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5042

ARCHEAN VOLCANIC STUDIES IN THE LAKE OF THE WOODS-MANITOU LAKE-WABIGOON REGION OF WESTERN ONTARIO

By

A.M. Goodwin

1970

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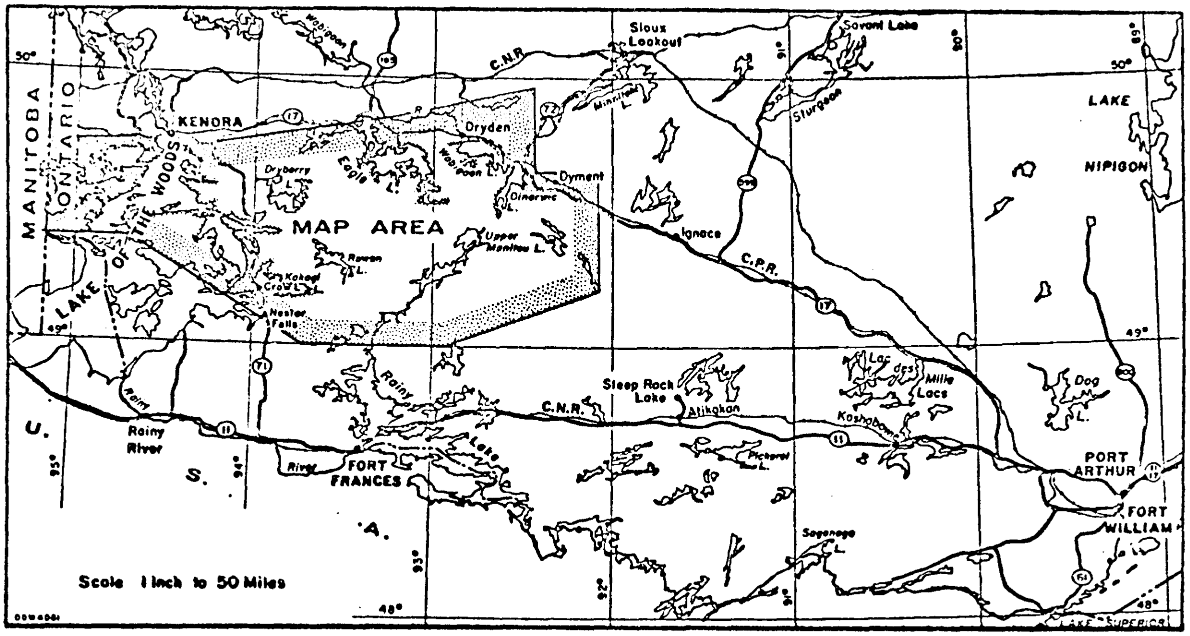
MANITOBA
ONTARIO
LAKE OF THE WOODS
KENORA
Dryden
Eagle
Wabigoon
Sioux Lookout
C.N.R.
Savant Lake
Sturgeon
LAKE NIPIGON
Dyment
MAP AREA
Upper Manitou L.
Ignace
C.P.R.
Rowan L.
Nestor Falls
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Atikokan
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Dog L.
Rainy River
Rainy Lake
FORT FRANCES
C.N.R.
Pickerel L.
PORT ARTHUR
FORT WILLIAM
Saganaga L.
U. S. A.
Scale 1 inch to 50 Miles
50°
49°
48°
95°
94°
93°
92°
91°
90°
89°

KEY MAP

ABSTRACT

Keewatin stratigraphy features two main superimposed mafic-felsic volcanic sequences in the western part of the region and a single mafic-felsic volcanic sequence with overlying clastic sediments in central and eastern parts. Total estimated stratigraphic thicknesses range from 21,800 to 28,500 and average 23,000 feet.

Regional structural patterns reflect superposition of dome patterns upon pre-existing east-trending linear fold patterns, the domes now occupied by granitic masses and intervening troughs by Keewatin supracrustal rocks.

The weighted average chemical composition of Keewatin volcanic rocks based on detailed stratigraphic studies and 420 whole rock analyses is as follows with available corresponding averages of Birch-Uchi volcanic rocks inserted in brackets for comparison: in percent, SiO_2-54.3 (54.4), Al_2O_3-14.9 (14.5), Fe_2O_3-2.37 (2.62), FeO-7.37 (7.06), MgO-4.81 (4.93), CaO-7.25 (6.84), Na_2O-2.78 (2.70), K_2O-.75 (.67), TiO_2-.87 (.83), MnO-.17 (.16), loss on ignition - 4.20 (4.56), CO_2-1.87, H_2O-1.79, P_2O_5-.26; and in ppm, Sr-210, Ba-195, Cr-161, Zr-140, V-271, Ni-131, Cu-76, Co-32, Zn-95, Pb-5.0, Ga-24, Sn-1.19, Ag-.11.

Keewatin volcanic rocks correspond closely to Nockolds' average basalt (tholeiitic)-andesite-dacite-rhyolite series the main differences being that Keewatin volcanics are comparatively low in K_2O, Sr and in the case of rhyolite, Pb, and comparatively high in CO_2, H_2O and $FeO:Fe_2O_3$ ratios. The weighted abundances of Keewatin volcanic classes are as follows, in percent: basalt - 55.7, andesite - 26.4, dacite - 11.5, rhyodacite - 1.8, rhyolite - 4.6. Average chemical compositions of the five Keewatin volcanic classes and of associated ultramafic intrusions are listed.

Volcanic distribution patterns indicate that during Keewatin time widespread, subaqueous, fissure-controlled mafic lava extrusion was succeeded cyclically by felsic pyroclastic discharge from several eruptive centres situated mainly in northern parts of the region notably Lake of the Woods area.

Close spatial relations exist between significant gold-silver and copper mineralization and the main mafic-felsic stratigraphic zone. Principal occurrences, as known, lie directly in Lower Keewatin felsic volcanic rocks, in subjacent

Lower Keewatin mafic volcanic rocks, and marginal to nearby coeval granitic stocks. Significant nickel-copper mineralization is associated with mafic igneous intrusions stratigraphically lower in the Keewatin assemblage and iron mineralization in the form of banded iron formation with clastic sediments in stratigraphically higher parts. Further assessment of stratigraphic and chemical data may reveal additional relationships of economic value. In this regard additional comparative studies of other Archean volcanic assemblages are required for full exploitation of available volcano-stratigraphic-metallogenic data.

ARCHEAN VOLCANIC STUDIES

IN THE

LAKE OF THE WOODS - MANITOU LAKE - WABIGOON

REGION OF WESTERN ONTARIO

By

A.M. Goodwin[1]

INTRODUCTION

Summary Statement

Volcanic studies were conducted in the Lake of the Woods-Manitou-Wabigoon region of western Ontario during the 1963 and 1964 field seasons. This region is of particular interest because it contains the type Keewatin assemblage as originally defined by A.C. Lawson in 1885. The current studies entailed stratigraphic sectioning and extensive sampling of volcanic units at suitably spaced intervals across the region followed by whole rock analyses for major and minor elements. This data when related to existing bedrock information provides substantial insight into the volcanic-tectonic history of the region. Assessment of established metallogenic patterns relative to this framework focuses attention on significant volcanic-metallogenic relationships.

From these studies, it is concluded that (1) the region experienced shifting centres of active volcanism and sedimentation during Keewatin time; the western part contains two superimposed mafic-felsic volcanic sequences; the central and eastern parts contain a single mafic-felsic volcanic sequence which is the stratigraphic equivalent of the lower

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[1]University of Toronto. Manuscript received by The Director, Geological Branch, 17 December 1969.

of the two volcanic sequences to the west together with substantial thicknesses of sediments; (2) the structure of the region is marked by the superposition of dome patterns upon pre-existing, east-trending, linear fold patterns; the domes are now occupied by granite masses and intervening troughs by volcanic and sedimentary rocks; and (3) most mineral production in the region has come from gold and copper deposits associated with the principal (lower) mafic-felsic volcanic contact zone mainly in the western part of the region; in addition, potential nickel and iron producers are associated respectively with mafic igneous rocks in the central part and sedimentary rocks in the eastern part of the region.

Location

The Lake of the Woods-Manitou-Wabigoon region lies in the west part of the Province of Ontario, the west border forming part of the Ontario-Manitoba interprovincial boundary. The region is bounded approximately by Longitudes 95°08'W. and 92°15'W. and by Latitudes 49°00'N. and 49°45'N. It is 120 miles long and 50 miles wide or 6,000 square miles in area.

The main inhabited centres are Kenora in the west and Dryden and Dinorwic in the east. The town of Sioux Narrows lies in the southcentral part.

The region contains a large number of attractive lakes, a principal appeal to summer tourists. The larger lakes, listed from west to east, are Shoal Lake, Lake of the Woods, Kakagi Lake, Lower and Upper Manitou Lakes, Eagle Lake, Wabigoon Lake and Dinorwic Lake.

Access

First class roads provide ready access to most parts of the region. Highway 17 (Trans-Canada) crosses the northern part; and Highway 71, joining Kenora and Fort Frances 100 miles to the south, transects the central part. The southeastern part of the region, however, lacks convenient road access and is best reached by means of float planes which may be hired at Kenora, Dryden, or Nestor Falls.

