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GEOLOGY
OF THE
ISSETT-OPACHUANAU-PEMICHIGAMAU-
EARP LAKES AREA

Parts of N.T.S. Maps
64B-5, 6, 10, 11 and 12

THE PAS MINING DISTRICT

BY
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INTRODUCTION

LOCATION AND ACCESS

The Opachuanau-Issett-Pemichigamau-Earp Lakes area* (parts of map-sheets 64 B/5, 64 B/6, 64 B/10, 64 B/11 and 64 B/12 of the National Topographic Series) is bounded on the north by the Twenty-third Base Line, and extends as far south as latitude $56^{\circ}15'N$ and as far east and west as longitudes $98^{\circ}41'W$ and $100^{\circ}00'W$ respectively (Figure 1). The centre of the area is approximately 60 miles east of Lynn Lake and 80 miles northwest of Thompson. The area is easily accessible by air from either Thompson or Lynn Lake. The western portion of the area is accessible from Lynn Lake by Provincial Road 391, which will also link the area with Thompson. A road from this highway leads to the Sherritt Gordon Mines Limited property at Ruttan Lake.

There are two main water routes in the area: the Churchill River which flows northeast into Opachuanau Lake and Southern Indian Lake; and the Rat River which flows southwest from Issett Lake through Karsakuwigamak and Pemichigamau Lakes, and continues beyond the map-area through Rat Lake to Nelson House. This latter route, with a portage from Issett Lake to South Bay, connects Nelson House with Southern Indian Lake settlement, which lies just to the north of the map-area at the entrance to South Bay.

DRAINAGE AND TOPOGRAPHY

The Churchill River and Rat River drainage systems are separated by a height of land along the Twenty-third Base Line. All lakes in the area are shallow, and some of the smaller lakes become weed-filled in mid-summer. Muskeg is widespread, and marshes are abundant along the Rat River. Small streams and tributaries tend to be narrow and winding, with many rapids and other obstructions, particularly fallen trees.

The topography of the area is influenced by the erosional characteristics of the underlying rocks. In the north, siliceous gneisses and granitic rocks form the divide between the two drainage systems. Elsewhere in the area, granitic rocks commonly form higher ground, whereas low swampy areas are generally underlain by sedimentary and volcanic rocks.

GLACIATION

Evidence of continental glaciation and former glacial lakes is found throughout the map-area. Glacial grooves, striae, and polish were observed on some outcrops of granitic, basic volcanic and quartzose sedimentary rocks. Striations striking 230 to 260 degrees indicate ice movement from the northwest. In places, unconsolidated deposits of granitic boulders, and sand and gravel, form mounds on the southwest side of ridges and hills. Several eskers trend northeasterly, but one on the northeast shore of Karsakuwigamak Lake trends east. Glacial lacustrine deposits of silt and clay are found in low-lying areas, where many are cut by streams.

Varved clays up to 60 feet thick are exposed on South Bay (Wright, 1953).

PREVIOUS WORK

A brief description of the geology of Southern Indian Lake was first given by McInnes (1913). Alcock (1921) later made a track survey along the Rat River, and

* hereinafter referred to as "the map-area"

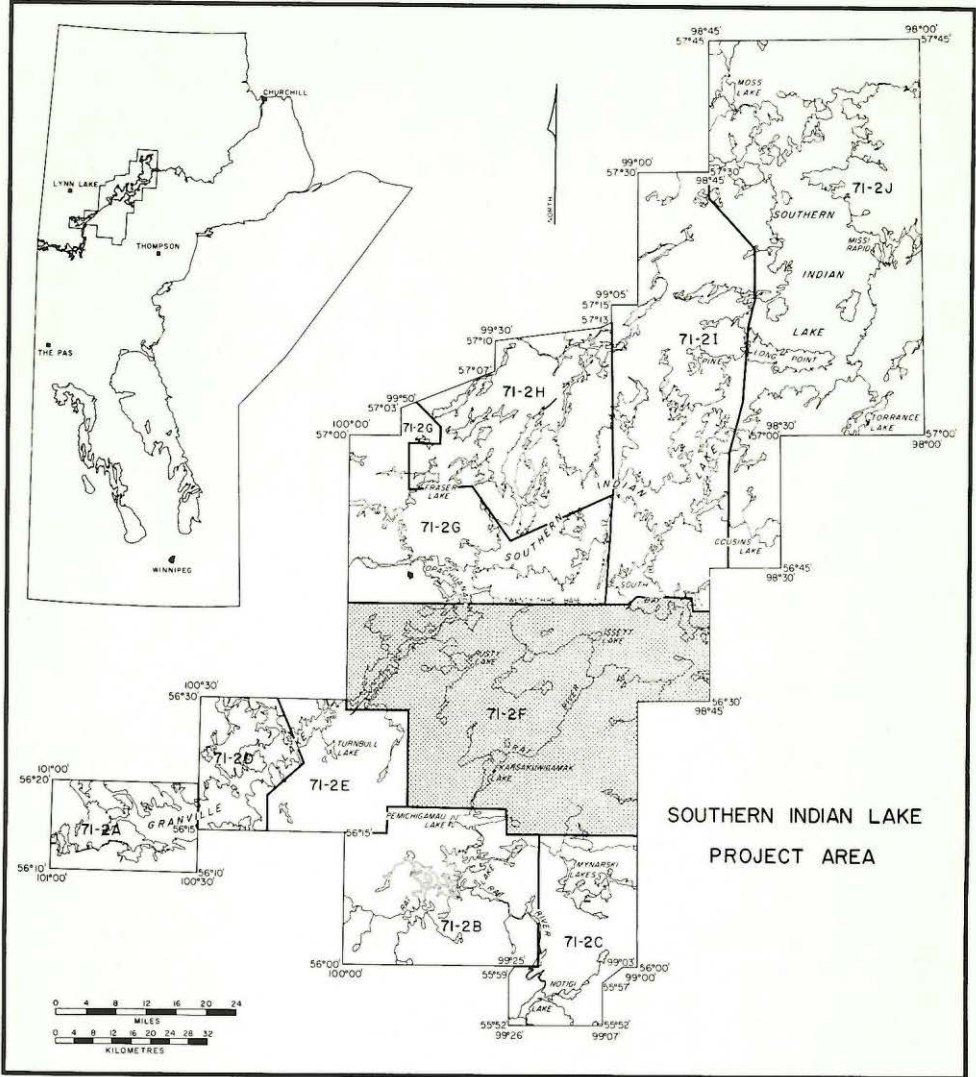


Figure 1: Location of map-area; Southern Indian Lake project.

the geology of the area was subsequently mapped by Wright (1953) at a scale of 4 miles to the inch. From 1960 to 1963 the Manitoba Mines Branch mapped most of the map-area at a scale of one inch to the mile (Burwash, 1962; Milligan, 1964; Pearse, 1964; Bristol, 1966).

PRESENT WORK AND ACKNOWLEDGEMENTS

The present work was carried out during the summers of 1969 and 1970 as part of the Southern Indian Lake project (Figure 1). Figure 2 shows how the area was divided between the writers. Steeves mapped the area around South Bay and initiated mapping in the western part of the area in 1969. In 1970 he completed the western portion, and at the same time Lamb mapped the eastern portion of the area. The geology of part of the Earp Lake sheet is after Milligan (1964), and the geology of the southeastern portion has been interpreted with the aid of aerial photographs and aeromagnetic maps.

Most of the geological data were obtained by pace and compass traverses, spaced 500 feet apart in areas of volcanic and sedimentary rocks, and 2600 feet apart in granitic terrain. An attempt was made to check all outcrops in the map-area, especially in the volcanic-sedimentary belt. All shoreline and riverside outcrops were visited by boat, and less accessible areas were reached by helicopter. Vertical aerial photographs (one-half mile to the inch) were used to locate outcrops. Field data were plotted at the same scale, on base maps prepared from 1:40,000 Advance Information Prints supplied by the Department of Energy, Mines and Resources in Ottawa. The final geological maps which accompany this report are at a scale of 1:50,000 (Map 71-2-6, Pemichigamau Lake; Map 71-2-7, Earp Lake; 71-2-8, Opachuanau Lake; Map 71-2-9, Issett Lake; Map 71-2-10, Swan Bay [West half]).

Assistance in mapped was rendered to M. Steeves by F. Dalidowitz in 1969 and N. Green in 1970, and to C. Lamb by N. Papish. M. Steeves was also assisted by R. Grey, B. Clattenburg, and J. MacBride in 1969 and by J. Pedora, W. Perlmutter, and P. Reynolds in 1970; while G. Johnston, R. Fedorowich, and L. Solkoski assisted C. Lamb. Supplies were arranged for the field parties in Lynn Lake by J. Gregorchuk, G. Morrison, and W. Lewis, and these were flown in by the Manitoba Government Air Service and by charter companies in Lynn Lake. Assays and chemical analyses were done in the Mines Branch Analytical laboratory in Winnipeg.

AVAILABLE MAPS AND AERIAL PHOTOGRAPHS

Copies of the Uhlman Lake sheet (64B) of the National Topographic Series at a scale of 1:250,000 are available from the Manitoba Surveys Branch, or from the Map Distribution Office in Ottawa.

Vertical aerial photographs at scales of one mile to the inch and one-half mile to the inch are available from the National Air Photo Library in Ottawa.

Claim maps of the area can be obtained from the Mining Recorder's Office in The Pas.

Aeromagnetic Series maps 2388, 2389, 2396, 2397 and 2405, produced jointly by the Geological Survey of Canada and the Manitoba Mines Branch, cover the map-area.

An airborne INPUT electromagnetic and magnetic survey of the Southern Indian Lake region was flown by Questor Surveys Ltd. under contract to the Manitoba Mines Branch in 1968; sheets 7, 10 and 11 were fully utilized by the authors. All data from this survey were released to the public in June, 1969 (Manitoba Mines Branch, 1969).

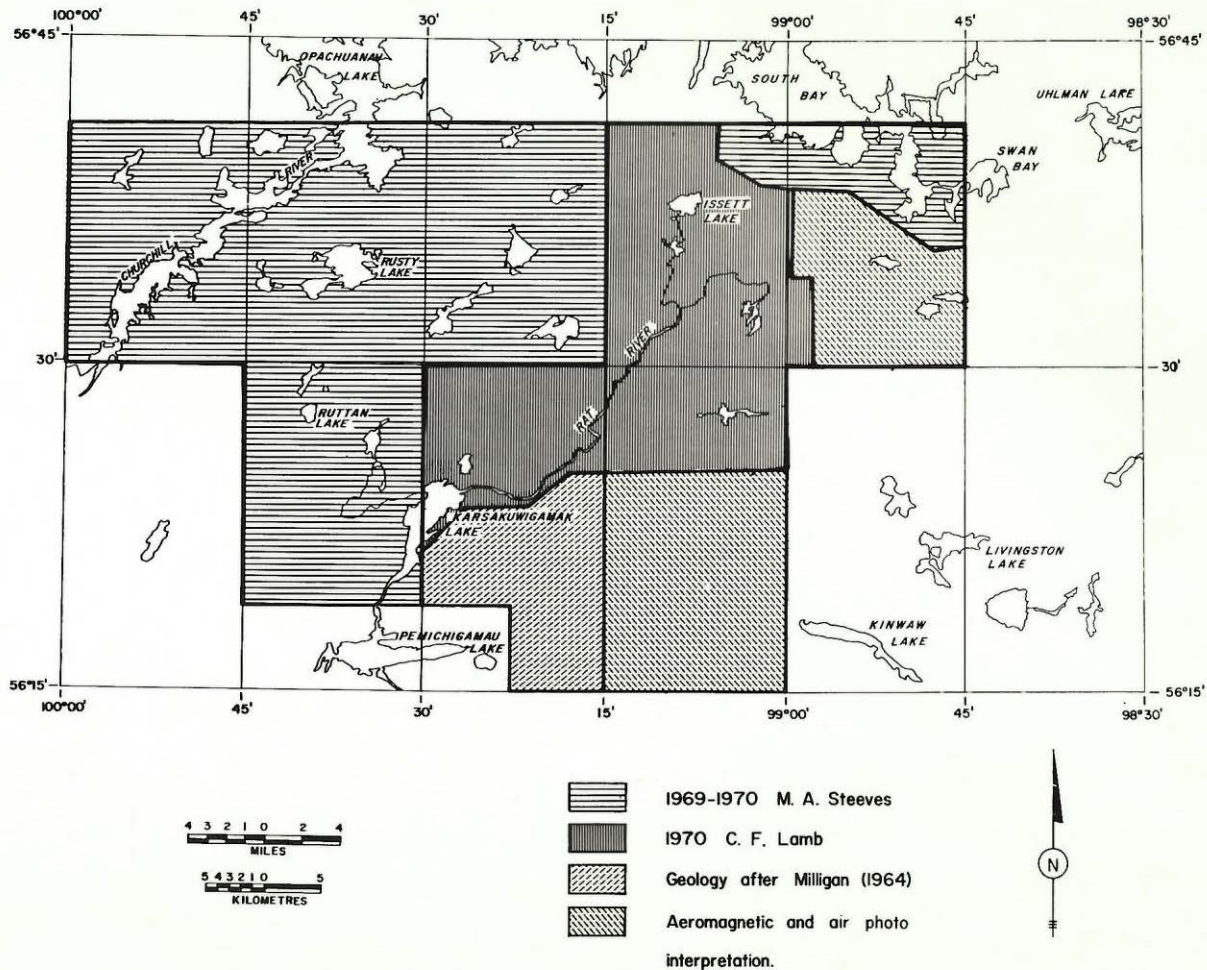


Figure 2: The Issett-Opachuanau-Pemichigamau-Earp Lakes map-area showing the division of mapping between Steeves and Lamb.

GENERAL GEOLOGY

INTRODUCTION

Reconnaissance mapping by Henderson, Norman and Downie (1936) in the Granville Lake area, established the presence of a Precambrian group of medium to coarse-grained clastic metasedimentary rocks, lying unconformably on a more highly metamorphosed complex of volcanic, pyroclastic and volcanoclastic rocks. The group of clastic metasedimentary rocks was called the Sickie Series. Bateman (1945) named the pre-Sickie metavolcanic and metasedimentary rocks the Wasekwan Series. Bateman also subdivided the intrusive rocks of the Granville Lake area into pre-Sickie and post-Sickie intrusions. Milligan (1960) used these terms in the Lynn Lake district and added a fifth group, the Kiseynew-type gneisses. This convention was adopted by Burwash (1962) for the rocks of the Rusty Lake area, and by Pearse (1964), Milligan (1964) and Bristol (1966) in adjoining areas.

In this report, the 19 map-units (Table 1) have been divided into five major groups: Wasekwan Group*, Pre-Sickie intrusive rocks, Sickie Group*, Opachuanau gneisses and Post-Sickie intrusive rocks. Map-units within each group conform to a hypothetical time sequence, although the age relationships among some of the intrusive rock units are not clear. The writers have adopted the terms Wasekwan Group and Sickie Group for the purpose of correlation with the Granville Lake and Lynn Lake areas. However, the only justifications for this correlation with the Granville Lake area are: (i) marked lithologic similarities of the Sickie and Wasekwan rocks in the two regions; (ii) assumed continuity of Wasekwan rocks in areas of poor exposure; and (iii) aeromagnetic data.

WASEKWAN GROUP

DISTRIBUTION AND FIELD RELATIONS

The Wasekwan Group, comprising the Rusty Lake-Karsakuwigamak Lake greenstone belt, consists of metamorphosed basic, intermediate and acid volcanic rocks, and derived metasedimentary rocks. Owing to isoclinal folding, the present combined total thickness of these rocks is approximately 80,000 feet (24,000 metres), but the original stratigraphic thickness was probably less than half of this figure. The lower 50,000 feet (15,000 metres), comprising the Lower Wasekwan Group, is made up of massive flows of picrite, basalt and andesite, with a number of small acid volcanic lenses and thin intercalated sediments. The upper 30,000 feet (9,000 metres), the Upper Wasekwan Group, consists mainly of metamorphosed volcanoclastics, pyroclastics, greywacke, argillite, and sedimentary amphibolite, with minor basic and intermediate volcanic flows. Wasekwan rocks occupy up to 25 per cent of the map-area, and are best exposed in the east halves of the Opachuanau Lake and Pemichigamau Lake map-sheets (Maps 71-2-6 and 8) and the northern portion of the Earp Lake map-sheet (Map 71-2-7). The metavolcanic rocks are much better exposed than the metasedimentary rocks; good outcrops of the latter are rare except on lake shores and along the Churchill River. Even shoreline outcrops are scarce towards the eastern and western margins of the Rusty Lake greenstone belt.

All the Wasekwan strata are cut by pre-Sickie intrusive rocks. Intrusive contacts are well exposed in the eastern halves of the Opachuanau Lake and Pemichigamau Lake map-sheets. To the north, Wasekwan metasediments are unconformably

* "Group" is now used instead of "Series" in accordance with the Code of Stratigraphic Nomenclature (see Campbell, 1969).

