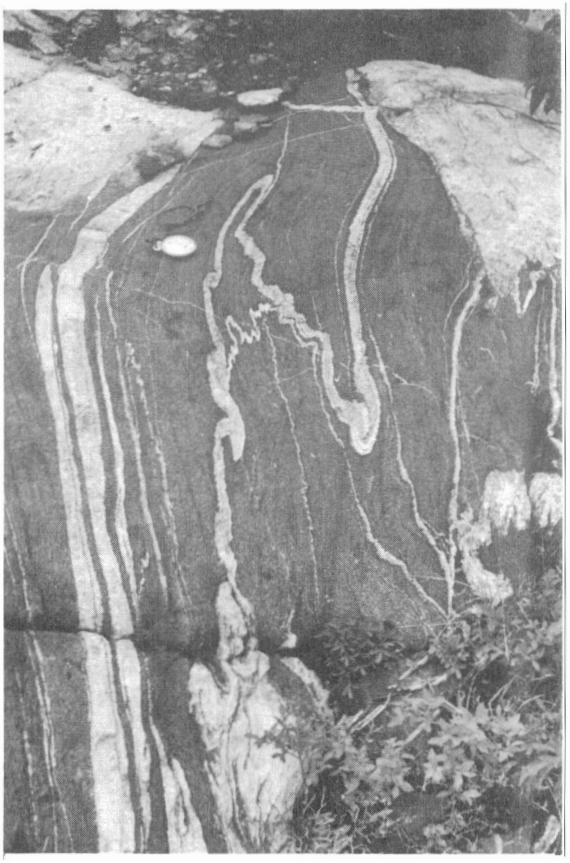
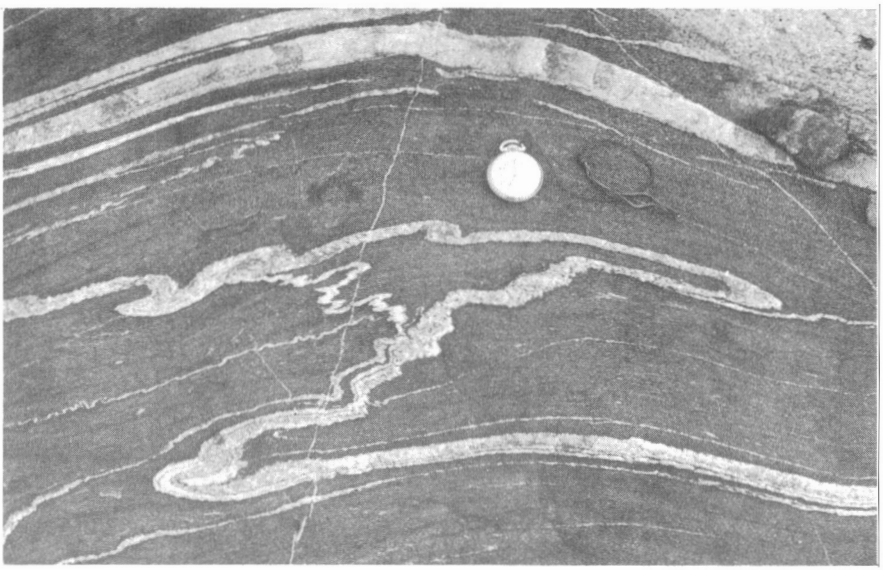


Figure 5.
Isoclinally folded, garnetiferous mafic and granodioritic gneiss (7c). Beaver Creek locality (146889).

Figure 6.
Detail of Figure 5 (146888).



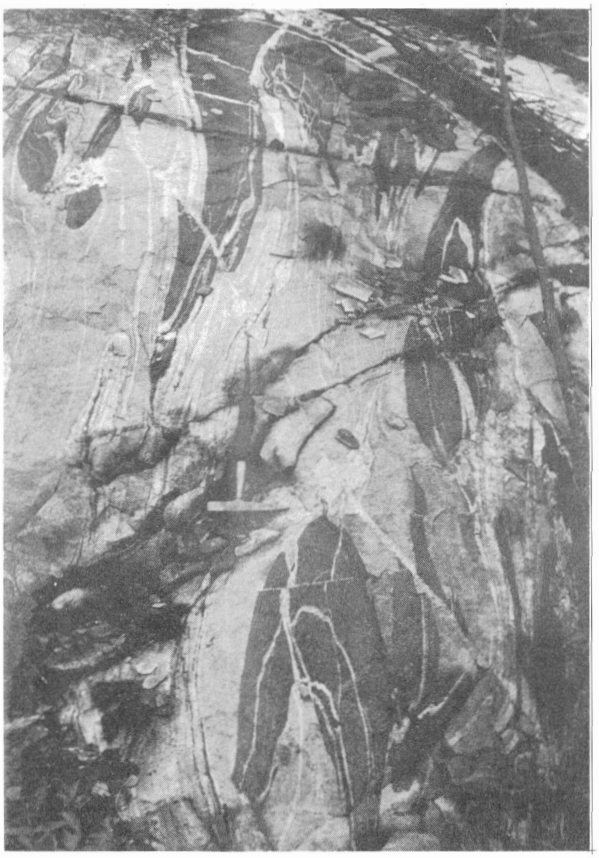


Figure 7. Folded and faulted, discontinuous, mafic gneiss markers in granodioritic gneiss (7c); Beaver Creek locality (146891).

this gneiss. The Beaver Brook and Shallow Lake regions represent structurally deep, high-temperature, keels of folds of the Rice Lake Group.

On Gammon Lake a pelitic band in rocks of unit 7c is grey, fine grained, granoblastic granular with 2 mm garnet porphyroblasts. The rock bears garnet + sillimanite + cordierite + biotite +An_{40} + quartz. Cordierite is pinitized; idioblastic garnet is poikilitic with quartz and has the composition of almandine 64 per cent, pyrope 21 per cent and grossularite 15 per cent. Sillimanite occurs as prismatic forms in cordierite and as needles in plagioclase. Cordierite and biotite, and sillimanite and biotite were not found to be in contact with one another.

Unit 8 is also a banded gneiss, but differs from the members of unit 7 in containing fewer mafic bands and by being both texturally and compositionally similar to hybrid, foliated granodiorite in the area. Alternating bands consisting of monzonitic, mafic granodiorite and granodioritic rocks constitute unit 8a. The rocks show seriate grain gradation, are fine to