History

The western part of the region including the Shoal Lake and Lake of the Woods areas was geologically mapped by A.C. Lawson of the Geological Survey of Canada in 1885. Since then, many parts of the region have been mapped in considerable detail by geologists of the Ontario Department of Mines (see attached bibliography).

Mineral exploration and mining operations were undertaken as early as 1880. Despite diligent search and the encouragement of numerous mineral occurrences, some extremely rich, only limited amounts of gold and copper have been produced so far. There is no active mining operation in the region at present. However, potential nickel and iron ores have been proved up in recent years.

Work Done

During the 1963-64 field program, detailed studies were made in the following seven key parts of the region - Shoal Lake, Lake of the Woods, Sioux Narrows, Kakagi Lake, Upper Manitou Lake, Eagle Lake, and Wabigoon areas (see Map No. 2115). Within each key area, complete stratigraphic sections across the volcanic-sedimentary assemblages between granite contacts were studied in detail; volcanic components were systematically sampled in preparation for bulk chemical analyses; fill-in mapping for local structural control was completed where necessary; and the more significant mineral occurrences were examined.

The following is a breakdown of time spent in the field: 1963 season - 3 men spent 4 weeks; 1964 season - 5 men spent 14 weeks; total for two seasons - 82 man-weeks.

A preliminary report on this project (P.R. 1965-2) was published by the Ontario Department of Mines in 1965. A coloured geological map of the area (Map 2115, Kenora-Fort Frances sheet) was published in 1967.

Acknowledgments

Field assistants in 1963 were F.H. Hubbard and D.J. Ellwood; in 1964 they were R.H. Ridler, D.J. Ellwood, B.J. Vander Kamp and J. Zurbrigge. I am especially indebted to Dr. Hubbard and Dr. Ridler who in capacity of senior assistants conducted independent mapping of unusually high calibre.

The full co-operation of Dr. J.C. Davies, formerly Resident Geologist at Kenora, is gratefully acknowledged. Particular thanks are due D.A. Moddle of the Ontario Department of Mines and H.D.B. Wilson of the Geology Department, University of Manitoba for major element analyses and J.A. Maxwell of the Geological Survey of Canada for minor element analyses as further specified below.

GENERAL GEOLOGY

General Statement

All the bedrock is Precambrian. The region is underlain by equal proportions of 1) Keewatin volcanic-sedimentary rocks with associated intrusions and, 2) younger granitic intrusions. Supracrustal rocks have been complexly folded and sheared. The present flat, lake-pocked topography bears imprint of regional glaciation.

Volcanic and sedimentary rocks in the western, or Shoal Lake-Lake of the Woods area, were originally defined by A.C. Lawson as belonging to the Keewatin "series". This particular part of the region thus constitutes the type Keewatin area. In the intervening years it has proved impossible to locate or even define lower and upper limits of the Keewatin "series"; nor has it been possible to demonstrate with reasonable certainty its presence in other "greenstone" belts of the Canadian Shield. For these reasons, the term "Keewatin" is now commonly used in a lithologic descriptive sense rather than in a rock- or time-classification sense. This notwithstanding, the present region does contain the original Keewatin of which certain key zones may be traced across the region with reasonable certainty and the facies correlation of others may be reasonably inferred. Therefore, the term Keewatin is retained and employed. Keewatin Group, broadly defined, is that assemblage of Archean volcanic and sedimentary rocks in the Lake of the Woods-Manitou-Wabigoon and adjoining region; it comprises predominantly assorted volcanic rocks in the lower stratigraphic parts and sedimentary rocks in upper stratigraphic parts. Keewatin rocks are transitional northward to felsic igneous and metamorphic rocks of the English River gneiss belt. The northern Keewatin boundary has not been adequately defined as discussed below but has been tentatively placed at the approximate northern boundary of the region. In other directions Keewatin rocks extend some distance beyond the (immediate) map region.

Certain sedimentary formations including those at Thunder Lake and Stormy Lake may in fact be unconformably separated from underlying Keewatin rocks and therefore not part of the Keewatin Group. Available evidence, although inconclusive, is considered to favour transitional rather than unconformable relations. Therefore all Archean sediments of the region are tentatively included in the Keewatin Group pending contrary evidence. The northern Keewatin boundary is placed in principle at the lithofacies transition from predominant volcanic rocks in the south to predominant metasedimentary and granitoid rocks of English River gneiss belt in the north. This contact extends along the north shore of Eagle and Wabigoon Lakes.

No attempt is made at present to define upper and lower limits of the Keewatin Group or to provide a time classification other than to refer it to the Archean eon of Precambrian time.

The Keewatin assemblage is of diverse composition containing a wide variety of volcanic and sedimentary rocks. Volcanic components, all of common calc-alkaline association, range from basalt flows to rhyolite pyroclastics. Sedimentary components range from coarse conglomerate, breccia, arkose and impure quartzite to thin bedded, fine-grained greywacke and argillite with banded iron formation. Lithofacies changes are numerous, irregular and abrupt. They feature overlapping, intertonguing and gradations of volcanics and sediments. This leads to the concept of the Keewatin assemblage as a mixture of volcanic and sedimentary materials deposited contemporaneously in diverse relationships and, locally, in distinct alternations - a view cogently and accurately expressed by A.C. Lawson in 1885 (p. 101-102).

Despite the complexity of distribution, a cyclical arrangement of lithic parts is apparent. The lithic parts of a complete cycle, arranged in ascending order, are (1) mafic volcanics, (2) felsic volcanics, and (3) sediments. Two such superimposed cycles named lower and upper Keewatin, are present in the western part of the region. In central and eastern parts only one cycle, probably the stratigraphic equivalent of lower Keewatin cycle to the west, together with greatly expanded thicknesses of sediments, is present.

Numerous mafic to ultramafic sills, dikes and irregular masses are present. They range from gabbro to peridotite in composition. Many are emplaced in mafic volcanic rocks and appear to represent surficial volcanic phases. Most are pre-tectonic bearing evidence of substantial deformation.

Younger granitic intrusions are common within the regional igneous-metamorphic complex bordering Keewatin rocks on the north. Also some granitic batholiths, stocks, sills and dikes are enclosed in Keewatin rocks.

According to a planimeter survey, the area (see Map in P.R. 1965-2) is 5,969 square miles (Goodwin 1965, Table 3). Of this, 2,790 square miles, or 46.8 percent is underlain by "granite" and 3,170 square miles, or 53.2 percent by "greenstone" or Keewatin rocks. Based on the planimeter survey the "greenstone" area is underlain by the following lithic percentages: mafic volcanic rocks - 61.1 percent; felsic volcanic rocks - 14.5 percent; sediments - 14.5 percent; mafic igneous intrusions - 3.0 percent; and granitic intrusions - 6.9 percent. These may be otherwise grouped as follows: volcanic rocks - 75 percent; sediments - 15 percent; and igneous rocks - 10 percent. The indicated ratio of mafic volcanics to felsic volcanics is 4.2:1.

Table of Formations

QUATERNARY

Pleistocene and lake deposits:	Varved clays, till, sand and gravel.

PRECAMBRIAN

Younger Mafic Igneous Intrusions:	Diabase dikes.
Felsic Igneous and Metamorphic Rocks:	Granodiorite, granite, quartz diorite, syenite, aplite, pegmatite, gneiss, migmatite.
Mafic and Ultramafic Igneous Rocks:	Gabbro, diorite, norite, anorthositic gabbro, peridotite, pyroxenite; amphibolite.
Keewatin:	
Sedimentary Rocks:	Arkose, feldspathic quartzite, conglomerate, breccia, greywacke, shale, iron formation; altered and metamorphosed equivalents.
Felsic Volcanic Rocks:	Rhyolite, dacite and rhyodacite pyroclastics, flows and intrusions; minor andesite and basalt flows and sediments; altered and metamorphosed equivalents.
Mafic Volcanic Rocks:	Flows of basalt and andesite and their pyroclastic and intrusive equivalents; minor dacite pyroclastics and sediments; altered and metamorphosed equivalents.

Mafic Volcanic Rocks

Mafic volcanic rocks of the region comprise basalt and andesite in that order of abundance. Thick successions of mafic lava flows with massive, pillowed, and breccia phases and associated intrusions greatly exceed pyroclastic forms. In composition, texture and structure, the mafic rocks are essentially uniform across the region.

Distribution: Substantial thicknesses of mafic volcanic rocks are present in most parts of the region (Map No. 2115). In the western or Shoal Lake-Lake of the Woods part, several narrow, east-trending mafic belts are intercalated with felsic volcanic and sedimentary belts. In the central part, broad mafic belts lie southwest of Long Bay, south and west of Kakagi Lake and in the Caviar-Rowan Lakes area. In the eastern part mafic volcanics are common near Lower and Upper Manitou Lakes, and at Wabigoon, Dinorwic and Stormy Lakes.