TABLE 1 TABLE OF FORMATIONS

PRECAMBRIAN	PLEISTOCENE AND RECENT	Till: lacustrine clays and silts; outwash deposits; minor sand and gravel deposits		
	GREAT UNCONFORMITY			
	POST-SICKLE INTRUSIONS			
	19	Diabase		
	18	Pegmatite and aplite		
	17c	Pink "quartz-eye" granite, quartz monzonite		
	17b	Quartz monzonite		
	17a	Porphyritic quartz monzonite		
	16	Nebulitic tonalite and granodiorite with inclusions of 10, 11 and 2a		
	15c	Pink granite and quartz monzonite, minor alaskite		
	15b	Coarse-grained gneissic granodiorite and quartz diorite		
	15a	Biotite-hornblende granodiorite with dioritic to quartz dioritic contact phases; minor quartz monzonite		
	14c	Quartz monzonite, granite		
	14b	Granodiorite		
	14a	Biotite-hornblende tonalite and diorite		
	13	Hornblende and associated amphibole-plagioclase gneiss		
	12	Foliated magnetiferous quartz diorite	Opachuanau Gneisses	
	11d	Gneissic hornblende granodiorite to quartz diorite	10c	Migmatite derived from 10a and 10b
	11c	Magnetite-biotite granodiorite	10b	Hornblende-biotite intermediate gneiss with amphibole-plagioclase gneiss and amphibolite
	11b	Diorite, associated quartz diorite and granodiorite	10a	Biotite-hornblende intermediate gneiss
	11a	Quartz diorite, leuco-quartz diorite		
	— INTRUSIVE CONTACT —			
	SICKLE GROUP			
	9	Biotite-muscovite-quartz schist		
	8c	Arkose-derived gneisses and migmatite		
	8b	Impure arkose, minor quartzite		
	8a	Arkosic conglomerate, minor arkose		
	UNCONFORMITY			
	PRE-SICKLE INTRUSIONS			
	7c	Diorite, quartz diorite		
	7b	Hornblende gabbro, hornblende, minor diorite and quartz diorite		
	7a	Ultramafic amphibolite and associated olivine-bearing rocks		
	— INTRUSIVE CONTACT —			
	WASEKWAN GROUP			
	6	Sulphide zone		
	5b	Porphyritic meta-basalt and meta-andesite		
	5a	Meta-basalt, meta-andesite		
	4d	Plagioclase paragneiss		
	4c	Meta-arkose, feldspathic quartzite, minor arkosic conglomerate		
	4b	Greywacke conglomerate		
	4a	Acid and intermediate pyroclastic rocks, metamorphosed volcanoclastic rocks, meta-argillite, amphibolite		
	3b	Dacite, minor rhyolite and rhyodacite, acid tuff, agglomerate, volcanic breccia		
	3a	Fragmental volcanic rocks and associated finely banded amphibole gneiss		
	2d	Banded amphibole-plagioclase and biotite-tremolite-garnet gneisses		
	2c	Porphyritic meta-basalt, meta-andesite, meta-picrite		
	2b	Meta-basalt, meta-andesite, meta-picrite; includes minor amounts of 3b and 4a		
	2a	Amphibolite, amphibole-plagioclase gneiss		
	1	Pelitic biotite gneiss		

Note: This Table of Formations covers a broader area than that mapped by the writers (see also Hinds, 1972; Kendrick, 1972). Only those units shown in upright characters occur in the area mapped by the writers.

overlain by less deformed Sickie rocks, and many clasts of Wasekwan rocks are incorporated in the basal conglomerate of the Sickie Group. Opachuanau gneisses appear to have been derived from both Wasekwan and Sickie Group rocks. Intrusive contacts were observed between the Wasekwan Group and all post-Sickie intrusive rocks except the pink "quartz-eye" granite and quartz monzonite (unit 17c). However, this latter unit cross-cuts both the Sickie Group and the Opachuanau gneisses. The Wasekwan Group tonalite (14) contact is exposed only to the north of "Eagle" Lake.

Lower Wasekwan Group

PELITIC BIOTITE GNEISS (1)

Pelitic biotite gneiss (1) outcrops immediately to the south of South Bay, in the northeastern part of the map-area. The unit has been extrapolated eastward across the Swan Bay map-sheet (Map 71-2-10), on the basis of air photo and aeromagnetic interpretations. The pelitic biotite gneiss (1) has been included in the Wasekwan Group, but its age relationships to other rocks within the group have been obscured by metamorphism and deformation, and by its lack of exposure in the Swan Bay area. However, it occurs as xenoliths, which are cut by granodiorite dykes, in the biotite-hornblende tonalite (14a) in the eastern portion of the map-area. Also, the pelitic biotite gneiss (1) is intruded by pegmatite (18) on the south shore of South Bay.

The composition of the biotite gneiss (1) varies from 30 to 50 per cent quartz (rounded grains), 10 to 15 per cent biotite and 30 to 50 per cent anhedral plagioclase. Anhedral cordierite (less than 1%) is surrounded by plagioclase and accompanied by traces of muscovite. Fractured pinkish euhedral garnets (1 cm) locally form clusters (3 cm). Minor potassium feldspar has replaced plagioclase. Graphite occurs along foliation planes at South Bay. Local hornblende gneiss, interlayered with the biotite gneiss, contains up to 50 per cent hornblende, with a corresponding decrease in plagioclase and biotite.

AMPHIBOLITE, AMPHIBOLE-PLAGIOCLASE GNEISS (2a)

Amphibolite and amphibole-plagioclase gneiss (2a) occur to the north of the map-area and are described by Hinds (1972).

META-BASALT; META-ANDESITE; META-PICRITE (2b); (INCLUDES MINOR AMOUNTS of 3b and 4a)

These basic to intermediate extrusive rocks, with subsidiary porphyritic varieties (2c) constitute the major part of the volcanic sequence. Owing to similarities in colour and texture, they are hardly distinguishable from each other in the field but they have been classified by chemical and microscopic analyses. Meta-basalt is the most common rock type in the sequence; meta-picrite is relatively rare. All the flow rocks are black to greenish black and generally very fine grained. They vary from almost massive to highly schistose, and primary features are rarely preserved except for local occurrences of ellipsoidal and amygdaloidal lavas. Variations in mineral composition are summarized in Table 2:

TABLE 2 MINERALOGICAL COMPOSITIONS OF META-PICRITE*,
META-BASALT AND META-ANDESITE

	Meta-picrite	Meta-basalt	Meta-andesite
Hornblende	65-85%	50-65%	35-50%
Andesine	15-25%	30%	40-45%
Biotite	trace	5%	10%
Magnetite/ilmenite	5-15%	5-15%	trace
Quartz	—	trace	3'
K-feldspar	—	trace	2-5%
Actinolite	trace	trace	trace
Epidote	trace	trace	trace
Sulphides	minor	trace	trace
Sphene	trace	trace	—
Apatite	—	trace	trace
Chlorite	—	—	trace
Zircon	—	—	trace

Meta-basalt

The hornblende in the meta-basalt occurs as subhedral, prismatic crystals, many of which have a planar preferred orientation which defines the schistosity. The long axes of the crystals however are randomly oriented. Most of the hornblende has a fresh appearance and is neither poikilitic nor zoned. However, some rare instances of well defined zoning, and the shape of some crystals, suggests that the hornblende is at least in part pseudomorphic after pyroxene. (Variation diagrams suggest that both hypersthene and pigeonite were originally present, see page 40). This is further substantiated by a peculiar hour-glass pattern of small anhedral magnetite inclusions in some of the zoned hornblende crystals. The plagioclase is usually subhedral, poorly twinned, and ranges in composition from An₃₂ to An₄₄. Relict cores of labradorite were observed in some grains, but these are generally confined to plagioclase phenocrysts in the porphyritic meta-basalts (unit 2c). The biotite occurs as subhedral laths in thin lenticular zones or as anhedral grains around the edges of hornblende crystals. Epidote and actinolite are more abundant in altered samples, and locally become major constituents of the rock. Pyrite is the commonest sulphide present; chalcopyrite and sphalerite occur locally.

Meta-picrite*

Meta-picrite is less abundant in the main volcanic sequence than either basalt or andesite, and was only identified as a result of chemical analyses. It is practically indistinguishable from basalt in the field although it appears to be confined, for the most part, to porphyritic flows. Textural features in the meta-picrite are similar to those in the meta-basalts and again it is probable that the hornblende is pseudomorphic after pyroxene. The composition of the plagioclase seldom exceeds An₄₀ except in the cores of plagioclase phenocrysts. Biotite occurs only as an alteration product of hornblende.

* Editor's note: In a strict sense these rocks are not true picrites but were classified as such by the writers on the basis of less than 45% SiO₂ content (see Table 5).

Meta-andesite

Rocks of andesitic composition are almost impossible to distinguish from the basalts by field techniques. Colour index was found to be totally unreliable in rocks of the main volcanic sequence. Subhedral hornblende and plagioclase are the main constituents of the meta-andesites. The hornblende is practically free of inclusions or zoning. The composition of the plagioclase is generally An_{30} to An_{35} (andesine) but a few determinations revealed a composition below An_{30} (oligoclase). The oligoclase occurs as fresh rims around the more altered laths of andesine. The biotite is subhedral, and appears to be a primary constituent rather than an alteration product of hornblende. Chlorite was observed in a few thin sections of andesite, and appears to be indicative of a lower initial grade of regional metamorphism (i.e. upper greenschist facies) rather than retrogressive metamorphism.

Thin acid flows and pyroclastic rocks, and thin beds of volcanoclastic rocks and meta-argillites are commonly present within the basic volcanic flows. These are similar to the rocks of the acid volcanic centres and the metasedimentary rocks of the Upper Wasekwan Group (see pages 11 and 12) but in most cases, they lack the necessary thickness and stratigraphic continuity to constitute mappable units.

PORPHYRITIC META-BASALT, META-ANDESITE AND META-PICRITE (2c)

These porphyritic rocks make up at least 10 per cent of the main volcanic sequence. Basalt and picrite are more commonly porphyritic than andesite. In extreme cases, phenocrysts may constitute up to 60 per cent of the rock, but usually comprise less than 25 per cent. The phenocrysts are mostly hornblende and plagioclase although phenocrysts of magnetite, ilmenite and biotite have also been observed. Hornblende phenocrysts, which are the most abundant, are subhedral and 2 to 6 mm in size. In the basalt and picrite, practically all of the hornblende appears to be pseudomorphic after pyroxene, with well defined zoning preserved in a few cases. The plagioclase phenocrysts which are generally less abundant than the hornblende, are subhedral to euhedral laths, 2 to 3 mm in width and 5 to 8 mm in length. Many contain relict cores of labradorite, enveloped by rims of andesine (An_{32-44}). Magnetite and ilmenite phenocrysts are fairly common in the more basic rocks. They are generally anhedral, corroded and extremely variable in size. Biotite phenocrysts are least abundant, and are generally confined to andesite. Usually they occur as aggregations of subhedral crystals, which are locally chloritized.

BANDED AMPHIBOLE-PLAGIOCLASE AND BIOTITE-TREMOLITE-GARNET GNEISSES (2d)

FRAGMENTAL VOLCANIC ROCKS AND ASSOCIATED FINELY BANDED AMPHIBOLE GNEISS (3a)

These rocks outcrop to the north of the map-area and are described by Hinds (1972).

DACITE; MINOR RHYOLITE AND RHYODACITE; ACID TUFF; AGGLOMERATE; VOLCANIC BRECCIA (3b)

The acid volcanics are almost entirely confined to two major centres: the first occurs just north of Karsakuwigamak Lake and the second (a series of small lenses around the main volcanic-sedimentary contact) south of Rusty Lake; small lenses elsewhere are seldom mappable. These rocks are readily distinguished from more basic varieties by their lighter colour and conchoidal fracture. Many of the fine-grained acid volcanic rocks display thin flow layering (1 mm to 3 cm wide) consisting

of pale quartzo-feldspathic and darker mafic layers. In places, this layering is obliterated by recrystallization. Phenocrysts, where present, are aligned parallel to the layering, which in places is cut obliquely at low angles by the regional foliation.

Dacite

Most of the acid volcanics are dacites of variable mineralogical composition. They are commonly fine grained, medium to light grey and porphyritic. The average dacite contains quartz (25–30%), plagioclase (40%), potassium feldspar (10%), hornblende (15%) and biotite (10%), with accessory magnetite, chlorite, sericite, apatite, zircon, and epidote. Phenocrysts of sodic plagioclase, biotite, hornblende, quartz, and potassium feldspar may constitute as much as 30 per cent of the rock.

Rhyolite and rhyodacite

The rhyolites and rhyodacites are greyish white to pink and exhibit a more perfect conchoidal fracture than the dacites. They are usually fine grained to aphanitic (except where recrystallized) but may also be porphyritic. In general, they are texturally and mineralogically similar to the dacites but are richer in quartz and potassium feldspar, and poorer in mafic minerals and plagioclase. Some of the greyish white rhyolites south of Rusty Lake consist of quartz (35–40%), potassium feldspar (40–45%), sodic plagioclase (15%), biotite (5%), and hornblende (1–2%) with trace amounts of sericite, chlorite, epidote and pyrite. The rhyodacites are very similar in composition, but contain less quartz and potassium feldspar, and more sodic plagioclase. Phenocrysts are usually bluish white quartz “eyes”, potassium feldspar and sodic plagioclase.

Acid tuff

Acid tuffs are very difficult to distinguish from the flows in the field, except where they are noticeably coarser, or fragmental. Because of this, and the fact that they are almost identical in mineral composition to the rhyolites and rhyodacites, the writers did not map them separately. Two occurrences of possible ignimbrite were found: (i) on an island in the Churchill River, about 6 miles east of the western boundary of the Opachuanau Lake map-sheet (Map 71–2–8); and (ii) in the south-eastern corner of the Opachuanau Lake map-sheet. Rhyolitic clasts of varying size and shape occur in a dacitic groundmass, and are visibly flattened, although regional foliation appears to be absent.

Agglomerate and volcanic breccia

Agglomerate and volcanic breccia are found mainly at the acid volcanic centres, and interbedded with rocks of the main basic volcanic sequence; some also occur with the Upper Wasekwan metasediments. Few were mapped separately as they are rarely thicker than 50 feet (15 m) and a stratigraphic continuity of more than 250 feet (75 m) is exceptional. The agglomerates are usually associated with acid flows and tuffs, and consist of white to greyish white, well rounded rhyolitic clasts in a fine-grained more mafic groundmass.

The volcanic breccias are usually found interbedded with basic volcanic rocks of the main volcanic sequence and less commonly with the metasedimentary rocks. The angular fragments are almost all basaltic and locally retain the spiral shape of volcanic ejecta. The groundmass is andesitic to dacitic in composition. Two occurrences of volcanic breccia are particularly noteworthy: (i) on the northeast shore of Eagle Lake (Map 71–2–9), where the basaltic clasts display a remarkable spiral shape, and a relict “bread crust” bomb was also identified; (ii) on the shoreline and

some small islands in Opachuanau Lake just south of the exit of the Churchill River, and opposite the upper sulphide zone (6) (Map 71-2-8). Here the clasts are again basaltic and exhibit well defined spiral shapes. At both localities, some clasts appear to have been torn apart and the interstices filled with tuffaceous groundmass. As the effects of deformation in these restricted areas is relatively minor, the writers ascribe this feature to the release of gas pressure, following deposition, during rapid cooling of the volcanic ejecta.

Some of the breccias interbedded with the basic and intermediate volcanic rocks contain clasts that vary in size, shape and composition. The lack of bedding, well defined contacts, and even rudimentary sorting suggests that these are laharic deposits (volcanic mudflows). This has also been suggested by Milligan (1964) who noted similar deposits in the Earp Lake area.

Upper Wasekwan Group

The Upper Wasekwan Group consists of a sequence of metasediments (4) with isolated intercalated basic and intermediate volcanic flows (5). This sequence rests on the metavolcanics (2b, 2c and 3) and is exposed to the north of the volcanic sequence, with the exception of the shallow-dipping metasediments (4a, 4c) exposed around Karasakuwigamak Lake.

ACID AND INTERMEDIATE PYROCLASTIC ROCKS; METAMORPHOSED VOLCANICLASTIC ROCKS; META-ARGILLITE; AMPHIBOLITE (4a)

These rocks comprise most of the main metasedimentary sequence, but also occur as thin intercalated bands in the main metavolcanic sequence where they are usually too small to map separately. Recrystallization appears to have obliterated all primary structures other than compositional layering (which probably represents bedding).

Acid to intermediate pyroclastic rocks

Acid to intermediate pyroclastic rocks constitute at least one-third of the Upper Wasekwan Group. In general, they comprise layers 50 to 200 feet thick (15-60 metres) which are rarely continuous for more than 1000 feet (300 metres). In the northwestern portion of the Upper Wasekwan Group however, intermediate tuffaceous rocks with minor basic and intermediate flows, occur in units which are 500 to 1000 feet (150-300 metres) thick. The pyroclastic rocks are generally non-fragmental, but in a few places they contain fragments ranging in size from lapilli to bombs and blocks. The prevalent dacitic to andesitic pyroclastic rocks contain variable amounts of biotite, plagioclase, hornblende and quartz. Quartz comprises 15 per cent of some dacitic tuffs, but otherwise 2 to 10 per cent is typical. The more acid pyroclastic rocks are similar to those at the acid volcanic centres (unit 3b) already described.

Volcaniclastic rocks

The volcaniclastic rocks consist of volcanic greywackes and siltstones. Both are dark grey to almost black and in many instances difficult to distinguish from flow rocks. In general, however, the volcaniclastic rocks appear granular and more siliceous, and they show a distinctive outcrop pattern. Whereas the flow outcrops are blocky and well jointed, the outcrops of volcaniclastic rocks are generally more rounded and weakly jointed. A typical volcaniclastic rock contains anhedral grains of plagioclase (40%), quartz (15-25%), hornblende (20-25%), biotite (15%) and potassium feldspar (less than 5%), with accessory sericite, epidote, diopside, magnetite, zircon, apatite and rare chlorite.

Meta-greywacke

The meta-greywackes resemble the volcanoclastic rocks in their granular appearance, but are distinguished by their lighter colour (light to medium grey) and visible quartz. They are usually bedded, with alternating thick quartzo-feldspathic and thin biotite-rich layers. Less common conglomeratic greywackes contain well rounded basic and acid clasts that vary considerably in size. Typical meta-greywacke consists of sodic plagioclase (40%), quartz (30-35%), biotite (25%) and hornblende (5%) with accessory chlorite, sericite, magnetite, carbonate and apatite. The chemical composition of typical greywacke is shown in Table 3.

TABLE 3. CHEMICAL COMPOSITION OF TYPICAL GREYWACKE

Sample No. 28-0-262 Lab. No. R-688	
SiO ₂	68.15
Al ₂ O ₃	16.00
TiO ₂	0.50
Fe ₂ O ₃	0.88
FeO	3.06
MnO	0.04
MgO	1.71
CaO	1.22
Na ₂ O	2.12
K ₂ O	3.95
P ₂ O ₅	0.20
H ₂ O	1.53
CO ₂	0.48
Total	99.85

Meta-argillite

Meta-argillite is the least abundant type of metasediment, occurring only as thin seams in the metavolcanic and metasedimentary rocks of the Wasekwan Group. The meta-argillite layers are rarely more than 50 feet (15 metres) thick in the southern half of the map-area, but may exceed 200 feet (60 metres) north and east of Rusty Lake. Those in the south are very fine grained, light grey, and extremely difficult to distinguish from some acid metavolcanics. They consist of 55 per cent quartz, 10 to 15 per cent feldspar (usually sodic plagioclase) and 30 to 35 per cent biotite with trace amounts of sericite, apatite, magnetite and garnet. The meta-argillites in the north are richer in biotite and commonly recrystallized to quartz-biotite schist. The meta-argillites are the only rocks in the Rusty Lake greenstone belt that commonly contain garnet.

Amphibolite

Typical amphibolite is medium to coarse grained and consists of 40 to 50 per cent hornblende, 40 per cent andesine (An₃₀₋₃₅), 10 per cent quartz and 5 per cent

epidote, with accessory potassium feldspar, sericite, epidote, magnetite and local sulphides. Most of the amphibolites have resulted from intense, local recrystallization of volcanoclastic and intermediate pyroclastic rocks. Some of them, however, are probably derived from thin layers of marl or impure dolomite.