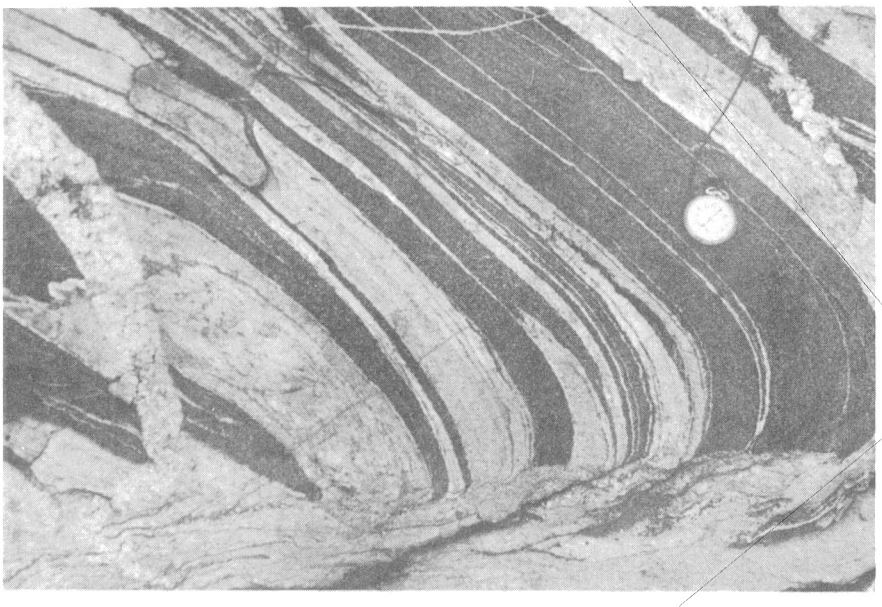


Figure 8. Drag-fold truncated against shearing plane. Beaver Creek locality, unit 7c (146897).

coarse grained, pink to grey and often granular. Quartz commonly exhibits mortar texture and recrystallized domains. Plagioclase compositions vary from An_{26} in salic fractions to An_{37} in mafic fractions. Mafic portions are fine grained, granular and contain sodic andesine, quartz and from 25 to 60 per cent biotite and hornblende generally in equal proportions; epidote, apatite, zircon, sphene and opaques are most common in mafic members. Alkali feldspar is usually absent. Augen texture is a common feature of 8b.

These rocks may have originated in higher structural levels adjacent to limbs of folds rather than in deeper, underlying 'keel' areas. Between Obukowin Lake and the Wallace Lake mylonite zone this relationship is clearly demonstrated. In this area basic agglomerate schists and cherty layers grade into adjacent granodiorite. Between these two end-members (units 1 and 11) rocks of units 8a and 8b are readily traced. However, included here also are probably rocks associated with major lineaments which may be shear or fault zones producing similar textural change through metamorphism producing banded gneiss; mafic granodiorite (11d and 11e) has the appropriate composition to produce such gneisses as, for example, on Pigeon River and Obukowin Lake.

Hybrid Quartz Monzonite to Granodiorite Gneiss (9)

This unit is structurally, compositionally and texturally heterogeneous. A single outcrop commonly displays a complex assortment of lithologies including fine- to medium-grained, granular, foliated, white to grey granodiorite, biotite-rich selvages, pink, massive, coarse-grained quartz

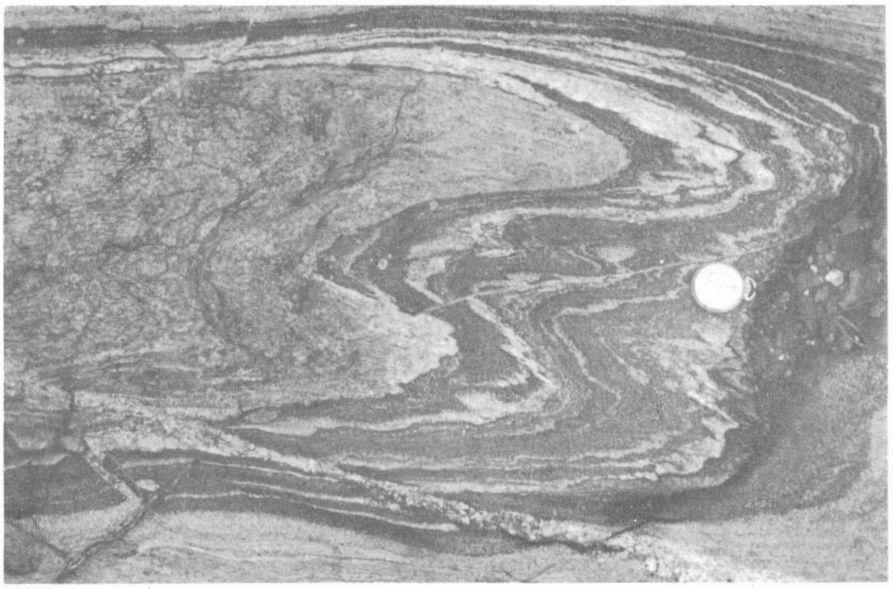


Figure 9. Shear-fold in garnetiferous gneiss; Beaver Creek locality (146881).

monzonite, zones of knotted pegmatite monzonite and inclusions of adjacent units. Here and there the presence of numerous long, extended mafic inclusions has produced a stratiform foliation similar in general appearance to that in the rocks of units 7 and 8. Such rocks form a transition zone between homogeneous plutonic rocks a few miles inland from the rocks of unit 7 along the shore of Lake Winnipeg. Tyrrell (1898) called them 'Laurentian gneisses' because of their textural and structural characteristics. Mafic inclusions are granitized in varying degrees but the unaltered members contain sodic andesine (occasionally zoned), amphibolite and biotite; alkali feldspar is absent. In quartz monzonite and granodiorite, feldspar constitutes 60 to 80 per cent of the rock; plagioclase to microcline ratios vary from 1:1 to 2:1; plagioclase compositions remain as oligoclase in both rock types. Quartz is abundant (30 per cent) and is usually strained or recrystallized commonly being aligned parallel to the foliation. Both biotite and hornblende (5 to 15 per cent) occur in the rocks but usually not in the same hand specimen. Some granodioritic fractions, although weakly permeated with alkali feldspar, are similar to rocks of unit 7c. The monzonitic fraction is commonly massive except where it has been injected into gneiss; this magmatic phase probably belongs to the massive granodiorite intrusions (11) or the Sasaginnigak Lake series of plutonic rocks (15).

From Virrs Point to Observation Point on Lake Winnipeg and in areas southeast from there and Duncan Creek various rock types, mainly quartz diorite, granodiorite, quartz monzonite and alaskitic granitoids, are broadly interbanded. Numerous quartzofeldspathic dykes intrude these rocks. The high degree of irregular shearing and the many 'greenstone' inclusions in these rocks along the shore of Lake Winnipeg suggests that the

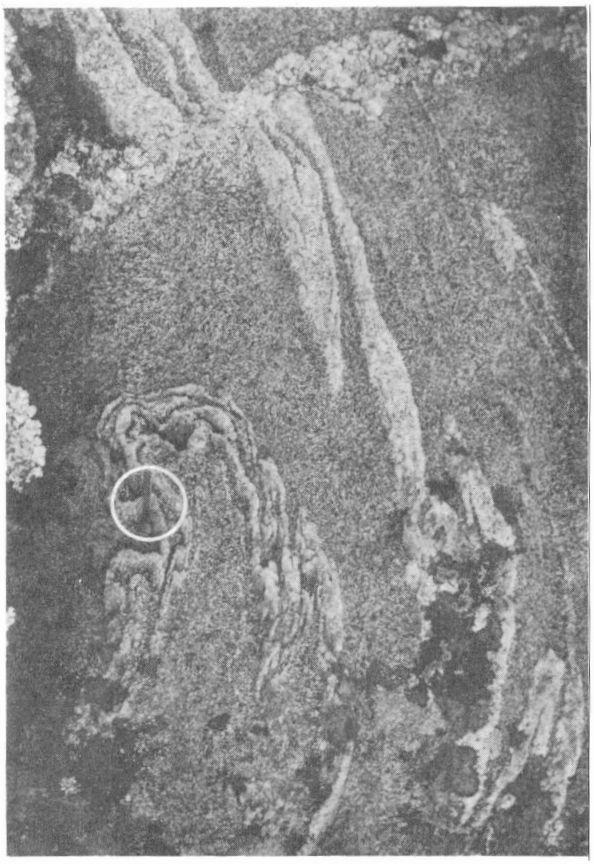


Figure 10. Folded, quartz-feldspar pegmatite in unit 7c; Beaver Creek locality. Match in middle-left indicates scale and plunge of fold (146886).