Lithology: Mafic lava flows, both basalt and andesite, far exceed all mafic pyroclastic forms. Massive uniform lava and associated intrusions are very common. Many lava flows, each 20 to 50 feet thick contain lower massive and upper pillowed zones commonly topped by 3 to 5 feet of flow breccia. Flow-upon-flow construction of this type has resulted in vast piles thousands of feet thick. Thicker flows are locally present; a maximum flow thickness of 110 feet was measured at Eagle Lake. The majority of pillows including the largest and best formed are found in basalt flows; andesite pillows are also common but dacite pillows are rare. Specifically of 104 pillowed flows which were sampled in the region 64 percent are basalt and 30 percent andesite. A great variety of shapes, including pancake, balloon, mattress, bun, "snowshoe", and irregularly bulbous are present. Pillows are normally 2-3 feet long and 1-2 feet wide as measured in outcrop; the maximum noted was 10 feet by 2 feet. Many pillow lavas are amygdaloidal, the amygdules being concentrated particularly at the top of the pillows occasionally in well-defined layers (see Satterly 1941, p. 8-9). Pillow selvages are from 1-3 inches thick. Large pillows such as those at Corkscrew Island and Shingwak Lake feature abundant well-developed radial and concentric cooling fractures which combine to produce a high degree of internal fragmentation. At Isinglass Lake pillows are encased in pale-grey chert. Adjacent pillows in a lava flow commonly contrast greatly in size and shape: small, bulbous, irregularly shaped units less than 6 inches in diameter are nestled in with large, well-formed, balloon- and mattress-shaped pillows many feet long. At Rowan Lake a thick succession of pillow flows, each 30-40 feet thick, contains occasional multiple pillows formed of two or three superimposed, interconnected bulbous units or buds of decreasing upward size. At Shingwak and Dogpaw Lakes pillow lava is a characteristic "battleship" grey colour due to pervasive zoisitization. Elsewhere common colours range from pale brown through aquamarine to deep green.

Flow breccia, an integral upper part of many lava flows, typically contains angular to rounded, small to medium, massive to porphyritic fragments in a dense matrix of similar composition. Flow breccia at Dogpaw Lake comprises greyish-green, angular to sub-rounded fragments up to 12 inches in diameter with delicately preserved flow laminae, in a chilled lava matrix replete with small amygdules and variolites. At Rowan Lake, a succesion of lava flows, each 12-15 feet thick, are pillowed throughout except for 1 to 2 feet of flow top breccia. Many apparently massive flow units are seen upon close examination to contain innumerable tiny angular fragments indicating ash flow derivation.

Feldspar porphyry lava is common in the mafic piles. Creamy white to pale-yellow feldspar phenocrysts contrast sharply with dark green to black lava matrix. Phenocrysts range greatly in size to a maximum of 3 inches as observed at Rowan Lake. Many crystals are notably euhedral but others form small sub-rounded pellets apparently derived by partial resorption of intratelluric crystals during lava ascent and (or) surface flow. Feldspar phenocrysts are typically clustered in poorly-defined conformable zones within specific flow units. Some zones are jammed with small anhedral crystals; others, as at Sioux Narrows, contain only sporadic, large euhedral crystals; still other zones contain a variety of crystal forms. Rarely feldspar phenocrysts are concentrated in pillows as well as in adjoining massive lava.

Vesicles and amygdules are widespread in the flows especially in pillowed phases. They are also common in and near flow tops. Amygdules vary greatly in size and shape the larger units being 1 inch in diameter and 3 to 4 inches long. The common filling is either quartz or calcite occasionally with minor zoisite or epidote. Locally contrasting amygdaloidal fillings are closely associated in the same flow.

Mafic pyroclastics ranging from lapilli-tuff to coarse breccia and most commonly non-descript grey-green ash rock, is closely associated with lava flows. Inter-flow pyroclastic bands and lenses, commonly well-banded and graded units 10 to 15 feet thick contain assorted, dense to highly vesicular, massive to porphyritic, angular to sub-rounded fragments in fine grained ashy matrix. Prominently vesicular andesitic tuff in northcentral Lake of the Woods includes many scoriaceous fragments up to 16 inches in diameter, evidence of highly explosive derivation. In this particular area bedded, graded tuff bands, each 2 to 4 feet thick, commonly separate thicker zones of coarser, highly vesicular breccia. Some interflow pyroclastic layers contain chert fragments particularly those in the vicinity of chert-encased pillows as at Isinglass Lake. At Shingwak Lake hybrid breccia contains andesite fragments in basaltic matrix; andesitic bombs up to 4 inches diameter comprising highly vesicular cores and chilled lithic margins. At Rowan Lake a thick succession of lava flows each 20 to 30 feet thick contains many thin ash-lapilli interflow layers. At Upper Manitou Lake large andesite breccia fragments are replete with small euhedral hornblende crystals.

Microscopic examination of many thin-sections reveals that mafic volcanics have undergone almost total recrystallization to secondary mineral aggregates. Typical basalt with relict diabasic texture is highly saussuritized; it contains faint remnants of idioblastic laths of plagioclase in a fine grained (<.05 mm.) chlorite-carbonate-zoisite-quartz matrix. Plagioclase remnants, both phenocrysts to 15 mm. diameter and matrix, have a composition range An_{30-40}. Small amygdules with carbonate, quartz and epidote fillings were observed. Fibrous aggregates of chlorite-zoisite are very common. Andesitic varieties, essentially similar, contain higher proportions of feldspar and quartz both as phenocrysts and in matrix.

Sparsely interspersed with mafic flows are thin but persistent felsic pyroclastic zones each 1 to 6 feet thick. They are present in central and eastern parts of the region as for example at Rowan Lake and south of Wabigoon Lake where they form possible marker horizons in otherwise uniform mafic volcanic successions. The relations suggest separate but concurrent sources of volcanic material - major mafic extrusive source and subordinate felsic explosive source.

Environment of Accumulation: Absence of erosional unconformities and abundance of pillowed lava with well-graded interflow pyroclastics demonstrate prevailing sub-aqueous environment during most if not all the period of mafic accumulation. The overall impression gained is one of overwhelming sub-aqueous mafic outflow from numerous, widespread vents and fissures. Dominant mafic lava extrusion was punctuated by intermittent and greatly subordinate felsic pyroclastic discharge. Mafic volcanics apparently accumulated in the form of numerous large intercalating shield volcanoes probably distributed along regional fissures. Subordinate felsic pyroclastics, explosively broadcasted with the aid of wind, wave and currents together with intermixed clastics, form local marker horizons in the mafic piles.

Felsic Volcanic Rocks

The Keewatin group contains a variety of felsic volcanic rocks mostly pyroclastics indicating highly explosive derivation. The pyroclastics are clustered in certain parts of the region thereby marking felsic eruptive centres. Felsic rocks stratigraphically overlie substantial thicknesses of mafic volcanics. Compositionally dacite is much more common than rhyolite.

Distribution: Four main concentrations of felsic volcanic rocks are present in the region (see Map No. 2115). By far the largest is in the Lake of the Woods-Shoal Lake area. Smaller concentrations occur at Kakagi Lake, Eagle-Wabigoon Lakes and Upper Manitou Lake. In addition thin discontinuous felsic zones are present in intervening predominantly mafic areas.

In the Lake of the Woods-Shoal Lake area six irregular east-trending felsic belts collectively represent structural duplication of two main stratigraphic zones. The belts cross 1) Clearwater Bay and Ptarmigan Bay in the north, 2) northern and southern parts of Western Peninsula in the centre, and, 3) Monument Bay-Whitefish Bay area in the south. Local extensions are present at Shoal Lake in the west and at Bigstone Bay and Eastern Peninsula in the east.

At Kakagi Lake an elliptical mass, 20 miles long by 10 miles wide, contains besides predominant felsic volcanics, sediments and layered mafic sills. A smaller elliptical mass (10 by 4 miles) of predominant felsic volcanics lies at Upper Manitou Lake. Several thin felsic zones extend from Eagle Lake to Wabigoon Lake. In addition thin discontinuous bands and lenses are present at Dogpaw, Rowan and Straw Lakes in the central part and at Kawashegamuk and Dinorwic Lakes in the eastern part.

The stratigraphic thickness of felsic volcanic successions are commonly 3,000 feet but locally attain 6,300 feet. Individual belts vary greatly in stratigraphic thickness along strike.

Lithology: Great lithic variety is present in the felsic masses. Fragmental forms, from bedded tuff to coarse agglomerate are most common. Massive to well-banded lava flows and Pelean-type extrusive domes are present. Abrupt lateral facies changes in composition, texture and grain size are characteristic. Clastic sediments are intimately associated.

Bedded to massive tuff and tuff breccia, commonly in pale shades of grey, brown, green and pink are very common. Lighter and darker coloured varieties representing subtle compositional changes are intimately associated. Much of the material is massive lacking discernible layering. Where definable, individual beds are commonly 1 to 2 feet but range to 50 feet thick. Many beds are crudely sorted and some are delicately graded. Dense lithic fragments predominate; porphyritic varieties are locally abundant; and pumiceous and highly scoriaceous varieties are not uncommon. Most fragments are angular but many are sub-angular to sub-rounded suggesting limited water abrasion during transport. The proportion of ashy matrix material varies considerably. For example many pyroclastic units near Luella Island in northcentral Lake of the Woods are notably deficient in normal complement of fine grained matrix material. Such units are interpreted as subaqueous ash flow deposits from which original fine grained pyroclastic complement has been winnowed out and removed during subaqueous transport.