GREYWACKE CONGLOMERATE (4b)

The two main occurrences of greywacke conglomerate (4b) are: (i) around "Eagle" Lake in the southwest part of the Issett Lake sheet (Map 71-2-9); and (ii) in the northwest corner of the Earp Lake sheet (Map 71-2-7). Clasts make up about 15 per cent of the rock. All are flattened in the plane of the regional foliation, and elongated down-dip. The three main types of clasts are: (a) abundant white fine-grained acid volcanic clasts, probably derived from acid flows and pyroclastic rocks (3) especially acid tuffs, but considerably recrystallized; (b) strongly epidotized clasts of Wasekwan volcanoclastic metasediments; and (c) pink, medium-grained granitic clasts, found only in the Earp Lake area and derived from an unknown source. No such leucocratic granitic rocks, younger than the post-Sickle intrusions, outcrop in the map-area. In some of the conglomerate layers, boudinaged quartz veins give the false impression of quartz clasts.

The matrix of the conglomerate, although somewhat variable, is mineralogically similar to the Wasekwan greywackes (4a), and thin greywacke layers (1 to 2 feet; 30-60 cm) are common in the conglomerate. An average matrix composition is plagioclase (40%), quartz (30%), biotite (20%), hornblende (10%) and potassium feldspar (1 to 2%), with accessory magnetite, sericite, carbonate, epidote and apatite. On the south shore of "Eagle" Lake, the matrix of the conglomerate contains greater amounts of quartz and potassium feldspar, apparently resulting from the introduction of silica and potash during intrusion of the tonalite batholith (14) to the north.

META-ARKOSE; FELDSPATHIC QUARTZITE; MINOR ARKOSIC CONGLOMERATE (4c)

These rocks are interbedded with other Wasekwan metasedimentary rocks but, as they are seldom thicker than 50 feet (15 metres), they were rarely mapped separately. They are not well exposed; the best outcrops occur on the shores of Rusty and Karsakuwigamak Lakes, and north of "Eagle" Lake (Maps 71-2-8, 71-2-6 and 71-2-9 respectively).

Meta-arkose

Probably 80 per cent of this unit (4c) is meta-arkose, which is especially abundant north of "Eagle" Lake. However, the great thickness of the arkose in this area [approximately 2 miles (3 km)] is due in part to the folding and buckling caused by intrusion of the tonalite batholithic complex (14). The arkose is fine to medium grained and grey to greyish white on both fresh and weathered surfaces. Bedding is well defined, and comprises alternating quartzo-feldspathic and more mafic layers. The latter are usually pink to red in colour, due to oxidation of biotite. Typical arkose contains quartz (50-70%), oligoclase An_{25} (20-30%), potassium feldspar (5%) and biotite (10-15%), with accessory apatite, hematite, hornblende, sericite, chlorite and magnetite. The composition is however, extremely variable, especially in the relative amounts of quartz and feldspar. In the area around Karsakuwigamak Lake, sericite exceeds biotite in abundance.

Feldspathic quartzite

Feldspathic quartzite was found only on the shore of Karsakuwigamak and

Rusty Lakes, interbedded with the more arkosic rocks, and rarely thicker than 50 feet (15 metres). This quartzite resembles the arkose, but is lighter in colour and more commonly shows red and white colour banding. The average composition is 75 to 80 per cent quartz, 10 to 15 per cent oligoclase (An_{25}), 5 per cent potassium feldspar, 5 to 15 per cent biotite and sericite, and accessory magnetite, apatite, chlorite and hematite. As in the case of the arkoses, the feldspathic quartzites of the Karsakuwigamak Lake area commonly contain more sericite than biotite.

Arkosic conglomerate

Arkosic conglomerate is restricted to the north shore of the large bay in the southwestern part of Rusty Lake. It occurs as narrow bands (too small to map separately) interbedded with arkose and feldspathic quartzite. The conglomerate matrix is similar to the more quartzose arkoses. Two types of clasts occur in the conglomerate: (a) clasts of fine-grained white acid lava and tuff; and (b) medium-grained, pink to pinkish white granitic clasts, which are almost identical to those found in the greywacke conglomerate (4b). The granitic clasts are well rounded and again appear to have been transported from a distant source area as no early leucocratic intrusive rocks have been observed in the map-area.

PLAGIOCLASE PARAGNEISS (4d)

This unit occurs within the Opachuanau Lake map-area and is described by Hinds (1972).

META-BASALT, META-ANDESITE (5a)

These rocks, and the porphyritic varieties (5b), were produced during a second basic extrusive episode, and are younger than most of the Upper Wasekwan meta-sediments. They are far less widespread than the basalts and andesites of the main volcanic sequence (2b, 2c), and occur only as thin flows intercalated with sediments.

The meta-basalt and meta-andesite are commonly aphanitic, and are much fresher in appearance than the earlier flows. Primary features such as amygdalae and vesicles are well preserved. Amygdaloidal and vesicular lavas are most prevalent in the northwestern portion of the area (Map 71-2-8). The amygdalae are now composed of quartz, but originally may have been zeolites or feldspathoids. Pillow structures were observed at only two localities, the first about 3000 feet (900 metres) due south of the Rusty Lake narrows, and the second in the northeast portion of the Earp Lake map-sheet. Flow top breccia is well preserved about 2 miles west of Rusty Lake.

Basalt appears to be much more abundant than andesite, but no picrite was detected. Texturally and mineralogically, these rocks are almost identical to those of the main sequence (2b), except that calcium-rich cores are more commonly preserved in the plagioclase laths, and hornblende crystals are more commonly zoned and poikilitic. No primary pyroxene was found.

PORPHYRITIC META-BASALT AND META-ANDESITE (5b)

These rocks are restricted to the northwestern portion of the map-area along the south shore of the Churchill River (Map 71-2-8).

Phenocrysts of hornblende and plagioclase are subhedral and strongly corroded. Most of the phenocrysts are hornblende, again apparently pseudomorphous after ortho and clinopyroxene, and commonly zoned and poikilitic. Plagioclase

phenocrysts are much less abundant than in the earlier porphyritic flows (2c). Typically, they have labradorite cores and rims of more sodic andesine. No biotite, magnetite or ilmenite phenocrysts were observed.

SULPHIDE ZONES (6)

Three separate sulphide zones occur north and slightly east of Rusty Lake, where they define some of the major fold structures in the area (Map 71-2-8). They vary from 2 to 6 miles (3-9.5 km) in length, and 500 to 600 feet (150-180 metres) in width. Numerous trenches and geophysical lines attest to the large amount of exploration work carried out on these zones. Burwash (1962) described the rocks as altered tuffs, consisting mainly of quartz and pyrrhotite, with varying amounts of plagioclase, microcline, hornblende, tremolite, diopside, epidote, carbonate, biotite and sphene. Samples examined by the writers contained at least 50 per cent quartz and up to 30 per cent sulphides. The sulphides are mainly pyrrhotite but considerable pyrite was also found. Assays revealed less than 0.02 per cent nickel and 0.01 per cent copper.

The writers do not concur with the conclusion of Burwash (1962) that the sulphide zones are altered pyrrhotite-bearing tuffs. The zones intersect the bedding at a small angle and thus appear to be secondary planar features (? shears) which were subsequently silicified and mineralized. The broad range in mineral composition of these zones suggests that they were derived from more than one original rock type and not simply from a porous tuff.

PRE-SICKLE INTRUSIVE ROCKS

DISTRIBUTION AND FIELD RELATIONS

Two related types of pre-Sickle intrusive rocks occur in the map-area: hornblende gabbro and hornblendite (7b); and hornblende diorite and quartz diorite (7c). They occur throughout the map-area and are well exposed, mainly as small stocks but also as sill-like bodies. The best exposures were found in the Pemichigamau Lake area (Map 71-2-6). Outcrops are generally low-lying, but south of Ruttan Lake, some attain a height of 75 feet.

The intrusions have been affected by the regional foliation and by easterly to northeasterly trending isoclinal folding, but neither of these structures is well defined in the coarser portions of the intrusions. A weak primary foliation occurs at a few localities around the peripheries of the intrusions, approximately parallel to the contacts. Almost all the mafic stocks display a rudimentary differentiation.

Intrusive relationships between the basic intrusive rocks and the Wasekwan Group clearly demonstrate that the intrusions are younger. Their pre-Sickle relationship is established by the presence of basic clasts from these intrusions in the basal Sickle conglomerate (8a). The basic intrusions (7b, c) are cut by members of the post-Sickle granodiorite complex (15). Both gabbro (7b) and diorite (7c) appear from analyses (Table 5) to be chemically similar to the Wasekwan basalts and andesites respectively, and are therefore considered by the writers to have probably been derived from the same magmatic source.

ULTRAMAFIC AMPHIBOLITE AND ASSOCIATED OLIVINE-BEARING ROCKS (7a)

This map-unit is exposed north of the Twenty-third Base Line and is described by Hinds (1972).

HORNBLENDE GABBRO; HORNBLENDITE; MINOR DIORITE AND QUARTZ DIORITE (7b)

A number of small well exposed sills and lensoid bodies of hornblende gabbro and hornblendite are scattered throughout the map-area. The largest body occurs due west of Karsakuwigamak Lake (Map 71-2-6). Both rock types are coarse-grained and dark green to black. Hornblendite is less common than gabbro, and usually occupies an inner zone in gabbroic bodies. A good example is the mafic sill on the southwest shore of Rusty Lake. The central portion is composed of hornblendite, which grades outwards into hornblende gabbro, which in turn grades into hornblende diorite at the outer margins. This gradation takes place over a distance of less than 40 feet (12 metres).

Hornblendite is composed of 80 per cent blue-green poikilitic hornblende, 10 per cent actinolite, 5 to 10 per cent epidotized andesine (An_{38-46}) and 5 per cent epidote with accessory magnetite, ilmenite, sphene, diopside, uraltite, biotite, chlorite, sericite and sulphides. Pearse (1964) reported augite in rocks of this composition, but the writers believe diopside and actinolite are more likely, in view of regional metamorphism to the lower amphibolite facies. It is possible that these rocks were originally pyroxenites, but no conclusive evidence was found in the thin sections examined.

The gabbro contains hornblende (60-75%), highly epidotized andesine (20-35%), magnetite (1-5%) and biotite (2-3%) with accessory ilmenite, sphene, tremolite, diopside, uraltite, sericite, epidote, chlorite and sulphides. Actinolite is locally present in amounts up to 10 per cent. Both hornblende and plagioclase are highly corroded. Apart from the presence of uraltite there is no evidence that hornblende has replaced pyroxene.

HORNBLENDE DIORITE, QUARTZ DIORITE (7c)

Diorite (7c) is more abundant than the more mafic rocks (7b) and occurs in larger bodies, mainly irregular stocks in the southern half of the map-area and north of Rusty Lake (Maps 71-2-6, 71-2-7, 71-2-8 and 71-2-9). A diorite sill was mapped just north of Ruttan Lake. The hornblende diorite and quartz diorite are both mesocratic and medium grained, and are difficult to distinguish in the field. Detailed sampling and petrographic studies would be necessary to completely separate the two varieties.

Typical hornblende diorite is composed of poikilitic hornblende (35%), oligoclase-andesine (An_{28-42} , 40-45%), biotite (5-10%), quartz (5-10%), and potassium feldspar (5%) with accessory magnetite, epidote, chlorite, sphene, apatite, zircon, sericite, and sulphides. Rocks containing more than 10 per cent quartz were classified as quartz diorites. A small stock on the west shore of Rusty Lake is the only homogeneous body of quartz diorite known in the map-area. Diorite is common in the outer margins of more mafic bodies (7c) and therefore appears to be genetically related to the gabbros and hornblendites.

SICKLE GROUP

DISTRIBUTION AND FIELD RELATIONS

Rocks of the Sickle Group within the map-area are principally arkosic conglomerate (8a) and quartz-mica schist (9). Exposures are practically restricted to the south bank of the Churchill River and the shores of Opachuanau Lake, (Map 71-2-8) where they are seldom more than 5 feet above water level. A few large outcrops

of the schist (9) were found east of Opachuanau Lake just south of the Twenty-third Base Line (Maps 71-2-8 and 9).

The quartz-mica schist was probably derived from arkose, shale and siltstone. A few hornblende-rich layers in the sequence probably represent thin calcareous beds. All primary structures have been obliterated by recrystallization.

The Sickie-Wasekwan contact is rarely well exposed in the map-area, but there is nevertheless good evidence of an unconformity (Milligan, 1960) at the base of the Sickie Group: (i) the Wasekwan is more intensely folded; (ii) a slight angular unconformity was observed locally; and (iii) abundant pebbles of Wasekwan metavolcanics and metasediments and pre-Sickie intrusive rocks occur in the Sickie arkosic conglomerate (8a) northwest of Rusty Lake. These pebbles could only have been derived after a prolonged period of erosion following deposition and intrusion of the Wasekwan rocks.

The northern contact of the arkosic rocks (8a) with the Opachuanau gneisses (10) is extremely gradational, in contrast to the much sharper contact between these gneisses (10) and the quartz-mica schist. Arkosic conglomerate (8a) is cut by the post-Sickie "quartz-eye" granite (17c), and inclusions of the schist (9) occur in both the tonalite complex (14) and pegmatite (18).

ARKOSIC CONGLOMERATE, MINOR ARKOSE (8a)

Arkosic conglomerate, composed of unsorted pebbles and cobbles, appears to be the least deformed of the Sickie rocks. In some outcrops the clasts still retain much of their original shape, with only minor elongation down the dip of the regional foliation. Near the contact with the Opachuanau gneisses (10), however, the pebbles and cobbles are severely deformed and the more siliceous clasts are no longer recognizable.

In general, clasts derived from five main sources have been recognized: (i) diorite and tonalite; (ii) Wasekwan metasediments; (iii) Wasekwan metavolcanics; (iv) fine-grained siliceous rocks; and (v) coarse-grained granitic rocks of unknown origin. Clasts derived from Wasekwan metasediments and from diorite and tonalite are the most abundant. Burwash (1962) considered that the latter were derived from the tonalite batholith (14), which he classified as pre-Sickie, but which current work shows to be post-Sickie. In any case, it now seems highly probable that these clasts were derived from pre-Sickie diorite and quartz diorite (7c), which they strongly resemble in both lithology and mineral composition. Most of the clasts derived from Wasekwan metasediments consist of intermediate tuff, greywacke or plagioclase amphibolite; many of the clasts are strongly epidotized. Clasts of Wasekwan lavas are mostly fine-grained meta-basalt or meta-andesite and are also epidotized. The fine-grained siliceous clasts are white to pink in colour, and many of them, with a saccharoidal texture, appear to be feldspathic quartzite. Quartzites are thin and somewhat rare in the Wasekwan, but their resistant character could account for their relative abundance as clasts. A much finer-grained and less common type of clast resembles Wasekwan rhyolite. The coarse white granitic clasts do not resemble any known source rock in the map-area.

It is interesting to note that the conglomerate fails to display even rudimentary sorting. The conglomerate matrix is light grey, fine to medium-grained arkose, and typically consists of quartz (60-65%), sodic plagioclase (15-20%), microcline (5-10%) and biotite (10%), with traces of magnetite, epidote, apatite, zircon and disseminated sulphides. Thin wedges of arkose, identical to the typical arkosic matrix, occur within the conglomerate. Locally, the matrix is more feldspathic, and also in places, more mafic, and becomes more of a subgreywacke than an arkose.

ARKOSE, QUARTZITE (8b)

ARKOSE-DERIVED GNEISSES AND MIGMATITE (8c)

Impure arkose with minor quartzite (8b), and arkosic gneiss and migmatite (8c), are restricted to the area around Pemichigamau Lake; both units are described by Schledewitz (1972). Gneisses and migmatites derived from arkose in the southwestern part of the Pemichigamau Lake sheet, are described by Kendrick (1972).

BIOTITE-MUSCOVITE-QUARTZ SCHIST (9)

Pelitic, brownish black, biotite-muscovite-quartz schists with a stratigraphic thickness up to 10,000 feet (3000 metres) occur in the northwestern part of the map-area due east of Opachuanau Lake (Maps 71-2-8 and 71-2-9). They are poorly exposed because of their susceptibility to weathering, but they may underlie a large drift-covered area southeast of Opachuanau Lake. The mica schists are accompanied by minor hornblende schists apparently derived from calcareous shale. The schists (9) do not overlie the arkosic Sickie rocks (8) but are found at approximately the same stratigraphic level, suggesting a possible lateral facies change between the two units.

The grain size of the schists is 1 to 3 mm and a typical composition is biotite (30%), muscovite (25%), quartz (25-30%), sodic plagioclase (15-20%) and potassium feldspar (5%), with accessory apatite, amphibole, magnetite, epidote, zircon and sphene. In calcareous zones, hornblende and actinolite may constitute as much as 50 per cent of the schist at the expense of mica and quartz; the plagioclase content also increases.

OPACHUANAU GNEISSES (10)

NOMENCLATURE

A band of gneisses extends eastward from the western margin of the Opachuanau Lake map-sheet (Map 71-2-8) through Opachuanau Lake, and forms the divide between Southern Indian Lake and the Rat River basin. These rocks have previously been called "Kisseynew-type" gneisses by Burwash (1962) and Bristol (1966), but the writers, along with Hinds (1972), prefer to introduce the term "Opachuanau gneisses" for the following reasons:

- (1) Milligan (1960) correlated gneisses in the Lynn Lake area (which he considered were derived from Sickie sediments) with the Kisseynew gneisses (see Harrison, 1951) partly on the grounds of lithologic similarity. During the present study, however, it has been found that the Opachuanau gneissic belt was derived from igneous as well as sedimentary rocks (Hinds, 1972).
- (2) The Opachuanau gneisses (10) are not continuous into the Lynn Lake district and so cannot be correlated with Milligan's "Kisseynew-type" gneisses.
- (3) Field relations (*q.v.*) indicate that some of the Opachuanau gneisses were derived from Sickie rocks. Others were possibly derived from Wasekwan amphibolites, and post-Sickie diorites (11) (Hinds, 1972).

The Opachuanau gneisses (10) have been divided into three subunits, only one of which, the biotite-hornblende intermediate gneiss (10a), outcrops within the present map-area. The other two subunits occur further north, and are described by Hinds (1972).

FIELD RELATIONS

On the south shore of the Churchill River, Sickle arkosic conglomerate (8a) grades into the biotite-hornblende intermediate gneisses (10a). On some islands in Opachuanau Lake, inclusions of gneiss (10a) occur in the post-Sickle tonalite (14a). Further east, the southern margin of the gneissic belt (10a) has been intruded by conformable sheets of pegmatite (18) which increases in quantity and thickness towards the main mass of pegmatite (18) further to the south (Map 71-2-9).

BIOTITE-HORNBLENDE INTERMEDIATE GNEISS (10a)

These gneisses (10a) are grey, fine to medium grained, and well foliated and layered. Quartzo-feldspathic *lit* are common.

Typically, the gneisses consist of sericitized andesine. An₃₀₋₄₀ (45%), quartz (30%), potassium feldspar (5%, locally 10%), hornblende (4-5%) and biotite (up to 15%) with accessory apatite, sphene, zircon, and magnetite with hematite. The biotite and hornblende are both partially altered to epidote. Both plagioclase and biotite show local strain effects. Myrmekitic intergrowths of quartz and andesine form less than 2 per cent of the rock. The foliation in the gneisses is defined by the preferred orientation of biotite, and locally by parallel biotite-hornblende clots.