shoreline must describe the contact with submerged 'greenstones'. Farther inland the shearing is less pronounced. Here the rocks within each compositional band are massive. There is no evidence to suggest that these gneisses are derived from sediments. Thus the inference is that they are orthogneisses which have been differentiated from various crystalline magmatic phases during a major period of metamorphism to which are attributed also the rocks at Beaver Creek and Shallow Lake. The Loon Bay suite, although including stratiform rocks, is easily demonstrated to be a part of the post-Rice Lake Group, simply because it contains inclusions of recognizable sedimentary and volcanic rocks. Therefore it is suggested that the type of rocks exposed near Observation Point and Duncan Creek areas represent original pre-Rice Lake Group basement material. Such material may be the source of pink granitic pebbles (third and oldest granitic phase discussed by Stockwell in Lowdon, 1961) found in lenses at the base of the upper stratigraphic part of the Rice Lake Group. The rocks at Observation Point would be expected to yield a

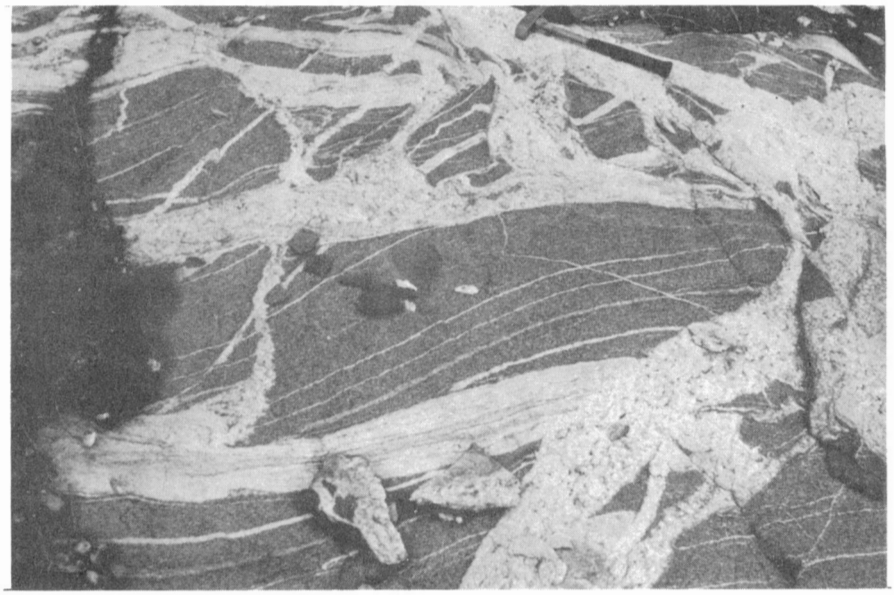


Figure 11. Brecciated gneiss (unit 7c) pervaded by pegmatite; Beaver Creek locality (146893).

K-Ar date on biotite or muscovite similar to that of the Manigotagan sediments (4) of 2,450 m.y. (metamorphic biotite and muscovite) which is also the K-Ar age of the Aikens Lake rocks (17). The Aikens Lake rocks represent the first major alkali-rich intrusion. Alkali metasomatism, probably of the same age as the Aikens Lake Intrusion, pervaded all older rocks and produced phenocrysts, knots, dykes and sills rich in alkali feldspar. Consequently within the confines of the present study the oldest rocks give some of the youngest K-Ar ages.

Gabbro, Quartz Gabbro and Diorite (10)

Gabbroic sills, dykes and lensoid stocks intrude the Rice Lake volcanic rocks and post-volcanic granodioritic rocks. Probably several periods of gabbro emplacement are represented but no attempt has been made to differentiate them. True gabbros occur along the Broad Leaf Lake belt, near Little Beaver Lake, and east of Rice Lake. Many of these were petrographically analyzed by Scoates (1968) who classified the gabbros into ophitic, spotted and orbicular varieties. Ultramafic rocks in the area were distinguished by him as serpentinized ultramafic lenses, a hornblende peridotite dyke and a stratiform complex composed of alternating layers of serpentinized peridotite and pyroxenite. The rocks east of English Lake, north of Manigotagan settlement, Shallow Lake and Black Island, are coarse grained, biotite-amphibole-quartz gabbro with dioritic phases; however diabasic gabbro lenses are found here also. The gabbro bodies in the eastern part of the area - especially those interlayered with lavas - are medium grained and

Figure 12. Absorbed mafic gneiss selvages in granodioritic gneiss (unit 7c); Beaver Creek locality (146894).

contain abundant plagioclase laths. In contrast those in the west are coarse-grained, and strongly foliated; also, augite is altered either to deep green hornblende or to actinolite with serpentine. East of English Lake the gabbro is associated with hornblende-plagioclase gneisses not unlike the mafic inclusions present elsewhere in the area. After these events the resulting complex was intruded by diorite and the entire pile was then sheared. A bright pink almandine is present in altered ultrabasic rocks (10a) at English Lake; epidote forms rims between hypersthene and plagioclase and between plagioclase and augite; pyroxene is rimmed by green hornblende. Labradorite (An_{55}) is 70 per cent saussuritized.

Quartz Diorite, Diorite and Granodiorite (11)

These rocks are well described by Davies (1950, 1949) and Russell (1949). A brief summary is offered here in addition to accompanying

petrographic notes. Rocks of this composition form large ovoid bodies (daipirs?). They are restricted in distribution to the southern part of the area where they lie adjacent to Rice Lake Group rocks and gneisses derived from them. Consequently, they are confined geographically to the southern part of the area. The rocks are medium to coarse grained and locally strongly foliated parallel to the irregularities of their margins; plagioclase (andesine) is green-pink as a result of epidote alteration. Many of these rocks show evidence of alkali metasomatism which has produced alkali feldspar phenocrysts. In one such area, near a 'greenstone' contact, zoned plagioclase crystals contain two major zones; an inner zone of composition An_{35} and an albitic overgrowth (An_8) which has destroyed the euhedral shape of the grain. Alkali feldspar is rare to absent; the content of oligoclase or andesine ranges from 55 to 60 per cent, quartz 15 to 30 per cent, and combined biotite and hornblende 10 per cent. Epidote and muscovite porphyroblasts formed in highly sheared recrystallized phases; elsewhere epidote forms laths on plagioclase or is part of saussurite on plagioclase. Green quartz eyes are a common feature of these rocks.