Many tuff breccia units contain scattered large angular to sub-rounded felsic fragments suggesting derivation by rapid avalanching of unsorted debris down precipitous volcanic slopes.

Tuff units locally contain zones of banded chert up to 24 feet thick. Some chert is distinctly carbonaceous and pyritiferous as on the northwest side of Corkscrew Island (see particularly Thomson 1937a, p. 11-14).

Breccia deposits are up to many hundreds of feet thick and are doubtless extremely variable in dimension. One such rhyolite explosion breccia deposit near Luella Island contains abundant large angular to sub-angular porphyry fragments up to 24 inches in diameter in a matrix of ever-smaller but equally angular fragments of identical composition. In the same vicinity a tuff breccia layer 15 feet thick is composed of white pumice fragments all less than 2 inches in diameter in a minor grey pumiceous matrix.

The main concentration of coarse felsic breccia is present in the eastern extension of Western Peninsula of Lake of the Woods where the presence of many large slabby lithic fragments up to 4 feet long indicates high-level explosive shattering of pre-existing volcanic necks, domes and other lithic units. Lesser but nonetheless substantial breccia concentrations are present at Deadman Portage on the south shore of Western Peninsula and in central part of Shoal Lake. Breccia concentrations of this type undoubtedly reflect proximity to source vents. Fragment size decreases away from these centres; distal equivalents, as for example along the south shore of Shoal Lake, feature fine grained, well-bedded, commonly graded tuff.

Fragment populations in the breccia are normally simple and represent at most a narrow range of compositions. Rarely mixed fragment populations are present, the common fragment always being more felsic than other fragments as well as matrix.

Unusually dense, commonly massive though locally well-banded rhyolite masses up to 1 mile in diameter and several thousand feet thick as occur at Rope Island in Lake of the Woods may represent Pelean-type extrusive or near-surface domes. Occasional thin massive rhyolitic units present in many places may represent lava flows rather than ash flows.

Along the north shore and adjoining islands of Kakagi Lake the common tuff breccia constitutes a chaotic jumble of angular to sub-rounded feldspar porphyry lithic fragments up to 2 feet in diameter in a grey feldspathic matrix. All fragments are uniform dacitic composition. Occasional thin, well-graded tuff beds are present. At the east end of

Kakagi Lake feldspar porphyry tuff breccia contains two main types of fragments - grey lithic feldspar porphyry and yellowish green amygdaloidal felsite with quartz fillings. Most fragments are 2 to 6 inches in diameter. The matrix is composed of smaller fragments of feldspar porphyry together with fragments of individual feldspar crystals. Occasional fragments of shale and banded chert are present. Kakagi breccia apparently represents widespread explosive shattering of pre-existing porphyry volcanic units followed by rapid subaqueous accumulation of lithic and pyroclastic debris. The association of sub-rounded clasts of mixed volcanic and sedimentary rocks with local crude bedding and grading suggests rapid subaqueous accumulation.

Felsic volcanic rocks at Upper Manitou Lake are essentially similar to those at Kakagi Lake. Fine to medium grained feldspar porphyry tuff breccia is distributed in highly irregular units practically devoid of recognizable bedding or sorting. Angular to sub-angular fragments are generally less than 6 inches but range to 24 inches in diameter. Porphyritic lithic fragments predominate but local concentrations of finely vesicular fragments are present. Rare tuff breccia units display limited bedding and sorting. Intercalated andesitic pillow lava flows are common.

Relations at Upper Manitou Lake point to preservation of a segment of a stratavolcano composed of alternating felsic pyroclastics and mafic lava flows. The nature of the tuff breccia particularly in composition and limited size range points to rapid subaqueous accumulation of pyroclastic debris upon volcanic slopes situated considerable distance down slope from principal felsic vents but close to flank sources of mafic extrusion.

At Eagle Lake the thickest and coarsest pyroclastic masses indicating proximity to source vents lie along the southern and southeastern shores. Typical pyroclastic units each 30 to 60 feet thick contain angular lithic to vesicular fragments each 2 to 6 inches in diameter in a fine grained ashy matrix. Thin-bedded fine grained ash rock and lapilli tuff is common particularly in the western and southeastern parts of the area. Some thin massive felsite units probably represent lava flows. Amygdaloidal and pillow interflows, mainly andesitic, are present.

To the east at Wabigoon and Dinorwic Lakes thin discontinuous felsic zones contain fine to medium grained pyroclastic material much of it highly vesicular together with coarser breccia units all indicative of subdued explosive activity with consequent accumulation of lithic debris at considerable distance from felsic vents.

Environment of Accumulation: The presence of bedded and sorted pyroclastic units, rounded clasts pillow lavas and intercalated sediments indicate prevailing subaqueous accumulation of felsic pyroclastics with intermittent mafic outflow from nearby sources. A principal felsic source was in the central part of Lake of the Woods. Others of lesser magnitude were located at or near Kakagi Lake, Eagle Lake and possibly Upper Manitou Lake. The chaotic, unsorted nature of much of the debris points to rapid deposition of subaqueous pyroclastic ash flows and of avalanche debris derived from steep volcanic slopes. However some pyroclastic material may well have been extruded subaerially from island vents.

Felsic volcanic rocks and clastic sediments are generally intimately associated throughout the region. Lensy pyroclastic units and bands, too restricted to warrant separate mapping, are widely distributed in the sedimentary bands; conversely clastic sedimentary units abound in felsic volcanic zones. Indeed clastics and pyroclastics are commonly difficult if not impossible to differentiate. Such an intimate physical relationship clearly marks the gradational character and common heritage of the two rock types. In this manner their intimate physical blending, gross chemical similarity, and apparent absence of significant time breaks between respective periods of pyroclastic and clastic accumulation are attributed in large part to derivation of clastic detritus from felsic pyroclastic piles.

Sedimentary Rocks

Distribution: Two main east-trending sedimentary belts cross the region (see Map No. 2115). The principal belt is continuous across the region for more than 100 miles from Monument Bay in Lake of the Woods on the west to the northeast corner of the region near Wabigoon on the east. To the south a second generally parallel though discontinuous belt extends from Kakagi Lake on the west through Straw and Manitou Lakes to

Bending Lake on the east. To the northwest additional smaller sedimentary belts lie at the southern shore of Shoal Lake, the southeastern shore of Western Peninsula in Lake of the Woods, and near High Lake and Clearwater Bay to the north.

Reflecting their upper stratigraphic positions in the Keewatin succession the sedimentary belts generally mark synclinal axes. Stratigraphic thicknesses range from 3,000 to 6,000 feet.

In the western part of the region as previously noted, sediments are commonly intercalated with volcanic rocks, notably felsic pyroclastics. In the central and eastern parts sediments either are intercalated with or, more commonly, overlie volcanic rocks.

Lithology: A great variety of clastic sediments is present. In general coarser grained facies predominate in westcentral parts and finer grained facies to the east. Greywacke, arkose and conglomerate with metamorphic equivalents are present in High Lake-Clearwater Bay area. Thin bedded, fine grained volcanic greywacke and tuff occurs along the southern shore of Shoal Lake and of Western Peninsula to the east. Coarser grained arkose, impure quartzite and greywacke with occasional conglomerate-breccia zones are common at Monument Bay and Whitefish Bay in Lake of the Woods. Similar medium to coarse grained arkosic assemblages with conglomerate and breccia occurs at Kakagi and Upper Manitou Lakes. East of Stormy Lake and north of Eagle and Wabigoon Lakes thin-bedded fine grained greywacke with banded magnetitic iron formation predominate. The main conglomerate zones in the region are at Clearwater Bay in Lake of the Woods, at Straw Lake, and near Upper Manitou and Washeibemaga Lakes to the east. So far as determined the conglomerates are conformably infolded with other clastic facies.

Much of the clastic detritus is clearly volcanic in origin. This is particularly obvious in coarse grained facies notably conglomerate and breccia, where amygdaloidal and porphyritic volcanic clasts abound. Finer grained clastic facies apparently has similar volcanic content. Indeed the close spatial association and lithic similarity of sediments and felsic volcanic rocks across the region suggests a co-genetic relationship. On the other hand the large quantities of clastic feldspar and quartz contained in the main sedimentary belts does impose some limitation on this interpretation and suggests an alternative non-volcanic crystalline provenance at least in part. Similarly the presence of occasional granitic clasts, although also attributable to sub-volcanic source, raises the possibility of clastic contribution from a crystalline igneous provenance outside the immediate Keewatin volcanic terrain.

Greywacke is the predominant sediment in the western part of the region as at Shoal Lake and the southwestern part of Lake of the Woods. Well-developed beds typically 2 to 24 inches thick are commonly graded. Scour and flame structures are widespread. Many thin cherty interbands, commonly carbonaceous and pyritiferous, as well as zones of bedded chert up to 25 feet thick, are present. Bedded tuff breccia is closely associated. The clastic association in this area indicates comparatively deep, quiet, reducing aqueous environment with rapid influx of volcanic ash and tuff from active volcanoes to the east.