HORNBLENDE-BIOTITE INTERMEDIATE GNEISS WITH AMPHIBOLE-PLAGIOCLASE GNEISS, AND AMPHIBOLITE (10b); MIGMATITE (10c)

These rocks are restricted to the northern part of the gneissic belt and are described by Hinds (1972).

POST-SICKLE INTRUSIVE ROCKS

The two most extensive post-Sickle intrusions in the map-area, both of batholithic proportions, are the biotite-hornblende tonalite and diorite batholith (14a), with granodioritic (14b), quartz monzonitic and granitic (14c) differentiation phases; and the biotite-hornblende granodiorite batholith (15a) with related stocks of pink granite, quartz monzonite and alaskite (15c). Smaller intrusions in the map-area, similarly considered to post-date the Sickie Group, are: (i) two small bodies of hornblendite (13), north of Issett Lake; (ii) a "quartz-eye" granite to quartz monzonite stock (17c) on Opachuanau Lake; (iii) dykes, sills and larger bodies of pegmatite and aplite (18); and (iv) diabase dykes (19).

DIORITE AND ASSOCIATED ROCKS (11)

These rocks occur within the Opachuanau gneissic belt and are described by Hinds (1972).

FOLIATED MAGNETIFEROUS QUARTZ DIORITE (12)

This unit (12) is restricted to the area around Pemichigamau Lake and is described by Schledewitz (1972).

HORNBLENDITE AND ASSOCIATED AMPHIBOLE-PLAGIOCLASE GNEISS (13)

Hornblendite (13) has been mapped in two small bodies, 4 miles north of Issett Lake (Map 71-2-9). The surrounding outcrops are biotite-hornblende intermediate gneiss (10a). Similar hornblendite, with associated amphibole-plagioclase gneiss (13), occurs in the map-area to the north, where Hinds (1972) has observed that it intrudes the gneiss (10a).

The hornblendite contains subhedral crystals of hornblende (5 mm) surrounded by small subhedral crystals of diopside. Saussuritized plagioclase (An_{28-34}) is anhedral and interstitial to the hornblende, in which it also forms inclusions.

TONALITE AND ASSOCIATED ROCKS (14)

Distribution and field relations

A tonalitic batholith occupies approximately 120 square miles in the north-eastern portion of the map-area (Maps 71-2-8, 71-2-9 and 71-2-10). The batholith is predominantly biotite-hornblende tonalite and diorite (14a) but these rock types grade into granodiorite (14b), and quartz monzonite and granite (14c). It is bounded to the north by pegmatite (18) and quartz-mica schist (9), but the contact is entirely obscured by swamp and glacial drift. Outcrops are sporadic except in the western and central portions of the batholith. The rocks are generally massive in the central portion of the batholith, but become increasingly foliated towards the outer margins, where biotite increases at the expense of hornblende. The foliation is parallel to the margin of the intrusion, and may be primary.

The batholith was previously classified as a pre-Sickle intrusion by Burwash (1962) and Bristol (1966). Present evidence, however, indicates a post-Sickle age. On the south shore of the Churchill River near Opachuanau Lake, and on islands in the lake, (Map 71-2-8), the tonalite cuts biotite-hornblende intermediate gneisses (10a) which are derived in part from Sickle rocks. On some of the islands, inclusions of the gneiss (10a) were also observed in the tonalite.

The southern contact of the batholith with Wasekwan metasediments (4) is sharp, except in the southeast corner of the Issett Lake map-sheet (Map 71-2-9), where large xenoliths of metasediment have been partially assimilated and granitized, while the contaminated intrusive rocks have become dioritic.

Biotite-hornblende tonalite and diorite (14a)

Biotite-hornblende tonalite (14a) is the dominant rock type in the batholith. It is coarse grained, inequigranular, and varies from light to medium grey in colour. The tonalite is composed of 50 to 55 per cent plagioclase (An_{27-44} and locally zoned), 20 to 25 per cent quartz, 5 per cent microcline (sericitized), 15 per cent biotite and 5 per cent hornblende, with accessory zircon, magnetite, sphene and clinozoisite. Diorite, which grades imperceptibly from tonalite, contains 35 to 40 per cent hornblende and biotite, 50 to 60 per cent plagioclase (An_{38-60}) and 5 to 10 per cent quartz (Burwash, 1962).

Granodiorite (14b)

The granodiorite (14b) is pale pink to light grey, medium to coarse grained and generally massive. Oligoclase (An_{25-30}) makes up 40 to 50 per cent of the rock, microcline 20 to 25 per cent, quartz 25 to 35 per cent, biotite 4 to 8 per cent, and hornblende generally less than 5 per cent. The accessory minerals are magnetite, zircon, sericite, apatite and sphene. The feldspar grains are slightly sericitized and some of the quartz grains show undulatory extinction.

Quartz monzonite and granite (14c)

These rocks resemble the tonalite (14a) in appearance but are pale pink and contain more potassium feldspar. They are inequigranular and coarse grained with local fine-grained phases. The quartz monzonite (14c) is composed of 25 per cent

plagioclase (highly sericitized), 35 per cent microcline, 30 per cent quartz and less than 10 per cent biotite, with accessory magnetite and zircon, and small amounts of myrmekite. The granite (14c) contains over 65 per cent microcline, 20 to 30 per cent quartz (strained), 5 to 10 per cent plagioclase, up to 15 per cent biotite, minor hornblende and less than 1 per cent magnetite, zircon, and myrmekite.

GRANODIORITE AND ASSOCIATED ROCKS (15)

Distribution and field relations

The batholithic complex (15) south and west of the Rusty Lake greenstone belt occupies at least one-quarter of the map-area. More than 70 per cent of the batholith is granodiorite, and the rest is mainly diorite (15a) and quartz monzonite (15c). All these rocks are generally well exposed, and larger outcrops rise 50 feet above the drift.

Central portions of the batholith are generally massive, but marginal zones show a well defined primary foliation. The batholith post-dates the regional foliation, and the periods of folding identified in the area, but has been affected by later faulting. The batholith is also exceptionally well jointed.

Parts of the batholith intrude the Wasekwan Group and pre-Sickle intrusions. Age relations between the granodiorite (15) and the Sickle Group cannot be demonstrated in the map-area, but Schledewitz (1972) reports a cross-cutting relationship further to the south. The granodiorite is cut by pegmatite (18) and diabase (19) and is probably older than the "quartz-eye" granite and associated rocks (17). Contacts between the granodiorite (15a) and the quartz monzonite, alaskite (15c) appear to be mostly gradational and no cross-cutting relationships were found by the writers. Pearse (1964) however, notes that dykes of alaskite cut the granodiorite but is nevertheless of the opinion that the two rocks are consanguineous. This view is shared by the writers who consider that the quartz monzonite, alaskite stocks (15c) are probably leucocratic differentiates of the granodiorite.

Biotite-hornblende granodiorite with dioritic to quartz dioritic contact phases; minor quartz monzonite (15a)

The granodiorite is pinkish white, and medium to coarse grained, rarely fine grained. It has a variable composition but generally consists of 50–55 per cent zoned plagioclase (oligoclase to sodic andesine), 15–20 per cent microcline, 20–25 per cent quartz, 5 per cent biotite, and 5 per cent hornblende, with accessory sphene, apatite, muscovite, zircon, magnetite, hematite, sericite, epidote and chlorite. The granodiorite appears to become richer in quartz and microcline towards the centre, as noted by Pearse (1964), and grades into quartz monzonite. This gradation is accompanied by a decrease in the amounts of hornblende and biotite present.

Near the contacts with Wasekwan rocks, the granodiorite becomes dioritic to quartz dioritic in composition, with more than 25 per cent mafic minerals, little or no microcline, and 5 to 15 per cent quartz. The dioritic contact phase of a quartz monzonite in the northeast corner of the Issett Lake area (Map 71–2–9) has also been designated as unit 15a, but the writers have no evidence of its age relationship with the main granodiorite complex (15).

Coarse-grained gneissic granodiorite and quartz diorite (15b)

These rocks (15b) are restricted to the Pemichigamau Lake area (Map 71–2–6) and are discussed by Kendrick (1972).

Pink granite and quartz monzonite, minor alaskite (15c)

Pink quartz monzonite and alaskite (15c) occur as small, irregular stocks, west and north of Karsakuwigamak Lake (Maps 71-2-6 and 71-2-7). Pink granite occurs only in the west half of the Pemichigamau Lake sheet (Kendrick, 1972). The quartz monzonite is similar to the granodiorite (15a), in texture and composition, but contains slightly more quartz, more microcline and less plagioclase. An average composition is quartz (30%), microcline (40%), plagioclase (25 to 30%) and biotite (5%), with accessory muscovite, sericite, apatite, chlorite, and zircon. Samples collected near contacts with more mafic rocks, contain as much as 25 per cent mafic minerals, but in the central portions of these stocks there is rarely more than 5 per cent biotite and hornblende. Where mafic minerals are virtually absent, the quartz monzonite grades into pink alaskite, which makes up perhaps one-fifth of this map-unit (15c). The alaskite is texturally similar to the quartz monzonite, and consists of quartz (35-40%), potassium feldspar (40%), sodic plagioclase (20-25%) and biotite (1-2%) with accessory muscovite, sericite, zircon, chlorite and apatite. The alaskite has a fresh appearance with only minor sericitization of the feldspars and some granulation of the larger quartz grains.

NEBULITIC TONALITE AND GRANODIORITE (16)

These rocks occur along the southern shore of Southern Indian Lake (Map sheet 71-2-9) and are described by Hinds (1972).

PORPHYRITIC QUARTZ MONZONITE (17a); QUARTZ MONZONITE (17b)

Except for restricted outcrops of porphyritic quartz monzonite (17a) in the extreme northwest (Map 71-2-8), these rocks are not exposed in the map-area. They are exposed in the adjoining area, north of the Twenty-third Base Line and are described by Hinds (1972).

"QUARTZ-EYE" GRANITE; QUARTZ MONZONITE (17c)

An ovoid stock of leucocratic, pink "quartz-eye" granite to quartz monzonite (17c) occurs in the northwest portion of the map-area (Map 71-2-8) and is particularly well exposed around Opachuanau Lake, on the Churchill River, and along the Twenty-third Base Line. Outcrops of the "quartz-eye" granite commonly rise 100 feet above the surrounding swamp and drift.

The stock cuts both the Sickie Group metasediments, and the Opachuanau gneisses. It was not seen in contact with other post-Sickie intrusive rocks (14-19) other than the later pegmatite (18), and its age relationships with them are therefore unknown. However, the stock apparently post-dates the northeast and northwest faults that cut the quartz monzonite of unit 15c, and it also appears to be later than the regional foliation. Its northern and southern contacts however, are affected by east-west faulting, and the stock displays some of the late regional jointing. A well defined primary foliation, which is developed in the outer portions of the stock, is parallel to the contacts.

The "quartz-eye" granite and quartz monzonite (17c) are the least altered of any rocks in the map-area, with the exception of the pegmatite (18) and diabase (19). They are medium to coarse grained, and readily distinguished by their salmon pink colour (due partly to hematite) and the peculiar "quartz-eye" phenocrysts. The elongation of these "quartz-eyes" and the preferred orientation of the biotite together define the primary foliation in the stock. The granite contains approximately 55 per cent perthitic microcline, 15 per cent zoned plagioclase (cores An_{18-25} , rims

Ang 14), 25 to 30 per cent quartz and 5 per cent biotite, with accessory muscovite, sericite, apatite, hematite and magnetite. Minor sericitization is the only visible alteration. In hand specimen, the quartz monzonite is indistinguishable from the granite, and the only difference between the two appears to be in the microcline to plagioclase ratio. Granite appears to be slightly more abundant than quartz monzonite, but more detailed studies would be necessary to prove this conclusively, or to define separate granitic and quartz monzonitic zones.

PEGMATITE AND APLITE (18)

Pegmatite (18) occurs as dykes and sills from a few inches to more than five hundred feet (150 metres) in width, and also as a large elongate body south of the Twenty-third Base Line on the Issett Lake map-sheet (Map 71-2-9). To some extent the dykes and sills follow joint patterns. Larger bodies form steep, bare-topped hills, which are prominent on aerial photographs. For present purposes the pegmatites (18) have been mapped as one unit, but detailed mapping would probably show at least four ages and possibly as many as six separate subunits.

Small dykes and sills of aplite are abundant, and aplitic phases occur with most pegmatites. Mutually cross-cutting relationships are common. The aplite is fine-grained to aphanitic and similar in composition to the pegmatite, but slightly richer in potassium feldspar.

Karsakuwigamak Lake — Opachuanau Lake areas

In the Karsakuwigamak Lake and the Opachuanau Lake areas (Maps 71-2-6, 71-2-7 and 71-2-8) pink pegmatite is associated with the granodiorite-quartz monzonite batholith (unit 15a). The contact is gradational and this pegmatite is regarded as a crystallization product of the residual magma. It contains more than 50 per cent perthitic potassium feldspar, graphically intergrown with quartz (30 per cent), some albite and 10 per cent biotite. Small garnets were noted by Pearse (1964).

Issett Lake area

A pegmatite sill, at least 14 miles (22.5 km) in length, outcrops along the Twenty-third Base Line (Map 71-2-9). The sill has sharp contacts with the Opachuanau gneisses (10) and contains xenoliths of gneiss up to twenty feet (6 metres) long. The pegmatite is generally white and albite-rich, but orthoclase and perthite are locally predominant. Muscovite usually exceeds biotite, except around the xenoliths. Garnet (2 mm) occurs locally. The pegmatite differs in composition from other rocks in the area, but may be genetically related to the tonalitic body (14) a mile or two to the south, from which it is separated, however, by drift and swamp. Since the tonalitic batholith contains granitic and quartz monzonitic phases, it is possible that the pegmatite is a late-stage differentiate.

An aplitic phase is common in both the tonalite (14) and granodiorite (15) batholiths, in the form of dykes, sills and small plugs. Aplite in the tonalite is probably related to one of the acid differentiation phases.

Northern Opachuanau Lake area

In the northern part of the Opachuanau Lake map-sheet (Map 72-2-8) pegmatite derived from the "quartz-eye" granite and quartz monzonite (14) forms dykes up to two feet (60 cm) in width. The pegmatite contains more than 60 per cent microcline-perthite-albite, 20 to 30 per cent quartz (graphically intergrown with potassium feldspar) and 5 to 10 per cent biotite. Aplite dykes of similar composition are much more prevalent than pegmatite in this area.

Swan Bay area

Dykes and sills of pegmatite in this area (Map 71-2-10) vary in width from a few inches to 300 feet (90 metres). Both pink (perthitic) and white (albitic) varieties occur. Pink pegmatite is more abundant, and forms an elliptical body on South Bay. It contains more than 60 per cent perthite, 15 to 30 per cent quartz and up to 15 per cent of either biotite or muscovite. It is clearly related to the Swan Bay quartz monzonite (17b). The white pegmatite is intimately associated with white medium-grained trondjemite, assumed to be a sodic phase of the Swan Bay quartz monzonite (17b). It contains more than 70 per cent albite, up to 15 per cent biotite and rarely more than 15 per cent quartz. Microcline and small garnets are also present locally. The white pegmatite was not seen in contact with the pink perthitic variety, and the age relationship between the two is therefore unknown.

DIABASE (19)

Black to greenish black diabase dykes [less than 1 foot (30 cm) to over 200 feet (60 metres) in width] are the youngest rocks in the map-area. Many of the dykes have sharp contacts with the country rock, and commonly display chilled margins. They are remarkably fresh in appearance and show relatively little alteration of the constituent minerals. The dykes can be subdivided into two distinct varieties, each restricted to a specific area. In the Opachuanau-Issett Lakes area, diabase occurs mainly in the Opachuanau gneisses (10), while in the Pemichigamau Lake area (Map 71-2-6) the dykes occur mostly in the granodiorite complex (15).

Opachuanau — Issett Lakes area

Diabase dykes in this area are rarely wider than 10 feet (3 metres) and they can seldom be traced for more than 100 feet (30 metres). The dykes all have steep to vertical dips but show no common strike direction. The diabase commonly has a well developed ophitic texture, and consists of approximately 25 per cent phenocrysts, and 75 per cent aphanitic groundmass. The phenocrysts are labradorite (16%), augite (5%), hypersthene (1-2%), magnetite and ilmenite (2%) and hornblende (1%). The labradorite (An_{65-70}) forms subhedral to euhedral laths. The augite and hypersthene are mostly subhedral, and many grains are poikilitic and corroded. The hornblende is also subhedral, while magnetite and ilmenite phenocrysts are usually anhedral. The aphanitic groundmass is hypidiomorphic and consists of approximately 35 per cent poikilitic augite (with perhaps 2-3% hypersthene), 25 per cent saussuritized plagioclase, 12 per cent magnetite and ilmenite and 3 per cent hornblende, with accessory sphene.

Pemichigamau Lake (East half) area

In this area, quartz diabase dykes occur *en echelon* (Pearse, 1964) and follow late, vertical joints which strike southeast (120 to 130). The larger dykes are coarse grained (with chilled margins) but smaller dykes and offshoots are aphanitic. Textures are hypidiomorphic granular and the typical composition is labradorite (45%), augite (40%), magnetite (10%), hornblende and tremolite (3%) and biotite (2%), with traces of quartz, orthoclase and epidote. The labradorite (An_{55-62}) is subhedral, well twinned and slightly altered to epidote. Subhedral augite is slightly titaniferous and shows hour-glass structure. It is poikilitic and has secondary hornblende and biotite around its corroded boundaries. Tremolite is interstitial among skeletal magnetite grains, while quartz and orthoclase are interstitial to plagioclase and augite.

STRUCTURAL GEOLOGY

INTRODUCTION

Several factors precluded a complete interpretation of the structure of the Rusty Lake greenstone belt, among them, the lack of good marker horizons, the discontinuity of rock units (especially in the metavolcanic sequences), and poor outcrop in key areas. On a regional scale, however, it is evident that the main part of the belt, north of Karsakuwigamak Lake, consists of a steeply dipping succession of metavolcanic and younger metasedimentary rocks. This sequence is normal and dips north in the central and eastern portions of the map-area, but is overturned and dips south in the western part of the map-area, south of Rusty Lake. Major folds have been defined in parts of the belt where marker horizons are present, and where tops of beds could be determined. Outliers of Upper Wasekwan metasediments (4a, 4c) in the area around Karsakuwigamak Lake are separated from the main part of the sedimentary sequence by the Lower Wasekwan metavolcanic rocks. These metasediments actually dip below the volcanic rocks and therefore must be overturned. This overturning probably resulted from intrusion of the granodiorite batholith (15) which caused rotation of a formerly steeply dipping sequence into parallelism with the shallow northward dipping contact of the batholith.