A distinct mafic phase (11d, 11e) is bounded by Wallace, Broad Leaf and Obukowin lakes. Here, amphibole, alone or together with biotite, commonly constitutes 40 per cent of the rock. Plagioclase is sodic andesine and is invariably saussuritized imparting a white-pink colour to the plagioclase in hand specimens. In the member designated 11e, alkali feldspar is rare or absent. The amount of quartz is generally less than 10 per cent. Biotite is chloritized. Amphibole (X=pale brown, Y=deep green, Z=green), poikilitic with quartz, is altered by chlorite and epidote; here and there amphibole has recrystallized to a green amphibole aggregate. Apatite, sphene, zircon and opaque minerals are ubiquitous. Mafic granodiorites are readily recognized as foliated inclusions in outcrops on Carroll Lake in rocks designated unit 11c and northwest of Gammon Lake in rocks designated as unit 13.

Rocks underlying the area just east of English Lake were designated by Russell (1949) as part of the Rice Lake rocks. The area is mainly inaccessible. Only small outcrops of basic greenschist (7) were found by the author; these in turn are intercalated with medium-grained, commonly granular plagioclase-hornblende gneiss, altered ultrabasic lenses and granodioritic phases of unit 11 of which the most common is 11e. The lithologic mélange was subsequently sheared and faulted making distinctions of various rock types difficult. A similar lithologic and structural mélange underlies the islands of Pipestone Rock on Lake Winnipeg where rocks are serpentinized and contain greenschist inclusions. The area east of English Lake contains copper-nickel gossans and prospects; outcrops of similar composition, which are part of unit 11e and situated just north of Wallace Lake, are being actively prospected also.

This unit constitutes a group of intrusive rocks which have given the oldest indicated absolute age dates in the map-area (Table 2). Thus biotite from hornblende-biotite granodiorite on the east shore of a lake 4 miles north of Wallace Lake (51°05'40"N, 95°22'35"W) gives a K-Ar age of 2,670 ± 125 m.y. (Stockwell in Lowdon, 1961). Biotite from granodiorite on the south shore of Faraway Lake (50°55'00"N, 95°26'05"W) also gives a K-Ar age of 2,670 ± 125 m.y. (Stockwell in Lowdon, 1961). Similar rocks dated by Turek and Peterman (1968) using a Rb-Sr isochron method yield ages of 2,550 ± 80 m.y.

Foliated and Porphyritic Granodiorite (12)

The rocks of this unit constitute a monotonous group of porphyritic and foliated, coarse-grained, white granodiorite with minor monzonite and diorite. They underlie a large region in the western part of the area where the foliation trends northwesterly. The belt of rocks and the foliation in it bend north and southward around the Sasaginnigak rocks (15). This suite may be equivalent to the granodiorites of unit 9. However, their dissimilar textures and structures makes this uncertain at present. The unit has four divisions: (12a) foliated granodiorite, (12b) bearing plagioclase augen or alkali feldspar phenocrysts, (12c) bearing monzonitic zones of inclusions and (12d) bearing mafic gneiss zones of inclusions. The rocks are similar to those described by Chown (1958) for Carroll Lake map-area (east half).

Granodiorite generally contains less than 10 per cent biotite or less commonly hornblende; quartz averages 10 per cent and alkali feldspar is usually absent except for rocks in 12b and 12c. Foliation is effected by alignment of biotite, recrystallization of quartz into lenses, and by streaks of mortar laminae; plagioclase augen texture is common. Plagioclase compositions vary from An_{27} to An_{34}; they are zoned and exhibit both Carlsbad and polysynthetic twins. Areas such as Hobbs Lake are underlain by rocks which are pervaded by a coarse-grained foliated monzonite phase with an alkali feldspar to plagioclase ratio of 3:4. Phenocrysts of perthitic microcline occur in these rocks in a medium-grained granodioritic matrix. Locally they occur in such great quantities that they are mapped separately.

Sugary-textured mafic gneiss inclusions constituting rocks of unit 12d, contain zoned andesine with Carlsbad and multiple twins. Biotite and hornblende commonly constitute 20 to 40 per cent of the rock. Biotite is deep brown to red brown; amphibole (X=pale brown, Y=green, Z=dark green) occurs as subhedral cross-sections. Sphene is abundant and locally is found as poikiloblastic forms.

All rocks of this unit are foliated and are thus akin to the hybrid granodiorite and monzonite gneiss of unit 9. The foliation in the granodiorites of unit 11 is not pervasive but rather concentrated near contacts and inclusions of adjacent schists and gneisses. On this basis it appears that units 12 and 9 may have been influenced by the same metamorphism, whereas rocks of unit 11 were not, the inference being that unit 11 is younger than unit 12.

Granodiorite, Minor Diorite (13)

Granodiorite of unit 13 represents the second major period of magmatic intrusion. The period is marked by intrusive rocks that are younger and smaller than those characterized by rocks of unit 11. Granodiorite of unit 13 occurs mainly adjacent to the Sasaginnigak rocks with which they are probably comagmatic; inclusions of foliated rocks, recognized as parts of units 11e, 11d, 9 and 12, are found throughout this unit.

The granodiorites and diorites are massive, medium to coarse grained, white-grey and generally bear plagioclase subhedra. Plagioclase of the diorites is saussuritized, zoned (An_{32} to An_{24}) and well twinned; plagioclase of granodiorites is calcic oligoclase (An_{29} to An_{25}). Alkali feldspar is perthitic and ranges from 15 per cent in granodiorite to less than 5 per cent

in diorites where it occurs primarily as antiperthite in plagioclase. Quartz constitutes from 15 per cent in granodiorites to less than 10 per cent in diorites. Biotite and hornblende (in equal amounts) form 10 per cent of the rock in diorites, and less than 5 per cent in granodiorites. Epidote (3 per cent), zircon, apatite, sphene and opaques are common accessory minerals.

Quartz Monzonite (14)

Monzonitic phases occur locally in many places. Where possible they have been designated separately with rock units with which they are associated e. g. (13a, 13b). These phases most commonly take the form of irregular masses with indistinct boundaries. Alkali feldspar embays plagioclase grains; in the matrix alkali feldspar is interstitially distributed with occasional amoeboid, serrated, large grains. Quartz generally shows strain extinction and here and there occurs in recrystallized forms within ovoid lenses.

The porphyritic phase (14a) bears alkali feldspar phenocrysts (10 to 30 mm in length). The phenocrysts may constitute 20 to 30 per cent of the rock, show simple twins, are poikilitic with matrix materials, contain string and patch perthites and lie in a medium-grained quartz monzonite matrix. Quartz varies from 5 to 20 per cent and biotite and hornblende from 10 to 25 per cent. The proportion of alkali feldspar to plagioclase averages 5:2. 5.

A persistent feature in the lowlands of the Family Lake area is a horizontally jointed, mafic, medium-grained granodiorite or diorite layer rising 2 to 10 feet above lake levels (Figs. 13 and 14). Andesine has a tendency to lath development, exhibits simple, multiple and pericline twins and is zoned (An_{37-25}). Quartz averages 5 per cent and biotite and hornblende combined average 25 per cent. This mafic rock grades into porphyritic quartz monzonite and quartz monzonite. The constant occurrence of this mafic phase below the porphyry suggests derivation by a process of layered magmatic differentiation, the porphyritic unit actually representing a thin sheet-like body. Rapid horizontal rock gradations with changes in relief of the Sasaginnigak Lake phase (15) similarly suggests that this body is not thick.