In the southern part of Lake of the Woods and eastward to Lobstick Bay arkose and impure quartzite with local conglomerate are common. The dominant facies is white to pink, medium to coarse grained, thin- to thick-bedded (2 to 8 feet), locally well-graded arkose with distinctive blue quartz grains. Arkosic breccia is common. Arkose is gradational on a local scale to impure quartzite by proportionate increase in quartz grains. Breccia and conglomerate zones which range to 40 feet thick typically contain sub-rounded fragments up to 18 inches in diameter composed of dense to highly vesicular felsite, amygdaloidal rhyolite, arkose, chert and occasional grey granite in a greyish green arkosic matrix which also includes distinctive blue quartz grains. In this area arkosic rocks are gradationally overlain by fine grained, thin bedded greywacke; these relations are well displayed at Long Bay and Lobstick Bay where coarse grained, thick-bedded arkose common at the north shore is gradationally overlain southward by fine grained, thin-bedded greywacke displaying local grain gradation and numerous cherty pyritiferous tops. Clearly the local environment of accumulation became more quiescent and reducing presumably with deepening water and greater tectonic stability.

Similar lithic associations are present at both Kakagi and Upper Manitou Lakes. Individual arkosic beds along the south shore of Kakagi Lake are mainly 2 to 4 feet thick but reach a maximum of 15 feet thick midway along the south shore. Such beds are typically well graded, gritty basal part grading imperceptibly upwards to shaly upper parts characteristically capped by bedded chert. Pebble zones occur at the base of some beds. Sediments at eastern Kakagi Lake, Cedartree Lake and Stephen Lake to the north are considerably finer grained and include substantial proportions of greywacke. At Upper Manitou Lake comparatively coarse grained sediments constitute the southern or stratigraphically lower part of the sedimentary sequence. For example massive thick-bedded arkose is common at Sunshine Lake; nearby at Uphill Lake south of Mosher Bay local conglomerate contains prominent, small to medium, rounded to sub-rounded clasts up to 6 inches in diameter of feldspar porphyry, amygdaloidal felsite and other volcanic rocks of dacitic composition. The presence of these and other conglomerate-breccia zones implies rapid erosion of rugged volcanic terrain undergoing active mechanical erosion with rapid transport to nearby sites. Immediately to the north near Manitou Straits arkose is conformably overlain by fine grained, thin-bedded greywacke. These greywacke beds are unusually well graded with sandy base and shaly top. Occasional beds up to 3 feet thick are also graded.

Similar associations of arkose, impure quartzite, greywacke and conglomerate are reported to be present at Washeibemaga and Stormy Lakes. At Bending Lake banded magnetitic iron formation is common.

To the north near Eagle and Wabigoon Lakes metamorphosed equivalents of thin-bedded, fine grained greywacke, commonly quartz-feldspar-mica and quartz-biotite-garnet assemblages, are associated with banded iron formation.

<u>Environment of Accumulation</u>: As previously noted coarser sedimentary facies particularly arkose and impure quartzite with conglomerate which are present in the southern and westcentral parts of the region are transitional northeastward and eastward to finer grained, thinner-bedded clastic sediments with banded iron formation. In addition at specific localities e.g. Long Bay, coarser grained clastics are conformably overlain by finer grained clastics. These relations suggest that clastics accumulated upon irregular, northward shelving flanks of intermittently active volcanoes with progressively deeper, quieter water encroaching from that direction. Volcanic rocks, particularly felsic components, were under active erosion. Additional quartzo-feldspathic detritus may have been contributed from external granitic provenance. Deposition of banded iron formation was substantially restricted to the deeper, quieter subaqueous environment to the east and northeast.

Older Mafic Intrusions

Numerous mafic sills and dikes are contained in volcanic and sedimentary sequences at Shoal Lake, Bigstone Bay and Long Bay of Lake of the Woods, Kakagi Lake, and at Eagle and Wabigoon Lakes. Most pre-date the main period of folding. Some may be syntectonic.

Layered mafic sills are present in some parts of the region. At Kakagi Lake three main sills are present (Ridler, 1966). The main sill which averages 3,000 feet thick, is infolded with felsic volcanic breccia. This sill contains seven zones arranged in ascending order: carbonate, peridotitic gabbro, peridotite, norite, diorite, granodiorite and granophyre. Much of the sill rock at Kakagi Lake is remarkably fresh. Elsewhere in the region mafic sill rock has been extensively sheared and altered.

Between Populus and Eagle Lakes large mafic intrusions contain gabbroic, noritic and anorthositic phases. Both altered and unaltered rocks are present. At Mulcahy Lake, southwest of Eagle Lake, progressive alteration is marked by faintly sheared norite or gabbro traceable through chloritic phases to strongly sheared chloritic rocks. In the Wabigoon-Dinorwic area to the east, pegmatitic phases occur within the gabbroic masses in the form of stringers and irregular masses.

Thin, irregular lamprophyre dikes are also present. They typically cross-cut and are clearly younger than Keewatin volcanic and sedimentary rocks. Their age relative to granite masses is not known.

Felsic Intrusions

Felsic intrusions are present both as large batholithic masses and as smaller, local units. Eight batholithic masses are present each containing a variety of rock types ranging from granitic at the core to dioritic at the margin. Each mass, roughly circular to elliptical in outline and 40 to 50 miles in diameter, represents a structural dome mantled with outward-facing supracrustal rocks.

Many small granitic stocks, sills and dikes are also present. In the Lake of the Woods-Shoal Lake area in particular, a number of small, granite-granodiorite stocks are distributed mainly along east-trending fold axes.

The common rock in the region is medium- to coarse-grained, pink to grey granodiorite or granite. The contact of the granitic intrusion with older volcanic sedimentary rock is either relatively abrupt e.g. north of Clearwater Bay in Lake of the Woods area, or gradational across several thousand feet of banded and lit-par-lit injected gneissic rock. Pegmatite is abundant as dikes, sills and small stocks near the margins of the Minnitaki granite mass.

Diabase Dikes

Occasional, northwest-trending diabase dikes transect all other consolidated rocks of the region. At least two thin, persistent dikes are present in the Lake of the Woods-Kakagi Lake area; another crosses Dinorwic-Eagle Lakes area.

STRUCTURAL GEOLOGY

General Statement

The structure of the region is complex. The rocks are highly folded and commonly sheared. Several persistent schist zones including a circumferential girdle about the Atikwa-Niven dome may mark extensive faulting. Despite the complexity, several patterns emerge. The regional fabric reflects the superposition of dome patterns upon pre-existing east- to northeast-trending linear fold patterns. The domes are now occupied by granite masses and the intervening troughs by supracrustal rocks.

Fold axes plunge steeply throughout the region. In the western, central and eastern parts respectively the plunge is steep to the west, to the east, and again to the west. These changes in plunge appear to mark out cross-fold axes.

At least 500 stratigraphic top determinations in the form of grain gradations in sediments and pillow structures in lava flows have been recorded (Map in P.R. 1965-2). Structural reliability is normally related to the number of supporting top determinations.

Folding

Regional fold traces are gently convex to the southeast. Local deflections of fold axes about granite domes obscure but do not obliterate this pattern.

As previously noted, eight large structural domes, now occupied by granite masses, are present in the region. In the northern part are the Dryberry and Minnitaki domes; to the south the Aulneau, Pipestone, Manitou and Entwine domes; to the east the Hodgson dome, and enclosed in the eastcentral part of the region the Atikwa-Niven dome (see Map in P.R. 1965-2). Some domes have marginal protuberances or lobes, e.g. Lawrence Lake lobe of the Atikwa-Niven dome. Others e.g. Dryberry and Minnitaki domes, are themselves but lobes of still larger granitic masses that extend far beyond the region. Of the eight specified domes, only one, Atikwa-Niven, is completely enclosed; the other seven lie at the margins of the region.

Because Keewatin supracrustal rocks face away from the domes it follows that stratigraphically older Keewatin rocks generally lie near granite margins whereas younger Keewatin rocks occupy intervening structural troughs.

One consequence of the association of east-trending linear fold pattern and imposed dome pattern is that local fold axes generally flow smoothly around north and south granite margins yet butt up against and occupy indentations in east and west granite margins.

Brief descriptions of structural patterns in the seven key areas are provided below.

Shoal Lake-Lake of the Woods Area: Keewatin rocks in this part of the region have been complexly folded about steeply plunging, east- to northeast-trending isoclinal axes. Individual folds vary considerably in continuity some being local and others apparently continuous across the area.

Three main anticlines and accompanying synclines are present, as follows (see Map No. 2115): Clearwater Bay syncline, High Lake-Corkscrew Island anticline, Indian Bay-Ptarmigan Bay syncline, Bag Bay-Brule Point-Kenora anticline, Spike Point-Luella Island-Eastern Peninsula anticline, and in the southern part of Lake of the Woods, Big Narrows syncline. In addition local folds are present, e.g. Bald Indian Bay and Andrew Bay synclines and Bigstone Bay anticline, all on the east side of Lake of the Woods.