The lack of exposure in parts of the map-area necessitated the use of aeromagnetic maps and electromagnetic anomaly trends to confirm the presence of folds. Aerial photographs were used in extrapolating faults.

PRIMARY STRUCTURES

1. VOLCANIC ROCKS

Fewer than a dozen occurrences of ellipsoidal lavas were observed in the Wasekwan Group, and top determinations were possible from only about half of them. Almost spherical pillows were observed at two localities just north of "Eske" Lake. These are taken to indicate subaerial extrusion flowing into shallow water, rather than submarine extrusion (Jones, 1969).

Well preserved amygdaloidal and vesicular lavas, common in the western extremity of the metavolcanic belt along the Churchill River, provided data for local top determinations. Tops were also determined from columnar jointing in basalt (2b) found at two localities five miles east of the Rat River, in the northeast corner of the Earp Lake map-sheet (Map 71-2-7).

Flow structures, volcanic breccias, agglomerates, ignimbrites and lahars are discussed in the section dealing with the acid volcanic and pyroclastic rocks (unit 3b, page 10). Both ignimbrites and lahars are indicative of subaerial volcanic activity. A subaerial to shallow water environment is also suggested by the unsorted state of the coarser pyroclastic rocks, and by several occurrences of cross-bedding in the acid to intermediate tuffs. The occurrence of a flow top breccia is mentioned in connection with the rocks of the second basic extrusion (unit 5, page 14).

2. SEDIMENTARY ROCKS

Relict bedding is preserved in metasedimentary rocks of both the Wasekwan and Sickie Groups. In general, however, primary sedimentary structures are too poorly developed or preserved to yield conclusive top determinations.

3. INTRUSIVE ROCKS

Both of the batholithic complexes (14 and 15) are foliated towards their margins, while foliation is generally absent from the central portions of the intrusions. The foliation is parallel to the main contacts, and is assumed to have been formed during intrusion.

Joints are well developed in the two batholiths. Many of the joints belong to regional joint systems, but those that form a concentric pattern, parallel to the peripheries, were most likely formed during the later stages of intrusion and cooling of the magmas (Hills, 1963).

SECONDARY STRUCTURES

1. REGIONAL FOLIATION

A regional east-west foliation has been superimposed on all rocks older than the post-Sickle intrusions, and represents the first identifiable period of deformation in the map-area. It is generally parallel to the primary layering in the metavolcanic and metasedimentary rocks, but locally cuts the layering at a low angle. The origin of the foliation is not known, and no associated folds have so far been identified.

2. FOLDING

Major folds have been recognized in the Rusty Lake and Ruttan Lake areas, but the relationship of the folding from one area to the other is not known.

In the Rusty Lake area (Map 71-2-8), two periods of folding have been recognized. Initially, the regional foliation and the layering were tightly folded about easterly trending axial planes in the vicinity of Rusty Lake. The eastern parts of these folds, which are outlined by the sulphide zones (6), were then distorted by the intrusion of the tonalite batholith (14), such that their axial planes now trend northeast. As noted on page 15, the sulphide zones (6) are not quite parallel to the bedding in the enclosing metasediments, and therefore do not show the true geometry of the folded sedimentary sequence.

The foliation in the Wasekwan metavolcanic rocks (2b) in the area 3 miles (5 km) south of Rusty Lake (Map 71-2-8), generally conforms to the contact of the wedge-shaped protuberance of the granodiorite (15a) batholith. The foliation thus defines a fairly open, steeply plunging fold. The writers believe that the Wasekwan rocks were folded prior to the intrusion of the granodiorite, probably at the same time as the folding around Rusty Lake, and the shape of the granodiorite intrusion was controlled by the pre-existing fold structure.

An anticline-syncline pair, plunging to the east, and with northeasterly trending axial planes, has been delineated in the area east of Ruttan Lake (Map 71-2-6). The elongate body of pink granite and quartz monzonite (15c) occupying the hinge zone of the anticline, appears to have post-dated the folding, since it is generally massive except for a primary foliation at the margins. The eastern end of this intrusive body possesses a planar fabric parallel to that in the adjoining metavolcanic rocks (2b and 3b). This fabric however, is due to numerous parallel inclusions of the metavolcanic rocks which appear to have retained their original orientation.

3. FAULTING

Faults (and minor shear zones) within the map-area tend to occur in three preferred directions: northeast, northwest and east. The majority of the faults trend northeasterly, especially north of Karsakuwigamak Lake, and east of Opachuanau

Lake. Apparent horizontal displacements have occurred on the northwesterly trending faults. Easterly trending faults in the map-area generally show normal dip-slip movement, although a fairly extensive fault in the eastern portion of the map-area (northeastern part of Map 71-2-7), shows an apparent right-lateral horizontal displacement.

METAMORPHISM

Pelitic gneisses of middle to upper amphibolite grade, bound the map-area to the north and south (Hinds, 1972; Schledewitz, 1972; and Elphick, 1972). These paragneisses contain both sillimanite and cordierite, indicating conditions of high temperature and low to moderate pressure (Abukuma-type).

The Opachuanau gneisses and metasedimentary rocks at the northern margin of the map-area, and some of the metasedimentary rocks at the southern extremity of the Rusty Lake greenstone belt, appear to have been metamorphosed to the lower amphibolite facies. Pelitic phases of the Opachuanau gneisses contain andalusite and/or cordierite; diopside occurs in more calcareous zones. Diopside is also present in some of the metasedimentary rocks in the southern portion of the greenstone belt, and garnets were found in appreciable amounts in the meta-argillites.

The metamorphic grade of most of the metavolcanic rocks appears to be variable, but is difficult to define owing to a lack of indicator minerals. The metavolcanics are composed mainly of hornblende and plagioclase, with significant amounts of biotite in the andesites. The hornblende is bluish green to green, highly pleochroic, and rarely zoned or poikiloblastic. The plagioclase is usually andesine (An_{32-36}) but has an extreme range of An_{24} to An_{42} . Armoured relics of labradorite, surrounded by a rim of andesine, were observed in some of the plagioclase phenocrysts in the porphyritic metavolcanic rocks. The plagioclase composition, and the colour of the hornblende, suggests that these are low-temperature amphibolites (Miyashiro, 1968). The presence of accessory actinolite and epidote also suggests that these rocks are of a slightly lower metamorphic grade than the diopside-bearing metasedimentary rocks, and are possibly transitional between the upper greenschist and lower amphibolite facies. Locally, however, in the central portions of the volcanic pile, minor chlorite was found in andesitic rocks containing more than 10 per cent greenish brown biotite. In these cases however, increased amounts of epidote and actinolite, and a slight decrease in the anorthite content of the plagioclase were usually noted, indicating that the rocks in these areas were regionally metamorphosed only to the upper greenschist facies.

ANALYSES AND CLASSIFICATION OF VOLCANIC IGNEOUS ROCKS

INTRODUCTION

At least one sample of each extrusive rock type found in the Rusty Lake greenstone belt has been chemically analyzed (Figure 3 and Table 5). Analyses of two pre-Sickle gabbros and three pre-Sickle diorites have also been included, in order to determine whether or not they differ substantially (in a chemical sense) from what are assumed to be their older extrusive equivalents. Variation diagrams have been constructed using different symbols to distinguish basalt, andesite, dacite, rhyodacite, rhyolite, gabbro and diorite. No distinction has been made on the diagrams, however, between picrite* and basalt, and both have been represented by the same symbol (Table 4). The various types of extrusive and intrusive rocks have been classified (Table 4), according to silica percentage (Goodwin, 1968).

TABLE 4. SILICA CONTENT AND IDENTIFICATION SYMBOLS FOR
LAVAS, GABBRO AND DIORITE.

Rock	%SiO ₂	Symbol	No. of analyses
picrite	<45	●	2
basalt	45-52	●	22
andesite	52-58	○	6
dacite	58-64	■	1
rhyodacite	64-71	▣	2
rhyolite	>71	□	1
gabbro	45-52	▲	2
diorite	52-58	△	3

Variation diagrams (Figures 5 and 6), after Kuno (1968), distinguish three categories of basalt: olivine-alkali basalt, tholeiite, and high-alumina basalt. Olivine-alkali basalts are characterized by magnesia-rich olivine (forsterite) and lime-rich clinopyroxene, with alkali feldspar, zeolite and less commonly, feldspathoid in the groundmass. In the tholeiites, orthopyroxene and pigeonite (both low in lime) take the place of forsterite and free silica is characteristic in the groundmass. High-alumina basalts show mineralogical features of both types. Kuno (1968) defines them as aphyric rocks containing more than 16.5 per cent alumina, and an alkalic content intermediate between tholeiitic and alkali-olivine basalts, for a given silica content.

In the present study, mineralogical criteria have been largely destroyed by recrystallization. Many of the volcanic rocks of the Rusty Lake greenstone belt contain minute amounts of both quartz and alkali feldspar in the groundmass, but the possibility exists that this is of secondary origin. Therefore, the distinction among the three categories of basaltic rocks is based almost exclusively on the variation diagrams and the chemical analyses.

* See footnote page 8.

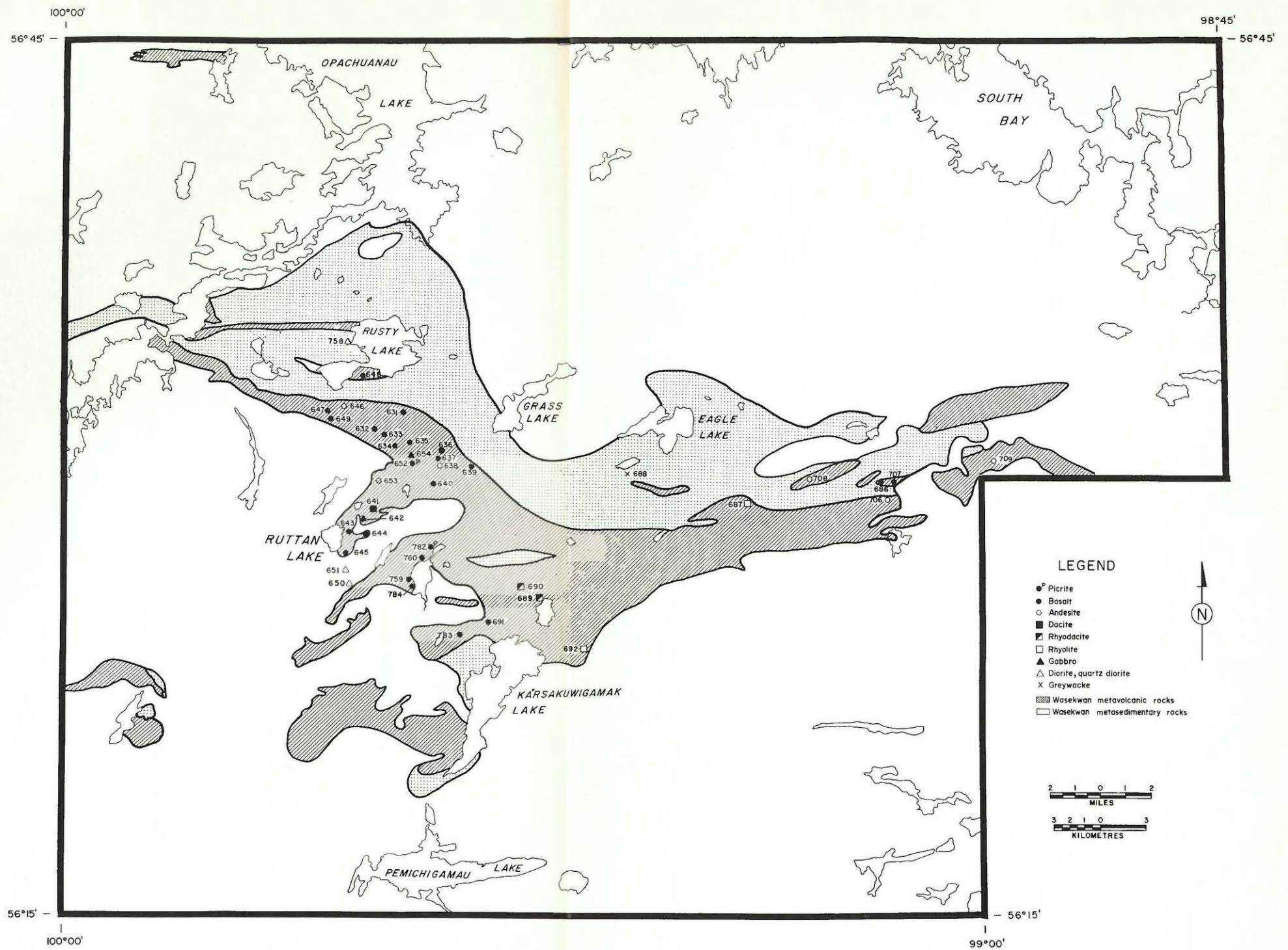


Figure 3: Location of chemically analyzed samples.

CHEMICAL ANALYSES

Chemical analyses (Table 5) reveal that the metavolcanic rocks of the Rusty Lake greenstone belt show six distinctive chemical characteristics: (i) a high but extremely variable Al_2O_3 content; (ii) a low TiO_2 content; (iii) high $\text{FeO}:\text{Fe}_2\text{O}_3$ ratios; (iv) a high CaO and correspondingly low MgO content; (v) low alkali content (particularly K_2O); and (vi) a high volatile content ($\text{CO}_2 + \text{H}_2\text{O}$).

The alumina content ranges from less than 12 per cent to more than 20 per cent; but most of the basalts and both the "picrites" contain at least 16.5 per cent Al_2O_3 , placing them well within the high-alumina category*.

The low TiO_2 content (generally less than 1 per cent) is characteristic of basic extrusive rocks in the Canadian Shield (Goodwin, 1968). High $\text{FeO}:\text{Fe}_2\text{O}_3$ ratios (usually 3:1 to greater than 5:1) are common in other Precambrian basalts (Goodwin, 1968), as well as in Tertiary volcanic suites (Kuno, 1960), and are not diagnostic of either tholeiites or alkali-olivine basalts.

The relatively high CaO and correspondingly low MgO content is not a common feature of either Precambrian or recent basalts. Metamorphism to the lower amphibolite facies, as proposed for these rocks, should cause removal of lime in preference to magnesia from mafic rocks, especially in the presence of volatiles (Vogt, 1927). An alternative suggestion is that the original composition was lime-rich, although this would imply that lime-rich clinopyroxene was the most common mafic mineral (i.e. an alkali-olivine association). The variation diagrams on the other hand, suggest that orthopyroxene and pigeonite were predominant (i.e. a tholeiitic association).

The low alkali content, particularly the low K_2O , is characteristic of tholeiitic magma, and is so pronounced that many of the basalts appear as tholeiites on the variation diagrams (Figures 5 and 6), notwithstanding the high alumina values. This leads to the conclusion that these rocks are transitional between the tholeiitic and high alumina categories, which seems compatible with statements of Wilson (1965) and Goodwin (1968) that volcanic suites of the Superior Province generally tend to be low in alkalis, and that alkali-olivine basalts are rare.

A high volatile ($\text{H}_2\text{O} + \text{CO}_2$) content, as in the basalts of the Rusty Lake greenstone belt, is common in other Precambrian metavolcanics according to Goodwin (1968). The CO_2 content may be original, since survival of lime in large quantities seems incompatible with late hydrothermal fluids rich in CO_2 . The H_2O has permitted formation of minerals such as hornblende and biotite, and may be either primary or secondary in origin.

C.I.P.W. NORMS

C.I.P.W. norms (Table 5) were calculated for all of the chemically analyzed samples. All contain at least trace amounts of orthoclase†. Quartz is present in all the acid and intermediate extrusive rocks (and also in the diorites) but is present in only about one-fifth of the more basic samples. Olivine is absent from the quartz-bearing samples, which instead contain increased amounts of orthopyroxene (enstatite and ferrosilite), and lesser amounts of clinopyroxene (diopside and hedenbergite). About one-quarter of the basic rocks were found to contain nepheline, with a corresponding absence of orthopyroxene and quartz. Such samples contain greatly increased amounts of clinopyroxene and olivine (especially forsterite).

*The apparent scarcity of high-alumina basalts in the Precambrian Shield is partly due to the scant attention that has been paid to alumina content; most studies have differentiated only between tholeiites and alkali-olivine basalts.

†All minerals mentioned in this section of the report are normative.

It is concluded that the basic extrusive rocks of the Rusty Lake greenstone belt display normative mineralogical characteristics of both tholeiitic and alkali-olivine basalts, and thus form an intermediate group which corresponds closely to Kuno's (1960) high-alumina basalts. The acid and intermediate extrusive rocks, however, tend to be more tholeiitic than the basic rocks. They all contain quartz and orthopyroxene but no olivine or nepheline; and with the exception of the diorites, only small amounts of clinopyroxene with respect to orthopyroxene.

TABLE 5. CHEMICAL ANALYSES AND C.I.P.W. NORMS, RUSTY LAKE GREENSTONE BELT.