Red, leucocratic, fine- to medium-grained quartz monzonite phase (14b) is mapped separately and included here because of its usual geographic proximity and similar composition to unit 14.

Quartz Monzonite to Granodiorite (15)

This massive, coarse-grained, buff pink igneous phase is centred about Sasaginnigak Lake and intrudes the alkali-rich unit 14, massive granodiorites of unit 13, and granodiorite gneiss of unit 12. The rocks of unit 15 are intermediate to quartz monzonite and granodiorite in which the plagioclase to alkali feldspar (perthitic microcline) ratio varies 5:2. 3, 5:3 and 1:1. Calcic oligoclase (An_{24} to An_{27}) is present in quartz monzonite and sodic andesine in granodiorite. The granodioritic fractions contain zoned plagioclase and resemble those of unit 13. Quartz ranges from 10 to 20 per cent. Biotite, the most common mafic mineral, averages 5 to 8 per cent. In addition to the coarse-grained pink-white granodiorite phase associated with

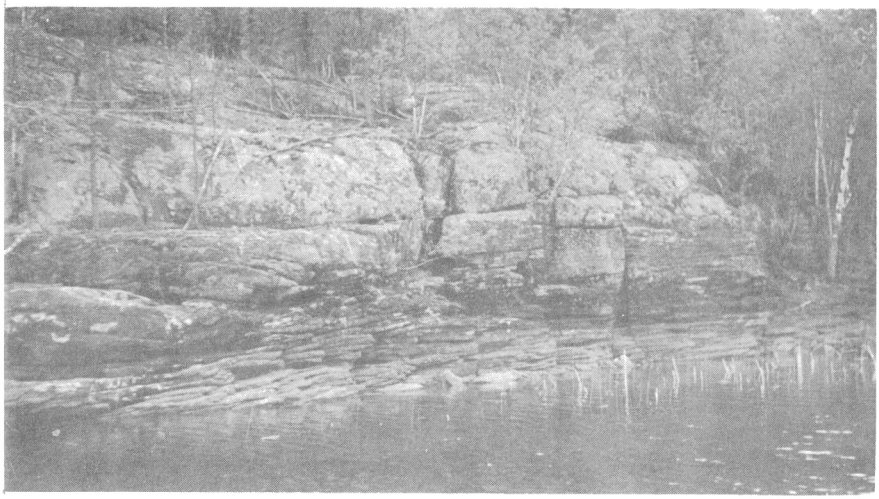


Figure 13. Basal, mafic granodiorite (horizontal jointing) grading upward to porphyritic quartz monzonite (14a); Pigeon River, east of Viking Lake (146905).

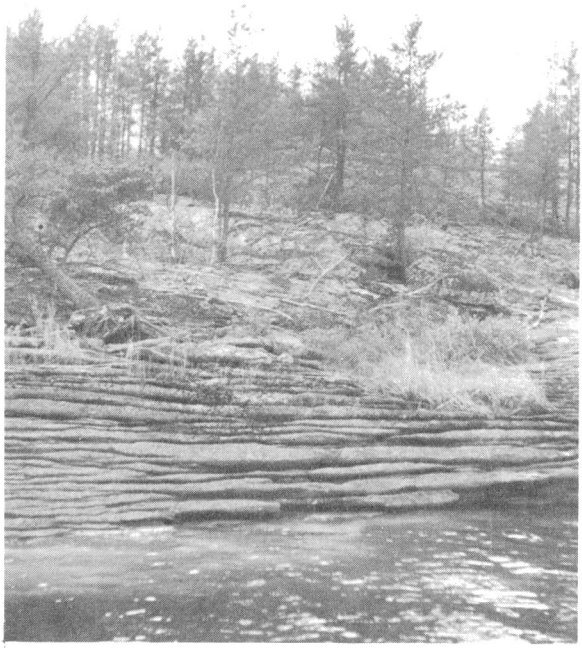


Figure 14. Basal, mafic diorite (horizontal jointing) grading upwards through porphyritic quartz monzonite (14a) to quartz monzonite (14) on top; string of lakes south of Shining Falls of Family Lake (146906).

the monzonite is a medium- to fine-grained, light-grey, granular granodiorite in the form of large inclusions (?) whose edges are indistinct and whose extent, size and origin are difficult to determine.

Undifferentiated Rocks (16)

An undifferentiable magmatic mélange of granodiorite and minor diorite (13), quartz monzonite (14) and quartz monzonite of the Sasaginnigak Lake type (15) occurs in areas underlain by rocks of unit 16. The rocks are locally weakly foliated and bear abundant monzonitic pegmatite.

Leucoquartz Monzonite (17)

Large-scale magmatic intrusions ceased with the emplacement of an alkali-rich, pink, medium-grained, massive leucoquartz monzonite which here and there contains small plagioclase or microcline phenocrysts. The term 'leuco' is prefixed to the rock name because the alkali feldspar (microcline perthite) to plagioclase (oligoclase An_{22} to An_{25}) ratios (5:3.5, 4:3.5, 1:1) lie intermediate to granite and quartz monzonite. Quartz averages 10 to 15 per cent and biotite, together with opaques, epidote, apatite, and sphene, rarely exceed 5 per cent. The rock at Leyond Lake is massive, tough, equigranular and fine to medium grained. Feldspar and quartz are intimately intergrown; myrmekite, symplektic intergrowth and graphic texture, are common.

A similar rock extends from Bushey Lake to Aikens Lake (Aikens Lake granite of Russell, 1949). At Aikens Lake the quartz monzonite contains 10 per cent pink alkali feldspar phenocrysts (5 to 15 mm in length) in an intergrown matrix (symplektic intergrowths) of microcline, oligoclase, myrmekite and quartz (10 to 15 per cent). Again biotite (partly altered to chlorite), epidote and muscovite constitute only 5 per cent of the rock volume. On the east shore of Aikens Lake (51° 11'40"N, 95° 18'00"W) a K-Ar age determination of biotite from an outcrop of monzonite gave 2,440 m.y. which is the same as the biotite/muscovite age in the Manigotagan metasediments but younger than the age of 2,670 m.y. obtained for the mafic granodiorite (11e) north of Wallace Lake and granodiorite (11) south of Rice Lake.

Inclusions

Mafic inclusions in massive igneous rocks as far as 80 miles from Rice Lake Group rocks and areas of gneiss (units 7, 8 and 9) form zones some of which are large enough to be mapped (e.g. 12d). The host rock of such zones is invariably weakly foliated granodiorite. The inclusions are all mafic-rich differing only in their basicity of plagioclase. While some inclusions are probably pieces of disconnected diabase dyke (e.g. Viking and Vickers lakes) others are more likely inclusions of recrystallized volcanic rock. The inclusions at Vickers and Viking lakes contain zoned laths of calcic andesine, 2 to 5 per cent quartz, 30 per cent amphibole, 15 per cent

biotite, and 5 per cent opaque minerals and apatite. Other inclusions elsewhere are coarse grained amphibolite bearing 60 per cent chloritized hornblende.