A hypothetical irregular diagonal line drawn southeastward across Lake of the Woods from the town of Keewatin on the north to the western boundary of Whitefish Bay on the south separates mutually facing rocks, i.e. east-facing strata to the west from west-facing strata to the east. Stated otherwise, to the west of this hypothetical diagonal line, younger strata are distributed tracing axially from west to east whereas east of the same diagonal line younger strata are distributed axially in the opposite direction i.e. from east to west. This hypothetical diagonal line marks the axis of cross-folding or down-buckling. As demanded by such a structural pattern youngest Keewatin rocks lie at the junction of this cross-fold and east-trending synclines.

East-trending folds as determined plunge steeply (60 to 85 degrees) to the west.

Long Bay-Sioux Narrows Area: The fold pattern is synformal about a southeast-trending axis; the strata generally face inwards away from two marginal granite masses situated respectively to the northeast (Dryberry dome) and southwest (Aulneau dome). Several re-entrants at the southern and southwestern margins of Dryberry dome reflect local east-trending folds.

The folded strata meet along the prominent Long Bay-Dogpaw Lake structural lineament. The presence of highly sheared rocks in this vicinity suggests complex fold-fault relationships.

Kakagi-Rowan Lakes Area: East- to northeast-trending, steeply east plunging folds intersect the prominent, southeast-trending Long Bay-Dogpaw-Flint-Cameron Lakes lineament. This lineament separates east-facing, open folded strata to the west (Kakagi Lake vicinity) from west-facing, isoclinally folded strata to the east (Rowan Lake vicinity). Again, this prominent lineament is characterized by highly sheared rock which appears to mark a zone of folding and faulting.

Populus Lake Area: Several close-spaced, northeast-trending, steeply plunging, isoclinal folds occupy the narrow constriction separating neighbouring granite masses (Dryberry and Atikwa-Niven domes). In general, supracrustal rocks marginal to Atikwa-Niven dome face northwestward away from the granite mass. Little is known about stratigraphic attitudes at the other granite contact to the northwest.

Eagle Lake Area: A similar pattern of northeast-trending, steeply plunging folds occupy deep indentations at the north margin of Atikwa-Niven dome. Along the north shore of Eagle Lake a zone of isoclinally folded, highly sheared rock separates predominantly north-facing volcanic rocks to the south from predominantly south-facing sedimentary rocks to the north. The sedimentary rocks to the north are considered by Moorhouse (1939, p. 20) to synclinally overlie the volcanic rocks.

Wabigoon-Dinorwic Lakes Area: In the southwest part of this area, volcanic rocks face radially away from a large granite mass (Dore Lake lobe of Atikwa-Niven dome); thus, the strata, traced continuously from northwest to southeast, face northward, northeastward, and then eastward. At greater distances from the granite margin the strata assume the normal northeast-trending fold pattern characteristic of the eastern part of the region. Northeast of Wabigoon and Dinorwic Lakes a series of close-spaced, steeply southwest plunging isoclinal folds are indicated to be present (see Map No. 2115).

Manitou Lakes Area: This area features closely spaced, northeast-plunging isoclinal folds. At Upper Manitou Lake a felsic pyroclastic mass marks a northeast-trending and plunging anticline. To the south, south-facing felsic volcanic rocks are in contact with north-facing sedimentary rocks. This lithic interface coincides with a prominent northeast-trending shear zone which in turn may define a sheared and faulted synclinal axial plane.

Little is known about the structure eastward to Upper Manitou-Stormy-Dinorwic Lakes vicinity. However it is probably complex. Lithic distribution is crudely triangular the strata so far as known facing centrally towards Boyer Lake and concurrently away from three marginal granite masses, namely Atikwa-Niven, Entwine, and Hodgson domes.

Shearing and Faulting

Shearing is widespread throughout the region. Sheared rocks are characteristically carbonatized the common minerals being calcite, ankerite and sideritic carbonate. Shearing is normally parallel to local lithic stratification. Direct evidence of major fault movement, in the form of significant stratigraphic offsets has not been presented. However local evidence suggesting fault movement has been noted.

In the Lake of the Woods area prominent shear zones are suggested by Thomson (1936, p. 25) to represent lines of fault movement along which fold-producing stresses were relieved.

In the Whitefish Bay area, no positive evidence of faulting involving large displacements was found (Fraser 1943, p. 14). However, Fraser notes that "some faulting might reasonably be expected to have accompanied the intense folding that the rocks have undergone; consequently, some of the strongly sheared zones noted in the area may be faults".

In the Kakagi-Rowan Lakes area, the deflections of fold axes about the Long Bay-Dogpaw-Flint-Cameron Lakes lineament is suggestive of fault movement.

In the Straw-Manitou-Stormy Lakes area, the volcanic-sediment interface is marked by a shear zone up to 200 feet wide (Thomson 1933, p. 17-20). Thomson notes that sedimentary beds near the contact are locally truncated by this shear zone at angles up to 50 degrees and concludes that the zone marks faulting of considerable magnitude.

In the Populus Lake area, Davies and Watowich (1956, p. 17-18) have defined faults and fractures mainly on the basis of intense shear effects and mylonitization in and adjacent to valleys and other linear topographic features and, less commonly, by brecciation, silicification and hematitization. However direct evidence of major faulting is not cited.

Faulting of any importance was not definitely recognized in the Eagle Lake area (Moorhouse 1939, p. 20). Structural adjustment in the area, according to Moorhouse, was probably largely accommodated by shearing and flow rather than actual faulting.

Satterly (1941, p. 31) states that the northern margin of north-facing mafic volcanics in contact with south-facing sediments to the north in the Wabigoon area is characterized by intense carbonatization and shearing. This distinct structural break at this contact is interpreted by Satterly as a major strike fault.

In considering the region at large it is apparent that shearing and carbonatization are widespread. Particular attention is drawn to the southeast-trending shear zone that extends intermittently if not continuously through Long Bay via Dogpaw, Flint, and Cameron Lakes to Pipestone Lake on the south; the possible extension of this shear zone passes eastward through Straw and Essex Lakes; similar shearing extends northeastward along Manitou Straits via Lower and Upper Manitou Lakes to Kabakugski Lake; to the northeast the rocks at Dinorwic Lake are also extensively sheared and carbonatized. In the northern part of the region, as previously noted, the northeast-trending volcanic-sediment interface is sheared and carbonatized.

In summary, it is apparent that a circumferential shear zone girdles the Atikwa-Niven granite mass. At many places along its course this elliptical schist zone marks the contact between peripherally disposed, inward facing sediments and centrally disposed outward facing volcanics. However no direct evidence of major faulting in the form of significant stratigraphic offsets has been recorded.

The relationships suggest to the writer that such schist girdles define zones of structural adjustment connected with emplacement of the granite domes. This involved downbuckling of the supracrustal assemblages preferentially along lithofacies transitions. The magnitude and extent of related fault movement is unknown but may have been substantial. The relative dispositions of clastic sediments and felsic pyroclastics about the domes suggest that pyroclastics accumulated at vents upon and marginal to rising granite dome whereas clastics accumulated contemporaneously mainly upon peripherally disposed volcanic slopes. During ensuing structural adjustments such lithofacies transitions became the focus of folding, shearing and faulting. According to this interpretation, felsic volcanics and sediments represent in large part cogenetic products of volcanic centres at sites now occupied by granite domes.

STRATIGRAPHY

General Statement

The following regional stratigraphic framework is based upon detailed stratigraphic studies in the following seven key areas: Shoal Lake, Lake of the Woods, Long Bay-Sioux Narrows, Kakagi Lake, Upper Manitou Lake, Eagle Lake, and Wabigoon-Dinorwic Lakes area (see map in pocket). In each area one or more complete sections across the Keewatin assemblage between granite contacts were studied in detail. It is apparent that, because of structural complexities, an individual section may include the complete succession, repeated successions, or parts only of the local stratigraphic succession. By this means and with due consideration to structure, the local stratigraphic succession in each area was determined. The assembled successions collectively provide the regional stratigraphic framework.

As previously noted, considerable stratigraphic variation is present throughout the region. In the western part two well-defined and superimposed sequences, each comprising mafic to felsic volcanic and sedimentary parts in ascending order are present. In central and eastern parts a thick assemblage of mafic volcanics is overlain by assorted felsic volcanic and sedimentary rocks. This stratigraphic diversity is attributed to mutually shifting centres of volcanism and sedimentation during Keewatin time.

Regional Framework

Common to the region at large is a mafic platform composed largely of basalt-andesite lavas and associated intrusions. The platform ranges in exposed thickness from 4,600 to 20,000 feet. It is present in the seven areas studied and may be correlated with reasonable certainty across the region.

In the west part of the region (Shoal Lake-Lake of the Woods) the mafic platform forms the basal part of the lower of two superimposed mafic-felsic volcanic sequences, each sequence comprising in ascending order mafic volcanic, felsic volcanic and sedimentary parts. This repeated three-fold succession provides a natural division of the local Keewatin assemblage into Lower and Upper Keewatin divisions. Each of the two divisions is approximately 12,000 feet thick. The total thickness of the Keewatin assemblage in this part ranges from 23,100 feet to 26,400 feet and averages 24,700 feet.