Sample No. Lab. No. Rock Type	23-1039-2 R-631 Basalt	23-1023-2 R-632 Basalt	23-1029-1 R-633 Basalt	23-1031-1 R-634 Basalt	23-59-1 R-635 Basalt
SiO ₂	50.00	46.65	47.25	47.25	47.95
Al ₂ O ₃	16.20	17.70	19.90	20.00	16.70
TiO ₂	1.36	0.46	0.65	0.61	0.72
Fe ₂ O ₃	2.27	2.53	1.74	2.71	1.97
FeO	7.80	8.34	9.03	7.90	9.19
MnO	0.17	0.23	0.20	0.19	0.21
MgO	5.12	6.95	4.45	4.50	8.45
CaO	10.00	11.40	12.20	13.15	9.90
Na ₂ O	4.13	2.53	1.78	1.66	1.94
K ₂ O	0.99	1.24	0.93	0.50	0.58
P ₂ O ₅	0.62	0.08	0.09	0.26	0.19
H ₂ O	1.47	1.91	1.79	1.42	1.98
CO ₂	0.28	0.07	0.12	0.13	0.11
Total	100.40	100.10	100.15	100.30	99.90
C.I.P.W. NORMS					
Quartz	—	—	—	.11	—
Orthoclase	5.99	7.46	5.60	2.99	3.51
Albite	27.12	15.86	15.33	14.22	16.78
Anorthite	27.88	33.92	44.35	46.23	35.94
Nepheline	—	3.23	—	—	—
Diopside	8.97	11.52	6.52	7.89	6.65
Ferrosilite	7.10	—	5.80	7.97	8.56
Enstatite	8.61	—	4.45	7.69	12.46
Hedenbergite	6.45	7.48	7.40	7.13	3.98
Forsterite	.20	8.62	2.67	—	4.18
Fayalite	.19	7.08	3.83	—	3.17
Magnetite	3.37	3.74	2.57	3.98	2.92
Ilmenite	2.65	.89	1.26	1.17	1.40
Corundum	—	—	—	—	—
Apatite	1.47	.19	.21	.61	.45
Total	100.00	99.99	99.99	99.99	100.00

TABLE 5 (Continued)

Sample No. Lab. No. Rock Type	23-273-1 R-636 Basalt	23-291-1 R-637 Basalt	23-290-1 R-638 Andesite	23-262-1 R-639 Basalt	23-66-2 R-640 Basalt
SiO ₂	51.65	46.60	53.35	48.00	45.60
Al ₂ O ₃	16.40	11.90	16.95	14.90	12.85
TiO ₂	0.75	0.70	0.76	0.72	0.60
Fe ₂ O ₃	2.38	3.49	2.66	4.25	1.73
FeO	7.29	7.35	8.82	6.84	9.15
MnO	0.19	0.21	0.21	0.20	0.22
MgO	5.45	11.35	3.65	8.00	12.15
CaO	9.60	12.65	8.55	12.00	12.00
Na ₂ O	3.37	2.14	3.06	2.46	1.67
K ₂ O	1.31	0.52	0.55	0.68	0.67
P ₂ O ₅	0.23	0.34	0.15	0.23	0.38
H ₂ O	1.54	2.02	1.35	1.81	2.51
CO ₂	0.29	0.95	0.22	0.18	0.49
Total	100.45	100.22	100.28	100.25	100.00

C.I.P.W. NORMS

Quartz	—	—	6.48	—	—
Orthoclase	7.86	3.16	3.30	4.10	4.09
Albite	28.91	17.60	26.23	21.18	13.78
Anorthite	26.11	21.93	31.30	28.09	26.37
Nepheline	—	.55	—	—	.42
Diopside	10.11	24.80	3.96	18.33	18.40
Ferrosilite	4.71	—	10.65	1.57	—
Enstatite	6.07	—	7.37	3.80	—
Hedenbergite	6.84	7.54	4.99	6.60	7.84
Forsterite	2.11	12.31	—	5.58	15.88
Fayalite	1.81	4.73	—	2.54	8.55
Magnetite	3.50	5.20	3.91	6.27	2.59
Ilmenite	1.44	1.37	1.46	1.40	1.18
Corundum	—	—	—	—	—
Apatite	.54	.81	.35	.54	.91
Total	100.01	100.00	100.00	100.00	100.01

TABLE 5 (Continued)

Sample No. Lab. No. Rock Type	23-236-1 R-641 Dacite	23-1166-1 R-642 Gabbro	23-1232-1 R-643 Basalt	23-248-1 R-644 Basalt	23-1179-1 R-645 Basalt
SiO ₂	58.65	44.90	51.00	46.60	51.35
Al ₂ O ₃	16.70	13.90	19.10	15.55	14.70
TiO ₂	0.75	0.73	0.66	1.45	1.81
Fe ₂ O ₃	1.70	3.43	3.26	3.27	3.65
FeO	7.21	7.49	7.14	9.49	8.26
MnO	0.15	0.21	0.21	0.26	0.27
MgO	2.82	11.30	3.12	7.15	4.80
CaO	6.27	11.70	9.35	11.95	8.50
Na ₂ O	2.40	1.90	3.42	1.98	2.87
K ₂ O	1.80	0.83	1.07	0.25	1.51
P ₂ O ₅	0.11	0.10	0.25	0.37	0.63
H ₂ O	1.26	2.60	1.33	1.81	1.84
CO ₂	0.21	0.76	0.18	0.25	0.26
Total	100.05	99.85	100.10	100.40	100.45

C.I.P.W. NORMS

Quartz	15.94	—	1.03	—	4.25
Orthoclase	10.80	5.09	6.42	1.50	9.08
Albite	20.60	13.14	29.35	17.04	24.69
Anorthite	29.91	27.93	34.09	33.37	23.15
Nepheline	—	1.91	—	—	—
Diopside	.33	19.29	4.51	12.31	7.49
Ferrosilite	10.80	—	7.24	6.19	7.02
Enstatite	6.97	—	5.79	8.60	8.68
Hedenbergite	.45	6.40	4.92	7.72	5.28
Forsterite	—	14.17	—	2.67	—
Fayalite	—	5.61	—	2.12	—
Magnetite	2.50	5.15	4.80	4.82	5.38
Ilmenite	1.45	1.44	1.27	2.80	3.50
Corundum	—	—	—	—	—
Apatite	.26	.24	.59	.87	1.49
Total	100.01	100.37	100.01	100.01	100.01

TABLE 5 (Continued)

Sample No. Lab. No. Rock Type	23-1068-1 R-646 Andesite	23-1084-1 R-647 Basalt	23-122-1 R-648 Basalt	23-1086-1 R-649 Basalt	23-79-1 R-650 Diorite
SiO ₂	54.70	46.60	48.30	47.65	54.80
Al ₂ O ₃	15.80	14.30	13.45	19.20	17.70
TiO ₂	0.53	0.62	2.47	0.54	0.62
Fe ₂ O ₃	2.73	3.64	1.34	1.73	2.31
FeO	5.87	7.91	11.66	8.63	5.26
MnO	0.19	0.21	0.27	0.21	0.16
MgO	4.80	7.00	7.10	5.20	4.70
CaO	8.45	14.80	10.45	12.50	8.80
Na ₂ O	2.64	1.53	2.99	1.70	3.45
K ₂ O	1.21	0.95	0.11	0.47	0.45
P ₂ O ₅	0.19	0.24	0.25	0.72	0.14
H ₂ O	1.26	1.66	1.55	1.26	1.28
CO ₂	0.16	0.15	0.49	0.09	0.20
Total	99.50	99.60	100.45	99.90	99.90

C.I.P.W. NORMS

Quartz	9.42	—	—	.13	6.89
Orthoclase	7.37	5.77	.66	2.82	2.71
Albite	23.00	8.50	25.71	14.59	29.67
Anorthite	28.51	30.12	23.33	44.01	32.00
Nepheline	—	2.60	—	—	—
Diopside	6.90	18.17	12.54	6.05	6.11
Ferrosilite	6.10	—	4.94	11.11	5.44
Enstatite	9.11	—	5.22	10.33	9.06
Hedenbergite	4.03	18.09	10.34	5.67	3.20
Forsterite	—	6.63	4.86	—	—
Fayalite	—	8.35	5.07	—	—
Magnetite	4.08	—	1.98	2.55	3.40
Ilmenite	1.04	1.21	4.77	1.04	1.20
Corundum	—	—	—	—	—
Apatite	.45	.57	.59	1.70	.33
Total	100.01	100.01	100.01	100.00	100.01

TABLE 5 (Continued)

Sample No.	23-1219-1	23-57-1	23-226-1	23-58-1	28-0-142-1
Lab. No.	R-651	R-652	R-653	R-654	R-686
Rock Type	Diorite	Picrite	Andesite	Gabbro	Basalt
SiO ₂	52.30	44.45	55.65	46.55	49.10
Al ₂ O ₃	18.35	17.70	12.00	19.55	16.60
TiO ₂	1.09	0.82	1.26	0.62	1.00
Fe ₂ O ₃	4.75	4.08	2.88	2.05	2.83
FeO	5.44	7.35	7.55	8.77	9.21
MnO	0.15	0.22	0.20	0.21	0.21
MgO	3.30	4.95	3.70	6.20	6.90
CaO	8.00	15.15	11.25	12.30	9.85
Na ₂ O	3.95	1.60	2.70	1.80	1.95
K ₂ O	0.84	0.60	0.17	0.30	0.13
P ₂ O ₅	0.42	0.15	0.14	0.08	0.14
H ₂ O	1.17	1.69	1.24	1.43	1.72
CO ₂	0.18	1.04	1.65	0.19	0.46
Total	99.95	99.80	100.40	100.05	100.15

C.I.P.W. NORMS

Quartz	4.76	—	13.46	—	2.81
Orthoclase	5.04	3.66	1.03	1.80	.79
Albite	33.90	11.22	23.43	15.47	16.85
Anorthite	30.29	40.53	20.64	45.09	36.93
Nepheline	—	1.48	—	—	—
Diopside	3.93	17.83	15.36	7.59	5.90
Ferrosilite	3.60	—	2.47	5.02	11.48
Enstatite	6.51	—	2.33	5.63	14.81
Hedenbergite	1.90	11.58	14.21	5.91	3.98
Forsterite	—	3.11	—	4.58	—
Fayalite	—	2.55	—	4.51	—
Magnetite	6.99	6.09	4.28	3.02	4.19
Ilmenite	2.10	1.60	2.45	1.12	1.94
Corundum	—	—	—	—	—
Apatite	.99	.36	.33	.19	.33
Total	100.01	100.01	99.99	99.93	100.01

TABLE 5 (Continued)

Sample No.	28-0-276-1	28-0-300-1	28-0-1192-1	28-0-1269-1	28-0-144-1
Lab. No.	R-689	R-690	R-691	R-692	R-706
Rock Type	Rhyodacite	Rhyodacite	Basalt	Rhyolite	Andesite
SiO ₂	70.10	64.75	48.75	72.20	53.75
Al ₂ O ₃	14.20	17.40	16.95	13.90	15.75
TiO ₂	0.36	0.65	0.54	0.19	0.86
Fe ₂ O ₃	2.06	3.62	1.27	1.66	1.41
FeO	3.26	2.56	7.97	2.66	8.97
MnO	0.07	0.11	0.21	0.12	0.22
MgO	0.80	0.90	4.90	0.75	5.75
CaO	1.10	1.75	14.80	1.60	6.50
Na ₂ O	3.65	4.75	1.85	3.45	4.55
K ₂ O	2.70	1.45	0.45	1.95	0.11
P ₂ O ₅	0.02	0.27	0.18	0.01	0.27
H ₂ O	0.96	0.70	0.86	0.99	1.13
CO ₂	0.55	0.95	0.76	0.41	0.46
Total	99.85	99.85	99.50	99.90	99.75

C.I.P.W. NORMS

Quartz	33.86	27.35	—	39.18	.41
Orthoclase	16.24	8.73	2.72	11.71	.66
Albite	31.41	40.92	15.99	29.64	39.23
Anorthite	5.42	7.04	37.41	7.99	22.65
Nepheline	—	—	—	—	—
Diopside	—	—	15.60	—	3.72
Ferrosilite	3.89	.86	4.59	3.48	12.85
Enstatite	2.03	2.28	4.28	1.90	12.87
Hedenbergite	—	—	14.59	—	3.24
Forsterite	—	—	.67	—	—
Fayalite	—	—	.79	—	—
Magnetite	3.04	5.34	1.88	2.44	2.08
Ilmenite	.70	1.26	1.05	.37	1.66
Corundum	3.38	5.58	—	3.28	—
Apatite	.05	.64	.43	.02	.64
Total	100.02	100.00	100.00	100.00	100.01

TABLE 5 (Continued)

Sample No.	28-0-158-1	28-0-229-1	28-0-1247-1	23-116-1	23-768-1
Lab. No.	R-707	R-708	R-709	R-758	R-759
Rock Type	Basalt	Andesite	Andesite	Quartz Diorite	Basalt
SiO ₂	49.50	55.00	56.00	60.40	47.60
Al ₂ O ₃	17.30	15.40	17.85	19.05	16.10
TiO ₂	0.67	1.71	0.72	0.28	0.64
Fe ₂ O ₃	2.19	1.85	1.88	1.20	3.88
FeO	8.45	9.49	6.51	2.31	7.25
MnO	0.21	0.22	0.17	0.05	0.20
MgO	6.37	2.88	3.47	1.45	7.86
CaO	10.40	6.45	6.75	3.36	11.12
Na ₂ O	2.60	4.75	3.15	2.62	2.40
K ₂ O	0.22	0.30	1.35	3.17	0.66
P ₂ O ₅	0.20	0.35	0.24	0.08	0.18
H ₂ O	1.59	1.05	1.37	0.82	1.63
CO ₂	0.19	0.05	0.41	0.57	0.08
Total	99.95	99.50	99.85	100.40	99.60

C.I.P.W. NORMS

Quartz	—	5.18	9.68	24.02	—
Orthoclase	1.33	1.80	8.14	19.95	3.99
Albite	22.42	40.84	27.17	23.59	20.74
Anorthite	35.56	20.14	31.17	17.18	31.88
Nepheline	—	—	—	—	—
Diopside	7.37	3.22	.58	—	13.26
Ferrosilite	9.92	10.90	9.42	3.07	2.71
Enstatite	12.11	5.80	8.54	3.84	5.62
Hedenbergite	5.38	5.28	.56	—	5.57
Forsterite	.40	—	—	—	5.77
Fayalite	.36	—	—	—	3.06
Magnetite	3.24	2.73	2.80	1.85	5.75
Ilmenite	1.30	3.30	1.40	.57	1.24
Corundum	—	—	—	5.74	—
Apatite	.47	.83	.57	.20	.43
Total	99.86	100.02	100.03	100.01	100.02

TABLE 5 (Continued)

Sample No.	23-773-1	23-2317-1	23-2407-1	23-767-1
Lab. No.	R-760	R-782	R-783	R-784
Rock Type	Basalt	Picrite	Basalt	Basalt
SiO ₂	49.85	44.45	49.85	48.65
Al ₂ O ₃	17.45	17.20	20.40	16.45
TiO ₂	0.69	0.64	0.48	0.65
Fe ₂ O ₃	5.28	5.07	1.41	2.94
FeO	5.18	6.27	5.67	8.59
MnO	0.19	0.19	0.13	0.21
MgO	5.97	8.23	4.76	7.05
CaO	8.00	12.10	11.90	10.60
Na ₂ O	2.61	1.83	2.34	2.82
K ₂ O	2.34	1.57	0.87	0.96
P ₂ O ₅	0.36	0.24	0.10	0.19
H ₂ O	1.75	2.16	1.35	1.62
CO ₂	0.13	0.24	0.47	0.19
Total	99.80	100.20	99.75	100.90

C.I.P.W. NORMS

Quartz	.51	—	.05	—
Orthoclase	14.14	9.51	5.26	5.73
Albite	22.56	3.96	20.22	24.07
Anorthite	29.60	35.05	43.50	29.66
Nepheline	—	6.48	—	—
Diopside	5.43	11.39	8.06	11.13
Ferrosilite	3.72	—	6.14	.98
Enstatite	12.67	—	8.37	1.36
Hendenbergite	1.39	9.30	5.15	7.00
Forsterite	—	11.06	—	7.84
Fayalite	—	11.41	—	6.23
Magnetite	7.82	—	2.09	4.30
Ilmenite	1.34	1.25	.93	1.25
Corundum	—	—	—	—
Apatite	.85	.57	.24	.45
Total	100.03	99.98	100.01	100.00

VARIATION DIAGRAMS

TERNARY OXIDE DIAGRAMS

Variations in magnesia/iron*/alkali ratios for volcanic and intrusive rocks in the Rusty Lake greenstone belt have been plotted on an MFA ternary oxide diagram (Figure 4). The fractionation trend almost parallels the MgO-FeO edge of the triangle for the early and intermediate stages, but breaks sharply towards the alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) corner in the later stages. Kuno (1968) states that this trend is characteristic of a high-iron type of fractionation. The pigeonitic, hypersthentic and alkali-olivine fields have also been shown in Figure 4, illustrating that the general trend of the rocks studied, embraces parts of both the pigeonitic and hypersthentic fields. The three acid volcanic samples are the most strongly pigeonitic. In general, the extrusive rocks studied show the high-iron type of fractionation characteristic of tholeiites, but not so strongly as the Skaergaard intrusive rocks (Figure 4).

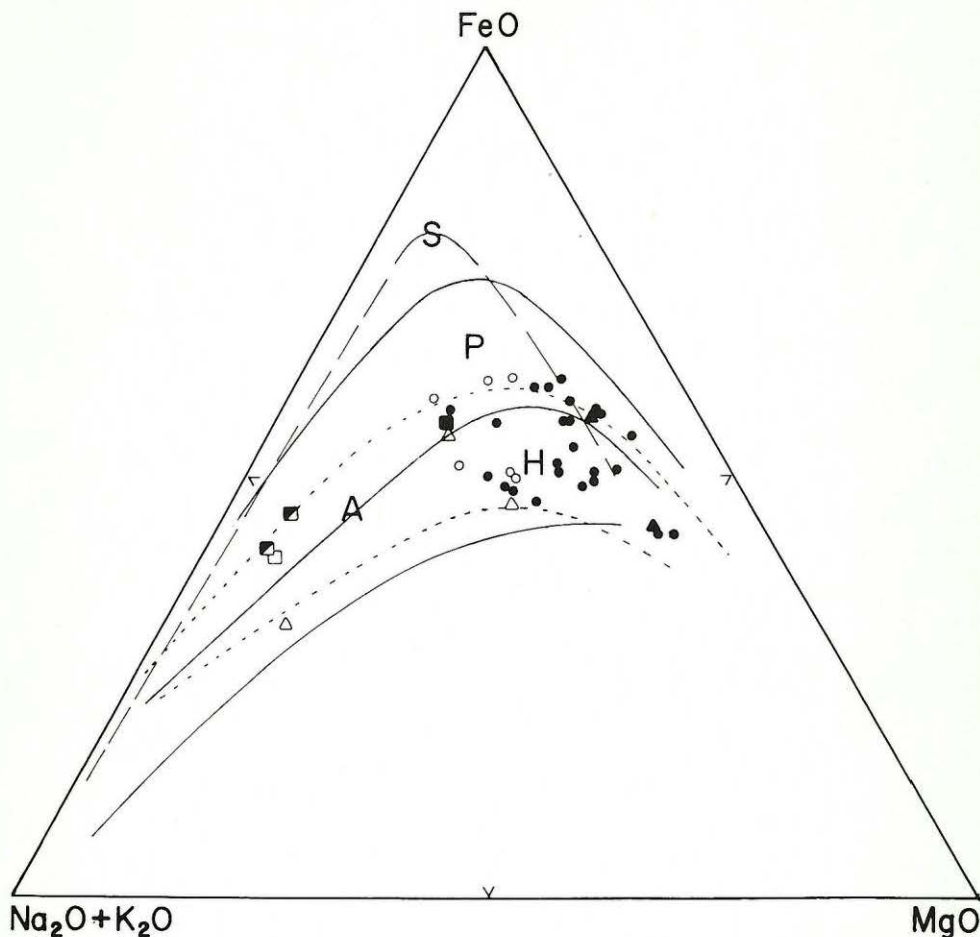


Figure 4: MFA ternary oxide diagram showing alkalic (A) (dashed line), hypersthentic (H), and pigeonitic (P) (solid lines) fields, and the variation trend line of the Skaergaard (S) intrusion (after Kuno, 1968). Symbols as shown in Table 4.