The majority of inclusions, however, are fine to medium grained, granular, with a salt and pepper texture, and contain various amounts of host materials. Unaltered inclusions bear 10 per cent quartz, 20 to 30 per cent hornblende or biotite, 20 per cent alkali feldspar and 50 per cent plagioclase. Plagioclase is generally well twinned, has lath forms and is zoned (An_{35} to An_{25}). The maximum absorption of biotite is deep brown to red brown. Apatite, sphene, opaques and zircon are common and abundant; muscovite, epidote, and chlorite are common alteration phases.

Winnipeg and Red River Formations (18, 19)

The Paleozoic rocks mapped by Baillie (1952) except for two previously unmapped islands (Goose and Little Punk islands), were not investigated by the author.

Goose Island has one outcrop 3 feet high and exhibits fossiliferous, knobby, buff-coloured sandstone. One 'grindstone' concretion 2 1/2 inches thick and 10 inches in diameter was removed from the top bed. Little Punk Island is underlain by similar rock. Both are shown on the present map as Red River Formation.

Metamorphic Grade

Metamorphic grade ranges from lower greenschist to upper amphibolite facies. The rocks of the area are characterized by steep metamorphic gradients. Structurally and mineralogically they grade from rocks bearing primary bedding and flow features to rocks altered to slates, phyllites, schists, gneisses and hornfels. Thin pelitic layers in plutonic igneous rocks reach biotite - garnet - cordierite - sillimanite grade. Basic lavas north of Saxton Lake are reported by Davies (1949) to grade from epidote-bearing andesite and basalt through chlorite schist to fine- to medium-grained acicular hornblende-plagioclase gneisses.

Lavas of the Rice Lake Group are represented by low grade, grey-green schists bearing saussuritized plagioclase, chlorite, epidote and magnetite. In basaltic or sheared pseudo-gabbroic rocks hornblende, pyroxene and plagioclase are altered to a mat of saussurite, chlorite and epidote. Epidote in 'greenschists' actually exceeds chlorite by 2:1. In more altered rocks green biotite forms from chlorite. Carbonate, talc and tremolite impart a greasy lustre to some fragmental volcanic rocks.

In the sediments of the Rice Lake Group biotite + pink garnet $\pm$ muscovite occur in quartzose rocks, whereas thin pelitic bands contain biotite + muscovite + staurolite.

Metamorphic mineral associations are shown schematically and tabulated in Figure 15 (in pocket). The ACF and AKF representation of mineral associations here lack chemical data control (e. g. determination of excess K_2O or Al_2O_3); consequently facies are difficult to establish. Aphanitic volcanic rocks exhibit the greatest resistance to alteration; the assemblages

epidote + tremolite/actinolite + green biotite, talc + tremolite (chlorite + quartz), magnetite + epidote + chlorite and serpentine, indicative of magnesian and Fe-magnesian compositions, are classified as middle greenschist facies (Fyfe, Turner and Verhoogen, 1962). Pelitic compositions in metasedimentary rocks bear quartz + biotite + muscovite + garnet and quartz + biotite + muscovite + staurolite. Depending upon the precise composition of these rocks the assemblages are compatible with upper greenschist/lower amphibolite facies.

In granitic terrain, outside the greenschist belt, mineral assemblages indicate higher facies. An augite-bearing ultrabasic rock east of English Lake is now represented by a granoblastic, garnetiferous gabbro. Original plagioclase (An_{55}) is saussuritized and is separated from augite by rims of epidote. Green rims of amphibole surround all augites. Garnet is bright pink. Thus epidote + garnet (almandine-pyrope?) + green amphibole, is compatible with the quartz-albite-epidote-almandine subfacies of the upper greenschist facies for basic assemblages (Fyfe et al., 1962). The most common assemblages found are hornblende + andesine + biotite + quartz (Domains 1, 2, 3, 4, 5, 6, 7, 8, 12 and 13, Fig. 15). Where garnet is present in these rocks it is not found in association with hornblende; in these, andesine + biotite + garnet ± muscovite is the stable assemblage.

The highest grade mineral assemblage outcrops on the south shore of Gammon Lake 200 feet east of the inlet of a 'finger lake' trending parallel to Gammon Lake. The biotite-rich band is characterized by small idioblastic red garnets and the rocks bear biotite, sillimanite, pinitized cordierite, andesine and quartz. The garnet composition is estimated best to fit 64 per cent almandine, 21 per cent pyrope and 15 per cent grossularite. Cordierite and biotite have no mutual grain boundary; nor have sillimanite and biotite (Fig. 15). Garnet ranges from 2 to 8 per cent; cordierite + sillimanite averages 5 per cent. The rocks of unit 7c must also represent upper amphibolite grade of metamorphism; however, highly aluminous compositions appear to be absent.

A quick petrographic survey of the Horseshoe Lake greenstones, 4 miles north of the present map-area, disclosed poikilitic diopside + hornblende + andesine + quartz and biotite + garnet + andesine + quartz (± muscovite) which are compatible with lower amphibolite grade of metamorphism.

The reaction epidote + albite $\rightleftarrows$ oligoclase in the area may be taken as the transition from upper greenschist to lower amphibolite facies. This transition is readily recognized in rocks outside the belt of Rice Lake rocks. Within the belt, however, the association of kyanite + staurolite + muscovite, almandine + staurolite + muscovite for pelitic compositions of the lower amphibolite facies, is absent. The reason for this in aluminous rocks may lie in the persistence of the 'mica-fence' (AKF diagram, domain 10, Fig. 15). The join muscovite-biotite separates the psammitic from pelitic assemblages i.e. it is a textural and mineralogical barrier. Only rocks deficient in K_2O will produce kyanite or staurolite in association with garnet. However, most clays generally contain some potassium with the result that the phases appearing on the AF join (if they appear) remain separated from the micas by almandine, chloritoid or Mg-chlorides. In the Manigotagan metasediments the mica fence appears to have been re-established by retrograde metamorphism during shearing. Biotite pseudomorphs staurolite; biotite is altered to kinked, chloritized forms. Lower amphibolite grade of metamorphism is

probably established in the metasediments at Manigotagan, even though the present mineral association does not indicate an assemblage in equilibrium.

Structural Geology

Rice Lake Group and San Antonio Formation

Moore (1912) interpreted the younger Wanipigow sediments as overlying the Rice Lake volcanic rocks. Both form an arcuate syncline plunging gently southeast. Cooke (1921) and Wright (1932) accepted this structure, but noted that locally volcanic rocks graded along strike into sedimentary rocks so that some areas received sediments at a time when others were being covered by lava flows. Both authors noted that bedding, flow laminations, shear folds and secondary foliation generally dip northward. Repetition of lithologies due to isoclinal folding is difficult to demonstrate because marker horizons are absent. The following discussion includes a summary of the work of Russell, Davies and Stockwell and the areas reported on by them will be discussed from west to east.