In central and eastern parts of the region a mafic platform 15,000-20,000 feet thick is overlain either by felsic volcanics, by sediments, or by intercalations of the two, the additional thickness being 2,500 to 6,000 feet. At Eagle and Wabigoon Lakes, an additional sequence of younger mafic volcanics about 3,000 feet thick, separates felsic volcanics and sediments. The relative ages of felsic volcanics and sediments vary across the region, the sediments locally overlying, locally intercalated with, and locally in abrupt sheared contact with felsic volcanic rocks. However most sediments are younger than or equivalent to upper stratigraphic parts of the felsic volcanics.

Regionally, Lower mafic volcanic rocks in all areas are interpreted to be stratigraphic equivalents. Felsic volcanic rocks in central and eastern parts are considered equivalent to Lower felsic volcanic rocks of Shoal Lake-Lake of the Woods areas to the west. Sediments in central and eastern parts are partly equivalent to and partly younger than Upper Keewatin volcanic rocks to the west; this implies that sedimentation in central and eastern areas accompanied and followed active volcanic discharge to the west.

As noted above, the nature of the sediments changes progressively across the region. In general, coarser phases such as conglomerate, breccia, arkose and feldspathic quartzite predominate in the western and southern areas e.g. Lake of the Woods, Sioux Narrows, Kakagi Lake and Upper Manitou Lake. In each area, coarse clastics are gradationally overlain by finer grained clastics. Traced laterally to the northeast clastic grain size decreases and, at Eagle and Wabigoon Lakes to the north and at Bending Lake to the east, thin bedded, fine grained greywacke, slate, phyllite and derived schists predominate. Banded iron formation is quantitatively restricted to such fine-grained sedimentary sequences.

This decrease in clastic grain size to the northeast and east suggests that quieter depositional environment prevailed in that direction. This may reflect a deeper water, chemically reducing off-shore environment; or, alternatively, a tectonically quiet, restricted lagoonal site receiving only fine-grained clastics and chemical constituents (banded iron formations). This period of fine-grained sedimentation marked the waning stages of Keewatin volcano-tectonic activity in the region.

Stratigraphy by Areas

Stratigraphic successions and thicknesses by areas are summarized in Table 1.

Shoal Lake-Lake of the Woods Area: The oldest exposed rocks are mafic lava flows and associated intrusions. They underlie three east-trending belts corresponding to anticlinal fold axes (Map No. 2115). The northern mafic belt extends from the southwest part of Shoal Lake through Bag Bay, Helldiver Bay, Ash Rapids and Brule Point to Kenora Indian Reserve and Bigstone Bay on the northeast shore of Lake of the Woods. The central mafic belt extends along Deadman Portage and Carl Bay, Crow Rock Island and Shammis Island, and Allie Island and Bottle Bay on Eastern Peninsula of Lake of the Woods. The southern mafic belt lies at the margin of the Aulneau granite dome; it extends southeastward without apparent break from Aulneau Peninsula through Sioux Narrows to Kakagi Lake. Additional thin, discontinuous patches of Lower mafic volcanic rocks are exposed at the northern margin of the area near the Trans-Canada highway and to the northwest near High Lake.

Assorted Upper Keewatin mafic to felsic volcanic rocks and sediments underlie three intervening synclinal belts. The northern belt extends eastward from Indian Bay of Shoal Lake through Echo and Ptarmigan Bays to Rat Portage vicinity in the east; at Clearwater Bay north of Corkscrew Island anticline is an additional local synclinal belt. The central synclinal belt passes northeastward through Spike Point at Shoal Lake, Hatmaker Lake and Luella and Whisky Islands in Lake of the Woods; here the belt bifurcates into northeasterly and southeasterly arms that together embrace Bigstone Bay on the east shore of Lake of the Woods. The southern synclinal belt extends eastward along the main southern expanse of Lake of the Woods; it includes Big Narrows, Crescent, and Britannia Islands and thence curves southeastward to Whitefish Bay.

In stratigraphic terms Lower Keewatin rocks underlie most of Shoal Lake, the northern part of Lake of the Woods, and a substantial part of the south half of Lake of the Woods. Upper Keewatin rocks are largely restricted to the northern and southern synclinal belt described above including the Clearwater Bay belt to the north. Other smaller patches of Upper Keewatin rocks may be present beneath the waters of Lake of the Woods particularly the central part.

Long Bay-Sioux Narrows Area: A thick sequence of northeast-facing mafic rocks lies along the south shore of the narrows between Whitefish Bay on the west and Long Bay on the east. The sequence is conformably overlain to the northeast by thin, discontinuous bands of northeast-facing, felsic volcanic rocks. These are in abrupt contact across the Long Bay-Sioux Narrows lineament with a thick, predominantly southwest-facing sequence of coarse-grained arkose, impure quartzite and breccia which, in turn, are underlain to the northeast by local remnants of mafic volcanic rocks.

Kakagi-Rowan Lakes Area: A thick sequence of mafic volcanic rocks stratigraphically underlies felsic volcanic rocks and sediments.

At Kakagi Lake felsic volcanic rocks and sediments are intercalated, one or the other immediately overlying mafic volcanic rocks. The relationships demonstrate essential contemporaneity of felsic pyroclastic discharge and clastic sedimentation in this area, a pattern repeated elsewhere in the region.

Upper Manitou Lake Area: Older mafic volcanic rocks, present south of Uphill and Sunshine Lakes and again north of Upper Manitou Lake, are conformably overlain by coarse arkosic grits, feldspathic quartzite and volcanic conglomerate, in turn conformably overlain to the north by fine-grained, well-banded greywacke argillite and sheared equivalents.

At the south shore of Upper Manitou Lake the sediments are in contact across a prominent northeast-trending shear zone with a thick sequence of felsic volcanic breccia, which underlies the main part of the lake.

The exact age relation of felsic volcanics and sediments has been obscured by shearing. However similar stratigraphic relationships at Kakagi Lake to the west suggest that sediments and felsic volcanics are essentially contemporaneous.

Eagle Lake Area: Highly folded mafic volcanic rocks situated southwest of the eastern part of Eagle Lake are conformably overlain by felsic volcanic rocks including siliceous rhyolite.

Felsic volcanic rocks are, in turn, overlain to the north by younger, predominantly north-facing mafic volcanic rocks. These are in contact to the north with highly folded, schistose sedimentary rocks. Considerable stratigraphic interbanding of lava flows and sediments at and near this contact suggests conformable relations. The sediments appear to occupy a syncline and are, therefore, to be considered somewhat younger than the volcanic rocks (Moorhouse 1939, p. 20).

Wabigoon-Dinorwic Lakes Area: Stratigraphic relations are similar to those at Eagle Lake. North- to northeast-facing, complexly folded mafic volcanic rocks with local thin felsic pyroclastic zones are in contact across an east-trending gradational, partly sheared zone with predominantly sedimentary rocks and derived schists to the north. Satterly has interpreted this sedimentary-volcanic contact as a major strike fault. However lithic interbanding and gradations in the vicinity raises the possibility of conformable relationships.

CHEMICAL COMPOSITION AND ABUNDANCES OF VOLCANIC ROCKS

Procedure

The following assessment of volcanic compositions and abundances is based upon detailed field studies and stratigraphic sampling in seven key areas followed by whole rock analyses (map in back pocket). Each area was examined and sampled in sufficient detail to provide structural and stratigraphic control for stratigraphic weighting of the samples. In general the more complex and varied the volcanic sequence the more closely spaced the sampling. Resulting stratigraphic and chemical data were used to determine average chemical compositions and abundances in each area and thereby the region at large.

A total of 420 volcanic units were sampled in the seven key areas (map in back pocket). The number of samples per area ranged from 26 (Sioux Narrows) to 104 (Lake of the Woods) and averaged 60. So far as possible only representative volcanic units of specific parts of the succession were sampled. Each sample taken was composed of chips of fresh rock taken at designated intervals (average 20 inches) across the outcrop. The length of sampled outcrop was up to 150 feet and averaged 30 feet per sample. The average weight of chip samples taken was 5 pounds. All samples were taken with the aid of 4 to 6 pound sledge hammers and hand moils as required. Each sample was submitted for chemical determination of thirteen major and thirteen minor elements as well as specific gravity of 202 samples.

All major elements were determined either at the Laboratory and Research Branch, Ontario Department of Mines (samples K - 31, 68-71, 76-77, 93-112, 114-124, 131-133, 207-230, 235-237, 243-311, 316-317, 319-400, 402-427) or at the Department of Geology, University of Manitoba (samples K 1-30, 32-67, 72-75, 78-92, 113, 125-130, 134-206, 231-234, 238-242, 312-315, 318, 401). All Ontario Department analyses include Loss on Ignition determinations whereas Manitoba analyses include CO_2, H_2O and P_2O_5 determinations. The laboratory responsible for each sample may be readily identified in Table 2 on this basis.