* $\text{FeO} + 0.8998 \text{ Fe}_2\text{O}_3$

ALUMINA-ALKALI DIAGRAMS

Alumina-alkali variation diagrams [Figure 5(a)-(d)] have been plotted for four silica percentage ranges. The tholeiitic, high-alumina and alkali-olivine fields have been delineated in each diagram.

Within the silica percentage range 45–50 [Figures 5(a) and (b)] the samples plot mainly as tholeiitic basalts, but close to the high-alumina field. Some of the samples containing at least 16.5 per cent alumina, plot as tholeiites rather than high-alumina basalts because of their low alkali content. Four basalt samples fall in the alkali-olivine field but only one is far removed from the high-alumina line. This sample is abnormally high in Na_2O , probably as a result of metasomatism.

Within the silica percentage range 50–55 [Figures 5(c) and (d)] there is a strong shift towards the high-alumina and alkali-olivine fields. In Figure 4(c), the samples plot on or near the division between the high-alumina and alkali-olivine fields. In the highest silica range (Figure 5d), five of the seven samples (four andesites and one diorite) fall in the high alumina field. One of the andesites plots in the alkali-olivine field, while the other appears as one of the most strongly tholeiitic rocks of the entire volcanic suite.

In summary, the alumina-alkali diagrams [Figures 5 (a)–(d)] indicate that most of the extrusive rocks of the Rusty Lake greenstone belt fall within the tholeiitic and high-alumina categories. Those rocks containing 45 to 50 per cent silica, tend to be tholeiitic, while those with silica contents between 50 and 55 per cent fall mainly in the high-alumina field.

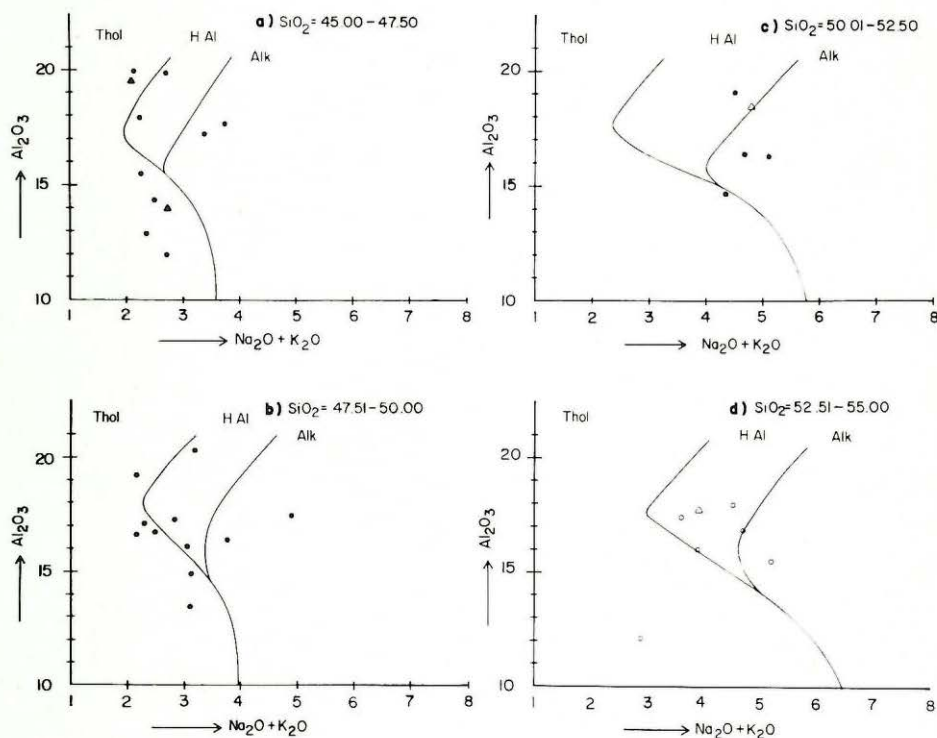


Figure 5: Alumina-alkali diagrams showing tholeiitic (Thol.) high-alumina (H. Al.) and alkali-olivine (Alk.) fields (after Kuno, 1968). Symbols as shown in Table 4.

ALKALI-SILICA DIAGRAM

The alkali-silica variation diagram used in this study (Figure 6) is a combination of two such diagrams taken from Kuno (1968) and MacDonald and Katsura (1964) respectively. Kuno's diagram depicts the alkali-olivine, high-alumina and tholeiitic fields while that of MacDonald and Katsura differentiates only between tholeiitic and alkali-olivine types.

Almost three-quarters of the samples plotted in Figure 6 fall in the high-alumina field, with the rest more or less equally divided between the tholeiitic and the alkali-olivine fields. Those samples in the alkali-olivine field are basaltic, while those in the tholeiitic field include some of the more acidic volcanic rocks. The alkali-silica variation diagram thus illustrates the high-alumina nature of these rocks more effectively than the alumina-alkali diagrams (Figure 5).

The dashed line on Figure 6 represents the division between tholeiitic and alkali-olivine magma types proposed by MacDonald and Katsura (1964) in their study of Hawaiian basalts. Using this classification, only 5 basalts and 1 gabbro plot in the alkali-olivine field, while the acid volcanic rocks again plot as the most strongly tholeiitic. Many of the samples plot close to the tholeiitic/alkali-olivine boundary, which further indicates the transitional nature of the volcanic and intrusive rocks in the Rusty Lake greenstone belt.

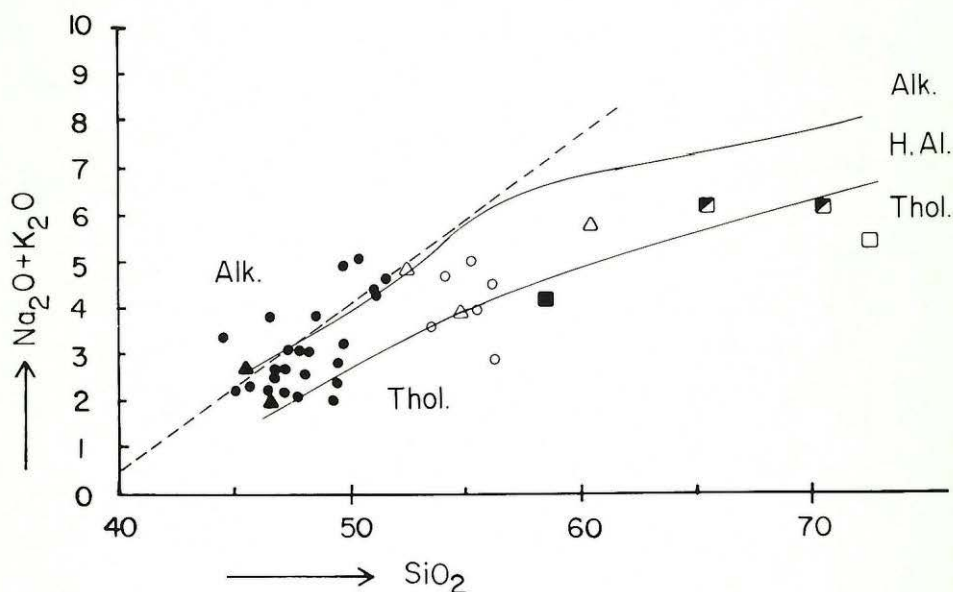


Figure 6: Alkali-silica diagram showing alkali-olivine (Alk.), high-alumina (H. Al.), and tholeiitic (Thol.) fields (after Kuno, 1968). Dashed line shows alkali-olivine/tholeiitic boundary of MacDonald and Katsura (1964). Symbols as shown in Table 4.

SILICA-SI* DIAGRAM

Figure 7 is a plot of SiO_2 against the solidification index (SI), with the hypersthenic and pigeonitic fields also delineated (after Kuno, 1968). Silica values in the rocks from the Rusty Lake greenstone belt rise very gradually up to a solidification index of approximately 20, indicating very little silica differentiation with respect to the solidification index. Below a solidification index of 20, however, (roughly corresponding to rocks that contain at least 50 per cent SiO_2) the silica values rise sharply. Kuno (1968) states that a trend of this type is characteristic of a pigeonitic rock series, whereas SiO_2 values of other rock series, when plotted against SI rise steadily throughout.

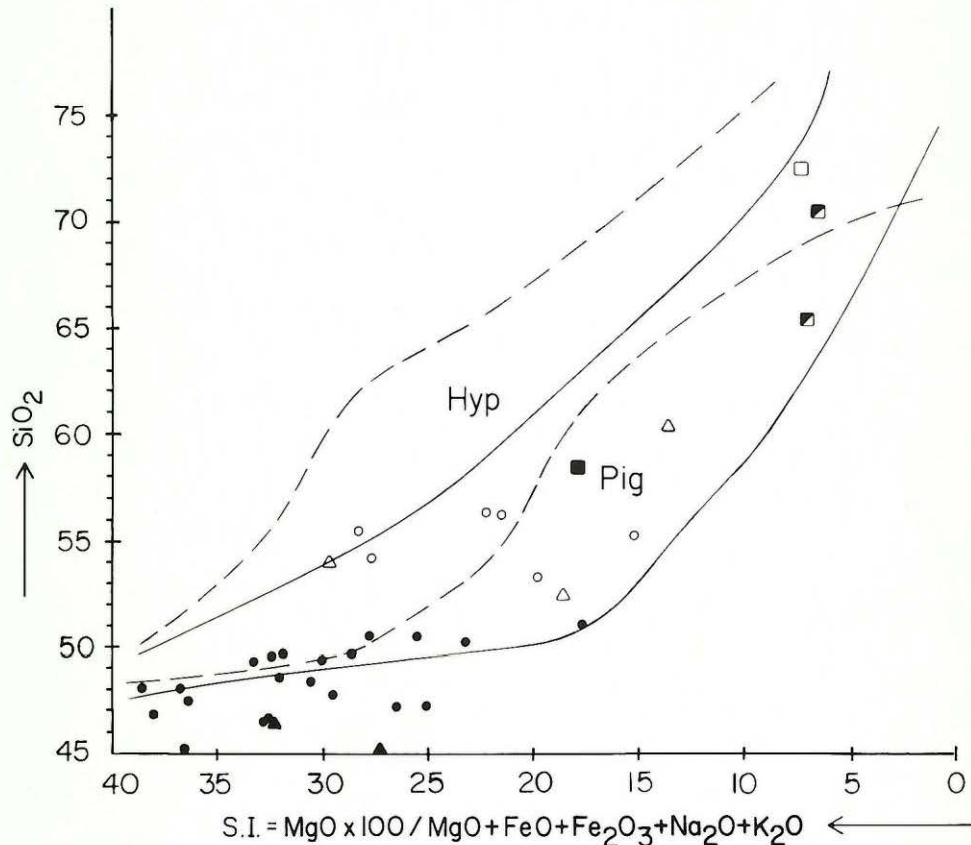


Figure 7: Silica vs. S.I. diagram showing pigeonitic (solid lines) and hypersthenic fields (dashed lines), (after Kuno, 1968). Symbols as shown in Table 4.

* Solidification Index, SI =
$$\frac{\text{MgO} \times 100}{\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3 + \text{Na}_2\text{O} + \text{K}_2\text{O}}$$

IRON OXIDE-SI DIAGRAM

The iron oxide* -SI variation diagram (Figure 8) displays a large pigeonitic and a narrow hypersthenic field. Despite the wide scatter of points between SI values of 30 to 35, the iron oxide variation trend approaches a maximum at an SI value of about 20. Kuno (1968) states that this type of trend is also characteristic of a pigeonitic rock series. The trend in other rock series lies below the pigeonitic field, and while nearly constant in the early stage, decreases in the middle to late stages.

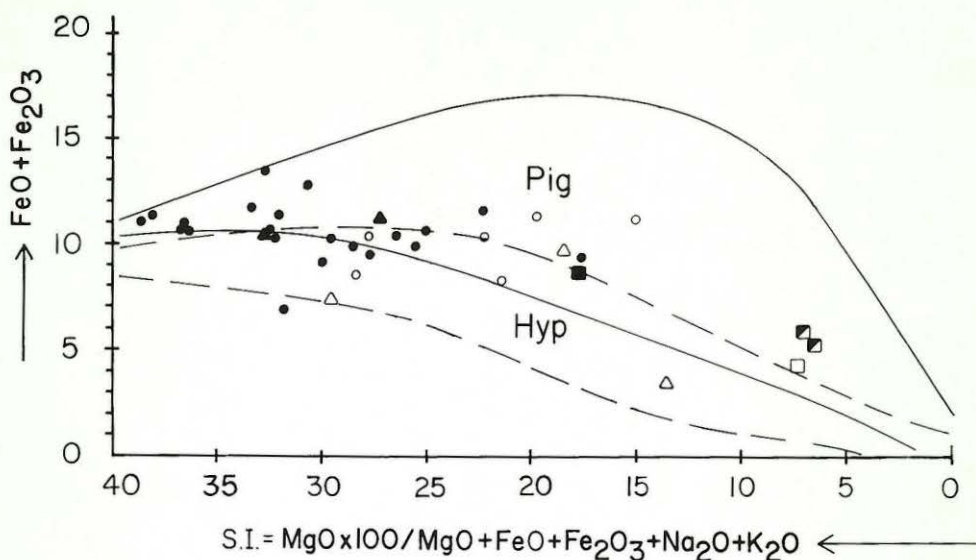


Figure 8: Iron oxide vs. S.I. diagram showing pigeonitic field (solid lines) and hypersthenic field (dashed lines) (after Kuno, 1968). Symbols as shown in Table 4.

SINGLE OXIDE-SI DIAGRAMS

All of the major oxides, with the possible exception of Al_2O_3 , appear to show at least a rudimentary variation trend when plotted against the solidification index (Figure 9). The silica-SI and iron oxide-SI diagrams are repeated in Figure 9 to facilitate comparison. The MgO versus SI plot shows the most profound variation trend but this is not indicative of any particular magma type. As with the SI versus iron oxide and silica trends, the TiO_2 -SI trend is fairly typical of a pigeonitic rock series. It reaches a maximum at an SI value of about 23 and shows no steady decrease thereafter as is the case in other rock series. The trend lines of CaO , Na_2O and K_2O are also compatible with a pigeonitic rock series. The Al_2O_3 variation trend is typical of neither a pigeonitic nor an alkali rock series. Classically, the Al_2O_3 trend line decreases steadily in a pigeonitic series, and remains constant in an alkalic series. In this case, however, the Al_2O_3 variation trend rises sharply to reach a maximum at an SI value of about 30, then very gradually decreases.

* $FeO + 0.8998 Fe_2O_3$

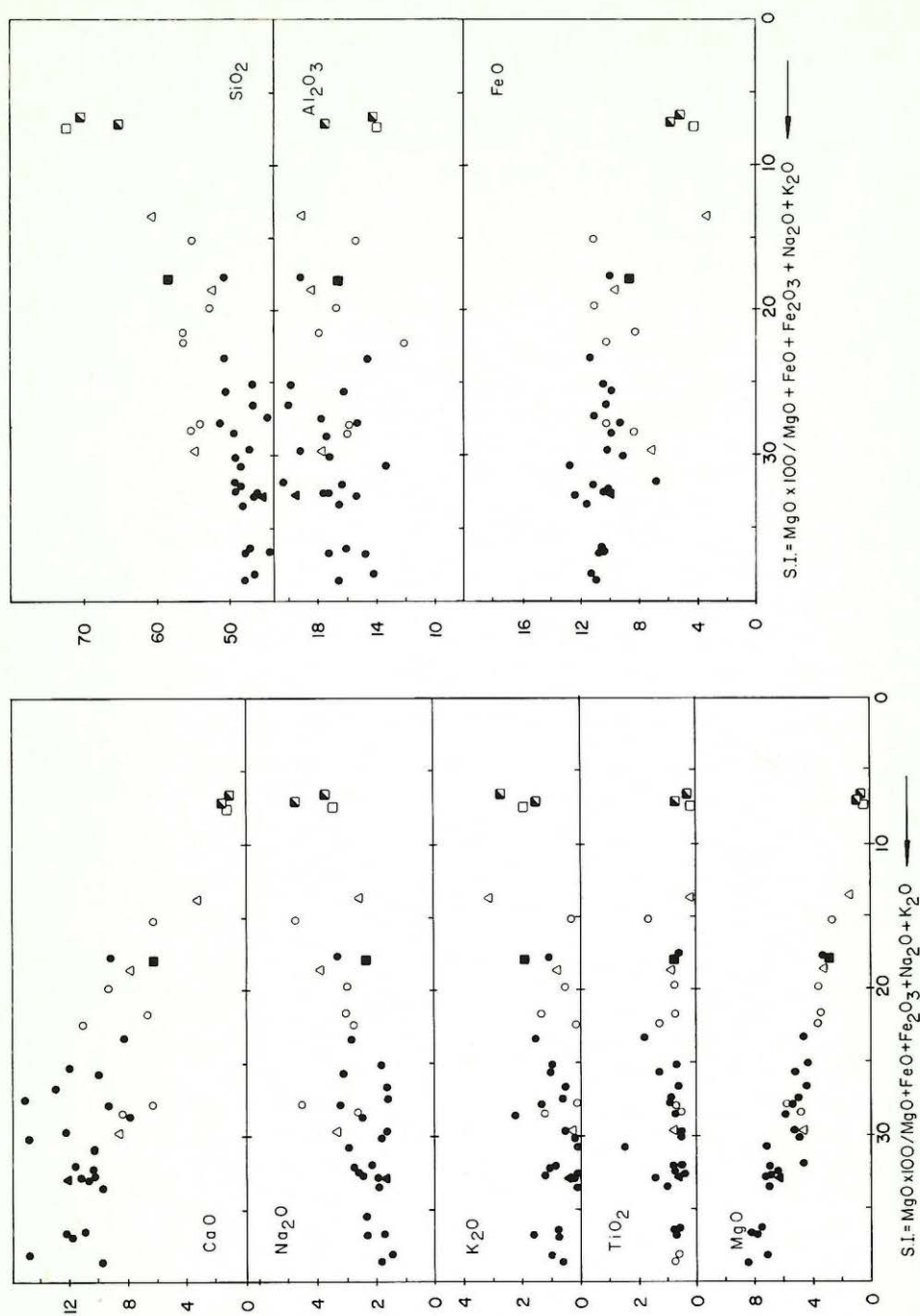


Figure 9: Single oxide vs. S.I. diagrams (after Kuno, 1968). Symbols as shown in Table 4.

SUMMARY

The main characteristics of the metavolcanic rocks in the Rusty Lake greenstone belt, are summarized below. The conclusions are based on field observations and a study of the chemical composition and normative mineralogy of the metavolcanic rocks and the pre-Sickle intrusive rocks.