In the Manigotagan-Rice River area, Davies (1951) reported that the sediments are well bedded and that dips of 80 degrees to vertical are common; cleavage is parallel to bedding; the beds face north and tops of drag-folds face north. Thus the minor rhyolite and basalts south of Manigotagan River are older than the sediments. On Black Island, Davies (1951) interpreted the sediments as underlying the lavas which is the reverse of the situation in the Manigotagan area. The present author found pillow lavas whose tops face north but dip south. The section is therefore overturned and prescribes a fold whose axis strikes southwest and plunges 45 degrees southwest. Lineations represent the axes of small folds, intersection of cleavage to bedding and long axes of ovoid amygdules. The northeastern extension of the axis is terminated by the Lake Winnipeg shear zone whose lineations, plunging southeast in the vicinity of Black Island, change plunge several times along the extent of the shear zone. It is probable that the fold traced out by the hybrid orthogneisses at Shallow Lake is an extension, along the axis, of the Black Island fold but interrupted by the Lake Winnipeg shear.

In the English Brook area Russell (1949) found alternating competent and crumpled, incompetent bands. He found evidence of overturned (towards the north) isoclinal folds in the northwestern region of Wanipigow Lake. He established northeast and west-northwest-trending faults which are directions of two shear zones in that area. Lineations from Manigotagan Bay to Wanipigow Lake vary. Lineations represent the intersection of cleavage with bedding in metavolcanic and sedimentary rocks and the intersection of cleavage with foliation in granitic rocks.

In the Wanipigow Lake area Davies (1949) reported flow banding in rhyolite and secondary foliation as being parallel to flow banding. Dips vary from 50 degrees north to vertical. Some tops point and dip north. A drag-fold against granodiorite plunges east which is the direction of linear elements in the granodiorite. Two shears – one parallel to the regional schistosity and one at N30° E – are in the same direction as that for the English Brook area. Church and Franchi (1968) postulate that most recent movement along the main east-west shear zone is dextral with a nearly horizontal

component. They predicted, correctly, sinistral movement on conjugate shear sets; such movement has been interpreted by the present author on a fault at Shallow Lake (Frontispiece).

In the Wanipigow River area Stockwell (1938) defined an easterly-trending anticline of which only the northern limb lies in the present area. Tops of beds face and dip north. The dips are more variable from 30 degrees to vertical, but most are greater than 60 degrees. Davies (1950) found, in addition to the east-west foliation, northerly dipping shears striking northeast and northwest; north-south tension fractures are filled with porphyry and felsite dykes. The foliation outlines an ellipsoidal bulge in the area whose short axis strikes north. It is at Rice Lake that the Rice Lake Group is split into separate belts by granodiorite. One band continues east-southeast, the other southeast.

An equal-area stereonet plot of the data measured from maps from Stockwell (1939, maps 458A, 459A, 465A) of the unconformable San Antonio Formation west of Rice Lake shows that the syncline (both limbs dipping north) plunges 20 degrees toward azimuth 328 degrees. The axial plane strikes 312 degrees and dips 52° NE. The intermediate angle between the overturned limb (dipping 72° NE) and the upright limb (dipping 34° NE) is 42 degrees. Poles to schistosity tend to cluster the pole maximum of the upright limb. Structural complications occur at the edges of the formation where bedding and foliation have been affected by later deformation. Lineations on Rice Lake at the edges of the San Antonio Formation and the Rice Lake Group rocks plunge north to northeast and may be the result of the intersection of the northeast-trending shear with the regional east-west foliation. However, pebble conglomerates outcropping on islands in Rice Lake probably should be placed with rocks of the San Antonio Formation. They have not been included as part of the San Antonio Formation by previous workers probably because of the steeply dipping, prominent shear zone which deforms the rocks along the southern shore of Rice Lake. The conglomerates on either side of the shear zone are lithologically similar.

Both the present author and Russell (1948) recognized a shear zone on Wallace Lake and Siderock Lake to the east. Two zones seem to merge into one east of Siderock Lake (3 miles south of Obukowin Lake of the present map-area). Mylonite and ultramylonite interlayered with crumpled schists form the cliffs just northeast of Siderock Lake. Folds striking and plunging north are bent eastward at the mylonite zone south of Obukowin Lake. Between these cliffs and those forming the sheared southern contact lies a valley underlain by complexly sheared and folded schists. Westward toward Wallace Lake one zone extends along the north shore of Wallace Lake (Wallace Lake fault; Russell, 1948) and the other along the southern shore through Conley Bay fault (Russell, 1948). Westward the zone splays into northern and southern branches leaving the rocks on the islands of Wallace Lake less sheared than those in contact with plutonic igneous rocks. The structure at Wallace Lake is suggested by Russell to be a drag-fold that strikes S65° E, dips 70° N and plunges southeast. A drag-fold model of deformation might explain the arched foliation pattern in the granodiorites north of Wallace Lake. Axes of small folds and lineations vary in amount and direction of plunge (in northeasterly to easterly directions). Many folds result from shear movement transverse to the N60° W foliation.

In conclusion, rocks of the Rice Lake Group have been affected by a late east-southeast penetrative deformation which has resulted in drag-folded rocks locally against granodiorite contacts. A prevailing northeasterly trending structural fabric is expressed by local features such as the Black Island-Shallow Lake fold axis and the English Brook-Wanipigow Lake shear. A northwesterly striking shear and fracture pattern includes the Lake Winnipeg fault zone, a left-handed fault in the Shallow Lake structure (Frontispiece) and mylonite and fracture zones in gneiss and plutonic rocks in the central portion of the area. Original folds in the Rice Lake Group were probably broad flexural folds which were later developed into shear and drag folds.

Gneisses and Plutonic Rocks

Hybrid gneisses which may represent deep portions of folds are located at Shallow Lake, Beaver Creek, Gammon Lake and Moor Lake. The folds are overturned and commonly isoclinal. At Shallow Lake the limbs of the fold (Frontispiece), lineations, and axes of small folds (Figs. 5 to 14), normal to the trace of the fold plane, plunge southeast. The lineations here are parallel to a major fault and consequently may represent the 'A' or movement direction. Axes of small folds and lineations due to crumpling of the foliation plane at Beaver Creek and Gammon Lake plunge southwest. The sialic fraction of these gneisses (7c) probably represents recrystallized and remobilized granodiorite basement on which Rice Lake Group rocks (now represented by the mafic gneiss fraction) were deposited. However it remains to be proven whether they actually are recrystallized Rice Lake rocks; it is presently assumed that they are because no pre-Rice Lake Group rocks are recognized.

Northwesterly trending lineaments are well developed (map in pocket). Some include well-developed slickensides; others constitute mylonite, shear or schist zones. Along the shore of Lake Winnipeg groups of lineations in the plane of shear plunge either northwest or southeast. Schistose rock along the shore is transitional inland to banded rock which in turn grades to progressively less foliated rock. A well-developed mylonite zone in granodiorite, extending from Pigeon River southeast to Vickers Lake progressively assumes a more southerly direction northeast of Sasaginnigak Lake. Some lineaments coincide with rock boundaries; others intersect gradational igneous rock boundaries. Collectively, such boundaries appear to represent structural as well as compositional change and may represent deep-seated fractures. On the other hand some shear- or mylonite-lineaments, which penetrate rocks of various compositions do not parallel lithologic boundaries and hence may represent late movement unrelated to deep-seated crustal movement.