- (1) Rock types present in the volcanic pile, in order of decreasing abundance, are: basalt, andesite, dacite, rhyodacite and rhyolite. This order however, by no means reflects the volcanic stratigraphy, which comprises an intimately interlayered sequence of basalt and andesite, followed by acid volcanic rocks. The latter range in composition from rhyolite to dacite, and were produced from a number of localized centres. A second extrusion of basic volcanic rocks followed, with basalt the main product.
- (2) Preserved primary structures suggest that the major part of the volcanic pile was extruded in a subaerial or shallow marine environment.
- (3) There is essentially no chemical difference between the two separate sequences of basic extrusive rocks. However, no acid volcanic rocks appear to have been produced during the second extrusive cycle. The second group of basic extrusive rocks are much fresher in appearance, having undergone less recrystallization, and primary structures are commonly preserved in them.
- (4) The pre-Sickle intrusive rocks show only minor differences in chemical and normative mineralogical composition from their respective extrusive equivalents.
- (5) The metavolcanic rocks in the Rusty Lake greenstone belt show six distinctive chemical characteristics: (a) a high and extremely variable Al_2O_3 content; (b) a low TiO_2 content; (c) high $\text{FeO}:\text{Fe}_2\text{O}_3$ ratios; (d) a high CaO content; (3) a low content of alkalis, especially K_2O ; and (f) a high volatile (CO_2 and H_2O) content.
- (6) The metavolcanic rocks generally show a consistent high-alumina to tholeiitic character. The andesites (and basalts with silica values between 50 and 52 per cent) display a marked high-alumina trend, while most of the basalts fall across the boundary between the tholeiitic and high-alumina fields. The acid volcanic rocks (dacites, rhyodacites and rhyolites) tend to be the most strongly tholeiitic.

Tholeiites are characteristic of continental orogenic regions, including island arc systems (Wilson *et al.*, 1965). Kuno (1960) states that volcanic rocks of a high-alumina character are found in the medial portions of island arcs, and are intermediate between the tholeiitic rocks of the continental side and the alkali-olivine rocks on the oceanic side. On this basis, the results of the present study are indicative of an island arc type of environment for the Rusty Lake greenstone belt. The precise spatial and temporal relationships of such an island arc system to the areas north and south of the greenstone belt are at present, however, extremely difficult to determine.

ECONOMIC GEOLOGY

INTRODUCTION

Discovery of the Ruttan Lake deposit was announced by Sherritt Gordon Mines Limited in early 1969, resulting in a flurry of staking and exploration activity throughout much of the Rusty Lake greenstone belt. This activity was intensified and extended beyond the greenstone belt, on release in June 1969 of the results of an INPUT electromagnetic survey, flown by Questor Surveys Ltd. for the Manitoba Department of Mines and Natural Resources in 1968.

A considerable amount of mineral exploration has been carried out in the map-area, especially in the metavolcanic and metamorphosed volcanoclastic rocks of the Rusty Lake greenstone belt. Previous ground geophysical surveys are evident from the numerous cut lines in the areas around Rusty and "Eagle" Lakes and north of Karsakuwigamak Lake, and in the tonalite batholith (14) and the biotite-plagioclase-quartz gneiss (10) to the north. Many of the electromagnetic anomalies in the area have been drilled, and a number of drilling programmes were still underway when the writers left the field in late August, 1970.

MINERALIZATION

All rock types in the map-area, with the exception of the pegmatites and leucogranites, contain at least minor sulphide mineralization, most of which is pyrite. Significant mineralization however appears to be confined to the Wasekwan Group. Apart from the Ruttan Lake deposit (described below), the mineralization encountered in the present survey, consists mainly of disseminated pyrite, with minor amounts of pyrrhotite, chalcopyrite and sphalerite (*var.* "blackjack"). The mineralization occurs mostly in thin tuffaceous beds or intercalated sedimentary layers (especially the meta-argillites) in the main volcanic sequence, and in certain beds in the sedimentary rocks of the Upper Wasekwan Group. Sulphide minerals are also locally concentrated in shear zones to form "spot-type" gossans that are seldom continuous over more than one outcrop. The large aeromagnetic high just north of Karsakuwigamak Lake is caused by large amounts of magnetite in the metavolcanic rocks.

The pre-Sickle intrusive rocks also contain disseminated sulphides, again usually pyrite. However, along the contacts between the diorite, quartz diorite (7c) and the metavolcanic rocks (2b, 2c), the writers encountered many small gossan zones that commonly contain chalcopyrite and pyrrhotite in addition to pyrite.

The sulphide mineralization observed in the Sickle rocks (8, 9) and the Opachuanau gneisses (10) is usually restricted to quartz veins, but small gossan zones containing pyrite and some chalcopyrite also occur in the Opachuanau gneisses. In the arkosic conglomerate (8a), a number of small quartz veins were found to contain chalcopyrite, pyrite, and galena.

The only sulphide common to the post-Sickle intrusive rocks is weakly disseminated pyrite. However, some small pyrite and pyrrhotite-bearing gossan zones were encountered near contacts between these intrusions and rocks of the Wasekwan Group.

No sulphides or other economic minerals were encountered in the pegmatites (18).

THE RUTTAN LAKE DEPOSIT

The Ruttan Lake copper-zinc deposit of Sherritt Gordon Mines Limited is situated in the extreme eastern portion of the Rusty Lake greenstone belt. The claims covering the orebody were staked by Sherritt Gordon in August 1968 following an airborne geophysical survey conducted by that company earlier in the year. The deposit corresponds to a six-channel anomaly on the airborne INPUT electromagnetic survey, (Manitoba Mines Branch, 1969) flanked to the east by a four-channel anomaly, and to the west by three and five-channel anomalies. The deposit appears to be confined to metavolcanic rocks containing numerous thin intercalated layers of metasediments (especially meta-argillite) and sills of diorite, quartz diorite (7c).

The Ruttan Lake ore deposit consists of two *en echelon* massive to semi-massive sulphide zones which strike in a northeasterly direction, plunge to the east, and dip approximately 67 degrees to the south. The length of the deposit is approximately 2700 feet, with an average combined width of 120 feet. The average width of each of the two individual zones is 65 feet. The reported average undiluted grades from the Sherritt Gordon Mines Limited Annual Report (1970) are 1.47 per cent copper and 1.61 per cent zinc, with reserves of 51,000,000 tons calculated to a depth of 2,000 feet. Construction and development are now under way to place the Ruttan mine in full production by July 1, 1973 (Thomas, 1971). Mining will commence from an open pit, with a planned annual output of 3,500,000 tons of ore for the first seven years, after which production from the underground mine will be phased in at an annual rate of 2,500,000 tons.

The Ruttan Lake deposit appears to be in part structurally controlled, along a northeasterly trending shear zone. However, the precise time relationship between ore emplacement and the shearing is not known. The main sulphides present in the ore body are pyrite, pyrrhotite, chalcopyrite and sphalerite with minor amounts of galena.

Two possible source rocks for the sulphides can be considered: (i) the numerous, small rhyolite (3b) lenses which outcrop near the deposit; or (ii) the diorite (7c) which occurs as a stock to the south of the deposit and in a sill to the north. The rhyolite contains small amounts of disseminated pyrite, but pyrrhotite, chalcopyrite and sphalerite, all of which are typical of the ore body, are absent. On the other hand, the diorite contains visible chalcopyrite and sphalerite, especially along its contact with the basic metavolcanic rocks (2b). Small dykes and sills of the diorite also show a close spatial relationship to the ore body. If the diorite (7c) was in fact the source of the sulphides, it can be further postulated that the sulphides were subsequently remobilized and concentrated into the shear zone during the regional metamorphism.

Evidence obtained from an examination of hand specimens collected from trenches in the ore deposit, suggests three possible stages of mineralization: (i) mainly pyrite with minor amounts of chalcopyrite and sphalerite; (ii) mainly pyrrhotite and chalcopyrite with some possible enrichment of sphalerite; and (iii) introduction of small veins of galena and sphalerite. The first stage of mineralization and subsequent enrichment of chalcopyrite and sphalerite during the second stage, may have occurred during the regional metamorphism. The third stage of mineralization appears to have entered along fractures and joints at a later date.

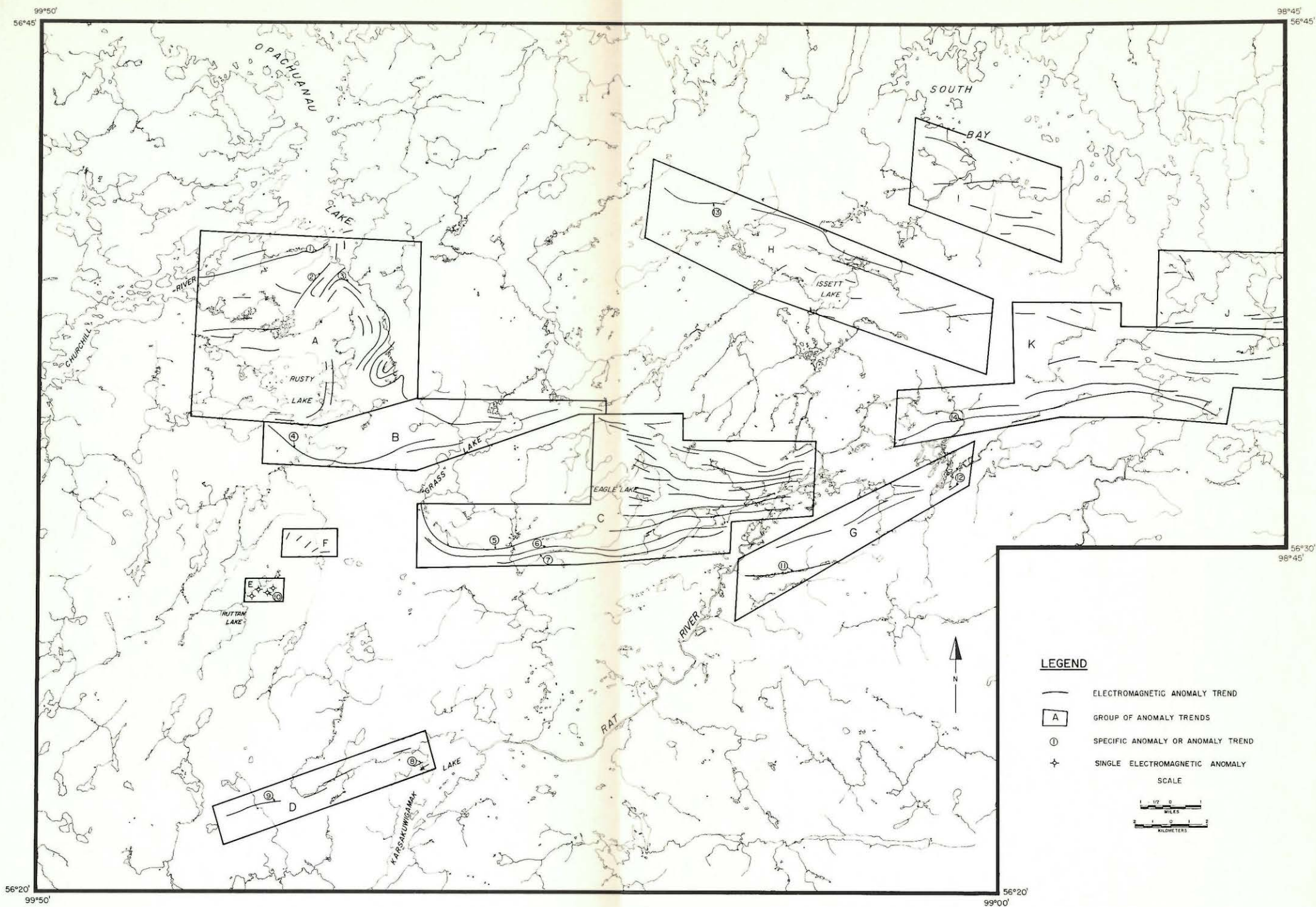


Figure 10: Electromagnetic anomaly trends in the map-area.

ELECTROMAGNETIC ANOMALIES

Numerous electromagnetic anomaly trends have been delineated within the map-area (Figure 10) using the results from the airborne INPUT survey (Manitoba Mines Branch, 1969) and the ground electromagnetic surveys carried out by various exploration companies*. For convenience in description, and partially on the basis of their relationship to the geology, the trends have been divided into groups which are outlined on Figure 10.

GROUP A

Group A comprises the electromagnetic anomaly trends around Rusty Lake. The trends are complex to the northeast of Rusty Lake, but follow an easterly direction to the northwest and south of the lake. The complex trends reflect folding in the metasediments (4a), adjacent to the tonalite batholith (14) (Map 71-2-8), with anomalies 1, 2, and 3 corresponding to the folded sulphide zones (unit 6). These zones contain pyrite and pyrrhotite, but only minor amounts of chalcopyrite and sphalerite, and have been extensively drilled and trenched by Hudson Bay Exploration and Development Limited.

The easterly trending anomalies in group A are parallel to the foliation in the metasediments (4a). The closure of a major fold is partially defined by the northerly trending conductors along the east shore of Rusty Lake.

GROUP B

Group B extends eastward from Rusty Lake to a point 3 miles east of the north end of "Grass" Lake. In the west, trend 4 corresponds to layering and foliation in the Wasekwan metasediments (4a) south of Rusty Lake, but in the vicinity of "Grass" Lake, the relationship of the anomaly to the geology is obscured by drift.

To the east of "Grass" Lake there are two anomaly trends over the biotite-hornblende tonalite (14a). From the small outcrop on the shore of "Grass" Lake, and from the easterly structure of the batholith in this area, it would appear that the anomalies are parallel to the foliation in the tonalite, and may be caused by graphite.

GROUP C

This group of anomaly trends extends east from the south end of "Grass" Lake, through "Eagle" Lake to the Rat River. The most westerly trends (5, 6, and 7) are parallel to the layering and foliation in the Wasekwan metasedimentary and meta-volcanic rocks. They correspond to seams of graphite along the foliation planes, and locally, to minor disseminated pyrite and pyrrhotite, especially in the metavolcanic rocks.

In the vicinity of "Eagle" Lake, and to the east, there are numerous easterly trending anomalies. The anomalies north of "Eagle" Lake correspond to gossans, containing pyrite and pyrrhotite, in the siliceous metasediments (4c) (Map 71-2-9). East of the lake, similar gossan zones were observed in the more basic metasediments (4c). However, most of the area in which the anomaly trends occur is drift-covered, and it is not known whether all the anomaly trends are related to sulphide zones. Drill core found on the shore of "Eagle" Lake indicates that graphite, in addition to sulphides, is responsible for some of the anomalies in this area. Drill core on the east shore of the lake contains graphite zones in the order of 1 to 5 feet (30 to

* Open file assessment data, Manitoba Mines Branch.

150 cm) thick. Seams of pyrite [generally less than 1 foot (30 cm) thick] are present in drill core found on the southwest shore of the lake.

The anomaly trends are terminated to the west when they come up against the tonalite batholith (14). The southern lobe of the tonalite batholith (14) between "Grass" and "Eagle" Lakes corresponds to an elliptical area of higher magnetic intensity (Federal-Provincial aeromagnetic map 2397). This elliptical area is bounded by a series of linear high magnetic anomalies along its eastern and southern margins, possibly related to higher concentrations of magnetite in the tonalite near the contact with the Wasekwan metasediments. The elliptical area of higher magnetic intensity itself overlaps the metasediments east of "Eagle" Lake suggesting that the tonalite underlies the metasediments at shallow depth in this area.

GROUP D

This linear anomaly trend extends west-southwest from the western shore of Karsakuwigamak Lake for a distance of 7 miles (11 km). A five-channel INPUT anomaly (anomaly 8) on the western shore of Karsakuwigamak Lake corresponds to pyrite-bearing iron formation. Five miles (8 km) to the west-southwest, anomaly 9 corresponds to a zinc showing which was not found by the writers, but has been described by Pearse (1964, page 15):

"Massive pyrrhotite, associated with surgery vein quartz, occurs in a narrow easterly-trending zone in the Wasekwan lavas in the central part of the Pemichigamau Lake area. The zone (locality 1) is 2 to 5 feet wide and has an exposed length of over 100 feet beyond which it passes beneath muskeg. Disseminated mineralization causes a rusty weathered surface more than 50 feet wide flanking the central zone. Grab samples assayed 2.5 per cent zinc and one stringer of chalcopyrite was noted in one of the specimens. Copper and lead, however, assayed nil. Some marcasite is present in the zone, probably as a secondary mineral."

Other anomalies on this trend are drift-covered.

GROUP E

This group consists of 4 individual INPUT anomalies. Anomaly 10 is a six-channel anomaly corresponding to the Ruttan Lake copper-zinc deposit, discussed above.

GROUP F

The five short trends in this group are located approximately two miles (3 km) to the northeast of the Ruttan Lake deposit. The two easternmost trends are in a drift-covered area, but the remaining three trends are over basic volcanic rocks (2b) and correspond to small gossan zones containing minor disseminated pyrite and pyrrhotite. These trends are parallel to the foliation in the volcanic rocks.

GROUP G

The anomaly trends in Group G, east of the Rat River, correspond to seams of graphite along foliation planes in the Wasekwan metasediments. Core left in the field from recent drilling of anomaly trend 11, contains only trace amounts of pyrite and pyrrhotite, but also contains hematite-bearing zones one foot (30 cm) thick. These zones comprise alternating seams of hematite [up to 2 inches (5 cm) thick] and layers of quartz, plagioclase, and minor disseminated hematite [up to 1 inch (2.5 cm) thick]. Magnetite (up to 5 per cent) is locally associated with the hematite. Anomaly trend 12 at the east end of this group, is caused by disseminated pyrite and

pyrrhotite, with traces of chalcopyrite, in epidotized basalt. Assays from a mineralized grab sample gave .06 per cent copper, .01 per cent zinc, and a trace of nickel.

GROUP H

Group H includes the east-southeasterly anomaly trends passing through Issett Lake. Most of these anomalies correspond to graphite concentrations along foliation planes in the biotite-muscovite-quartz schist (9) and in the biotite-hornblende intermediate gneiss (10a). Anomaly 13 occurs over the pegmatite (18) (Map 71-2-9), near its northern contact, but is probably caused by graphite in large xenoliths of biotite-hornblende intermediate gneiss.

The two easternmost anomalies in this group are in a drift-covered area, but lie close to the inferred northern contact of the tonalite (14) batholith.

GROUPS I AND J

Two groups of electromagnetic anomaly trends (I and J) were examined in the Swan Bay area. Because of extensive drift cover, the cause of these anomalies could only be investigated in shoreline outcrops, where they were found to correspond to sheared zones containing pyrite and/or pyrrhotite. These zones appear to be confined to the Wasekwan pelitic biotite gneiss (1), and may also be responsible for some of the anomalies in this group.

GROUP K

This group consists of a number of easterly trending anomalies, most of which are in an area (Map 71-2-10) where the geology has been interpreted with the aid of aeromagnetic maps and aerial photographs.

Overburden precluded investigation of most of the anomalies in the area actually visited by the writers. However, one pyrite-bearing gossan zone was observed in meta-basalt (5a) (Map 71-2-9), on the shore of the Rat River. Anomaly trend 14 cuts across the river at this point.

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