Diapiric, plutons in hybrid, gneiss terrain are suggested by the following bodies established during regional mapping: (1) quartz diorite, granodiorite (unit 10) adjacent and northwest of Shallow Lake; (2) diorite (unit 11) and granodiorite (unit 8) southeast of the Shallow Lake structure; (3) granodioritic (unit 11) terrain southeast of Manigotagan settlement and south of Wanipigow Lake; (4) granodiorites (unit 11) northwest, northeast and southeast of Rice Lake; (5) mafic granodiorite (units 11d and 11e) north of Wallace

Lake. The Sasaginnigak Lake pluton (unit 15) however, bespeaks a less dynamic mode of intrusion and indeed may be related to the porphyrite (unit 14a) and massive granodiorite (unit 13) by a quiescent mode of magmatic differentiation.

ECONOMIC GEOLOGY

The history and state of economic mineral development in the area up to 1962 is given by Davies et al. (1962). With the close of gold mining at the San Antonio Mine in the summer of 1968 active mining in the area ceased. However, claim-development work is active in most areas underlain by granodioritic rocks adjacent to the metasedimentary and volcanic belt. Silica sand is presently being shipped from Grey Point on Black Island.

No new mineral occurrences of economic importance were located in the course of the field studies. Minor disseminations of molybdenite were noted in widely-spaced joints in granitoid rocks (17). Rocks of units 7 and 8 in the area appear to have been deformed by flow during lit-par-lit injection of granitoid materials and are thought to be comparatively barren.

Northeast of Carroll Lake at a lake underlain by rocks of unit 8a, rusty granitoid, banded gneiss is associated with zones containing disseminated pyritohedral pyrite crystals; the gneiss outcrops north of the northeastern end of the lake. An area which may be similar to the copper-nickel bearing mélange comprising greenschist, diorite, gabbro and small ultrabasic bodies east of English Lake is northwest of Shallow Lake which bears hybrid quartz diorites and quartz gabbro mixed with granodiorite and granodiorite gneiss.

In the past this area has been extensively explored for gold (Phillips, 1968). However the presence of numerous sulphide concentrations (pyrite, arsenopyrite, pyrrhotite) along granodiorite-volcanic rock boundaries and near altered basic and ultrabasic bodies in granodiorite make it a favourable area for base metal exploration. The present author, and Church and Franchi (1968) delineated previously unrecognized basic and serpentinized ultrabasic bodies in granodiorite in the Wanipigow Lake area. Also, structurally favourable sites occur such as east of Clangula Lake where the deep-seated Lake Winnipeg shear and the Rice Lake shear zone intersect. Linear magnetic anomalies representing submerged, possibly serpentinitic rocks south of Observation Point and east of Black Island on Lake Winnipeg warrant further investigation for nickel-copper mineralization.

SUMMARY OF GEOLOGIC HISTORY

1. Basic to intermediate lavas were irrupted onto a presumed granodioritic or protoclastic gneiss terrain; elsewhere psammitic and pelitic rocks (whose provenance is unknown) were deposited on a basement composed of lava rocks. Remnants of these deposits now constitute the Rice Lake Group. Some rocks of unit 9c, southeast of Observation Point and phases of unit 7c at Beaver Creek, are thought to contain presumed basement rocks upon which the Rice Lake Group rocks were deposited.

2. Granodiorite (2,670 m.y.) intruded the Rice Lake Group producing diapir-like plutonic forms with selvages of hybrid gneiss (units 7, 8 and 9); protoclastic gneiss and upper amphibolite grade of metamorphism develop in structurally deeper levels. A 20-foot-long paragneiss inclusion in 'grey granite' (52° 45'00"N, 95° 13'00"W, Stockwell in Lowdon, 1961) yielded a K-Ar age date of 2,600 m.y. Broad flexural folds may have been developed at this time concomitantly with metamorphism of the Rice Lake rocks. However, K-Ar ages on recrystallized biotite and muscovite of 2,435 m.y. and 2,455 m.y. respectively, taken from a shear zone at Manigotagan settlement, appear to date the latest period of deformation.

3. Mineralization associated with quartz veins cutting rocks of the Rice Lake Group and San Antonio Formation occurred 2,720 ± 185 m.y. ago (Turek and Peterman, 1968) and represents a minimum age for both the group and formation. San Antonio sediments were deposited in part unconformably upon Rice Lake rocks and adjacent granodiorites (11), but in part, as in the Wanipigow Lake area, concurrently with volcanic rocks. Minor gabbro rock, trap, felsite and acid porphyry dyke emplacement preceded and postdated the deposition of sedimentary rocks.

4. Monzonitic phases of unit 14 are probably related to the early granodiorites (11) and appear to have escaped regional cataclasis (foliation) affecting the granodiorite gneiss of unit 12.

5. Subsequently, a group of igneous rocks, here informally called the Sasaginnigak Lake rocks, were emplaced in granodiorite. This group constitutes massive granodiorite and diorite (13), granodiorite and quartz monzonite (15). It is not known what relationship the porphyritic quartz monzonites at Family Lake have to the quartz monzonite of unit 15 or to the quartz monzonites (14) at Bloodvein Bay.

6. The youngest intrusion consists of massive quartz monzonite (17) whose K-Ar age is the same as the thermal metamorphism of the sediments at Manigotagan settlement (2,450 m.y.) which also coincides with the last metamorphic event which affected San Antonio and Rice Lake rocks. Rice Lake rocks pass southward into a belt of paragneiss, lit-par-lit gneiss and granite (Stockwell in Lowdon, 1961, p. 54) which gave a K-Ar age on biotite of 1,700 ± 90 m.y. but a Rb-Sr age of 2,630 m.y. (Turek and Peterman, 1968). Consequently the K-Ar age date on fresh biotite records yet another period of metamorphism in the area 1,700 m.y. ago. As yet of unknown age is the metamorphism accompanying shearing in the area just east of Black Island.

In connection with 'greenstone belts' of the Superior Province of Manitoba it is interesting that K-Ar age dates clearly record the last mobility of potassium and associated argon and hence all magmatic phases dated by this method yield minimum ages. Most greenstone belts are sufficiently well mapped to determine the gross interrelationship between supracrustal and intrusive rocks. Structural characteristics within each 'greenstone' belt are variable and largely governed by the nature and distribution of plutons within them. Grades of metamorphism too, seem to be a function of proximity to magma and depth of intrusion and thus contact metamorphic and regional metamorphic effects may overlap. Foliated and massive rocks are mutually transitional; both rock types may have been developed during one period of intrusion and the proximity of some magma to intensely folding greenstones produces protoclastic gneiss and local variations in the chemistry of the

solidified products. Pb-U dating of zircons may shed light on these early events including the clarification of periods of sedimentation and volcanicity. Subsequent intrusions and pervasive alkali metasomatism could then be understood in relation to metamorphism in various areas. Presently all greenstones necessarily bear the minimum age of the intruding rocks (2,700 m.y.) which consequently must be only the minimum age of the greenstones and does not establish the time of deposition.

Studies using seismic refraction and 'smoothed' aeromagnetic data appear to be promising approaches in determining crustal structures. The origin of many intrusive rocks of intermediate compositions is still unknown and rocks of the 'granitic' terrain immediately east of Lake Winnipeg are no exception. Perhaps with the development of new interpretative models from geophysical data the terrain, which heretofore traditionally has been difficult to decipher and place in a context of crustal development, will in the future add to our knowledge in this part of the Superior Province.

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