All major elements were analyzed by rapid methods. The estimated accuracy of the individual determinations is approximately as follows, expressed as $\pm$ 1 standard deviation: SiO_2 - $\pm$ 1.2%, Al_2O_3 - $\pm$ 0.7%, Fe_2O_3 - $\pm$ 0.5%, CaO - $\pm$ 0.3%, MgO - $\pm$ 1.0%, K_2O - $\pm$ 0.1%, TiO_2 - $\pm$ 0.05%, MnO - $\pm$ 0.02%, FeO - $\pm$ 0.2%, Na_2O - $\pm$ 0.15%, P_2O_5 - $\pm$ 0.04%, CO_2 - $\pm$ 0.1%, H_2O - $\pm$ 0.1%.

All minor elements were analysed by spectrograph at the Geological Survey of Canada. The analyses are expected by the laboratory to have accuracies as follows: Sr, Ba, Cr, Zr, V, Ni, Cu, Co, $\pm$ 15%; Zn, Pb, Ga, Sn, Ag $\pm$ 30%.

Chemical compositions of samples arranged stratigraphically by areas from west to east are listed in Table 2. Weighted average compositions of stratigraphic sections by areas are listed in Table 3.

All volcanic samples were classified on the basis of normative compositions according to the classification proposed by Irvine (1966). Average composition of each volcanic class was calculated (Table 4), as well as the abundances of volcanic classes by area and for the entire region (Table 5).

Average Composition of Stratigraphic Sections by Area

Table 3 presents weighted average chemical compositions of structural sections and composite stratigraphic sequences by areas together with Keewatin volcanic average of the region. As previously stated the averages are weighted with respect to estimated stratigraphic thicknesses assigned to individual samples.

Local stratigraphic sequences have been complicated by structural duplication. Thus individual structural sections listed in Table 2 may represent part only, all, or repetitions of the local stratigraphic succession. However it is assumed that the structural sections sampled in each area represent the local stratigraphic sequence. It is further assumed that the stratigraphic sequences in the seven key areas collectively represent the Keewatin group in this region.

Individual sections vary considerably in average composition as well as in stratigraphic thickness. Without exception lower stratigraphic parts are more mafic than those higher in the sequence. This reflects a preponderance of mafic volcanic rocks in lower stratigraphic parts and felsic volcanics in upper parts. For example the Long Bay section of the Sioux Narrows area which represents the lowest stratigraphic part, has an average composition close to that of Keewatin basalt (Table 3) whereas the north limb of the Luella Island Syncline in Lake of the Woods area, which is considerably higher in the stratigraphic succession, approaches Keewatin dacite in average composition.

In general the average compositions of the stratigraphic sequences in the seven key areas are remarkably similar despite variations by sections. The Sioux Narrows and, in lesser degree, Manitou Lake sequences are more mafic in average composition due to high basalt content. On the other hand the Lake of the Woods sequence is more felsic due to higher rhyolite and dacite contents.

Of the seven key areas those to the north (Shoal Lake, Lake of the Woods, Eagle Lake and Wabigoon Lake) are comparatively felsic in average composition compared with those to the south (Sioux Narrows, Kakagi Lake and Manitou Lake). This distribution pattern suggests that the northern parts, particularly Lake of the Woods, were closer to felsic eruptive centres. The seven areas collectively are considered to provide a reasonable average of Keewatin volcanic rocks in the region.

Classification

All Keewatin volcanic rocks sampled with the exception of ultramafic intrusions classify readily in the basalt-andesite-dacite-rhyolite series according to the system proposed by Irvine (1966). The three fundamental parameters used in this classification are normative quartz, normative colour index, and normative feldspar (anorthite-albite-orthoclase) ratios. All Keewatin volcanic samples have been classified as listed in Table 2. Included are 155 basalt, 146 andesite, 79 dacite, 9 rhyodacite, 28 rhyolite and 5 samples of ultramafic rocks.

Normative feldspar ratios in chemically analysed samples by areas are shown in figures 4 a-g (omitted). The figures provide ready measure of the compositional range and proportions of volcanic rocks present in each area. According to the Irvine classification the basalt-andesite, andesite-dacite and dacite-rhyolite boundaries are located respectively at approximately 50, 30 and 12 percent normative anorthite. The two other parameters essential to the classification, namely normative quartz and normative colour index, are listed by sample in Table 2.

All areas with the exception of Sioux Narrows (4c) and Kakagi Lake (4d) show the full basalt-rhyolite compositional range. Sioux Narrows and Kakagi Lake areas lack rhyolite. Upper Manitou Lake has limited rhyolite. The greatest concentrations of rhyolite samples are from Shoal Lake and Lake of the Woods areas.

The considerable lateral spread of sample plots evident in figures 4 a-g (omitted) is considered to reflect original compositional variety present in the volcanic suite accentuated by metamorphic alteration (marked by high CO_2 and H_2O contents) as well as limited accuracy of rapid methods of chemical analysis.

With due allowance for these complications and limitations the results still indicate clearly that a full compositional range from basalt to rhyolite is present in the Keewatin assemblage. Most Keewatin samples plot on the orthoclase -

deficient side of the conventional Tertiary-Quaternary volcanic trends as plotted in corresponding normative feldspar triangular diagrams (Goodwin 1968, Fig. 7). However, Shoal Lake and Lake of the Woods samples do include some with substantial normative orthoclase thereby suggesting the presence of more complex, including potassic, trends in the volcanic suites of those two areas.

Abundances and Distribution of Volcanic Classes

The abundances of volcanic classes in the region weighted by stratigraphic thickness are shown in Table 5. The average for the region is as follows: basalt - 55.7 percent, andesite - 26.4 percent, dacite - 11.5 percent, rhyodacite - 1.8 percent and rhyolite - 4.6 percent. Thus for the region at large with the exception of rhyodacite the classes are arranged in order of decreasing abundance from mafic to felsic components.

Considered by areas the abundances of volcanic classes vary considerably. For example basalt abundances range from 30.5 percent at Wabigoon to 86.6 percent at Sioux Narrows, and those of andesite from zero at Sioux Narrows to 55.2 percent at Wabigoon. Dacite abundance is highest by far at Lake of the Woods (30.4 percent). Rhyolite is most abundant at Shoal Lake and Lake of the Woods followed in decreasing order by Sioux Narrows and Eagle Lake, Kakagi Lake and Wabigoon, and Manitou Lake.

The five classes grouped into combined mafics (basalt and andesite) and combined felsic (dacite, rhyodacite and rhyolite) provide a first order division of Keewatin volcanic rocks. Combined mafics range in abundance from a low of 61 percent (Lake of the Woods) to a high of 90.4 percent (Manitou Lake) and average 82.1 percent by area. It is highest by far at Lake of the Woods followed in decreasing order by Eagle Lake, Shoal Lake, Wabigoon, Sioux Narrows, Kakagi Lake and Manitou Lake. The abundance ratio of combined mafic to combined felsic is 4.5 to 1.

Thus Keewatin abundance ratio of combined mafic to combined felsic based on stratigraphic thickness is 4.5 to 1. This ratio compares closely with that of 4.2:1 based on planimeter survey of the geological map (see p. 6). This close correspondence offers strong mutual support to

a) reliability and petrographic significance of the traditional two-fold field classification of "basic" and "acid" volcanic rocks as expressed in the geological map (Map No. 2115) and, b) the accuracy of detailed stratigraphic measurements of Keewatin units made in the field in the course of the present study.

Thus felsic volcanic rocks including rhyolite are more abundant in northern parts (especially Lake of the Woods, Eagle Lake and Shoal Lake) compared with southern parts (Kakagi Lake and Manitou Lake). Using abundances of felsic rocks as an indication of proximity to felsic vents this pattern suggests that principal felsic eruptive centres were situated to the north particularly in Lake of the Woods-Shoal Lake and Eagle Lake areas.

Composition of Volcanic Classes

Average compositions of five volcanic classes by areas are listed in Table 4.

Keewatin basalt is remarkably uniform across the region. The only significant difference by areas is in Al_2O_3 content; it is commonly less than 14.5 percent but locally exceeds 15 percent mainly in stratigraphically higher parts of the Keewatin succession.

Keewatin andesite is also chemically uniform by areas. Al_2O_3 content of individual samples is from 13 to 19 percent with the large majority between 13 and 15 percent. Again higher Al_2O_3 contents are found in stratigraphically higher parts of the succession.

Keewatin dacite, rhyodacite and rhyolite are generally uniform by areas. Rhyolite displays the greatest range in chemical composition - for example, a spread in SiO_2 content from 69.9 to 76.1 percent.

As is to be expected most major and minor elements change progressively in content from basalt through andesite to rhyolite. SiO_2, Na_2O, K_2O contents increase in that order whereas Fe_2O_3, FeO, MgO, CaO, TiO_2, MnO, CO_2 and H_2O contents decrease. Al_2O_3 content is generally constant.

The average content of thirteen minor elements (expressed in ppm) is shown by structural sections and area (Table 3) as well as by volcanic classes (Table 4). Compared with average worldwide basalt (Taylor 1964), Keewatin basalt is very low in Sr, low in Ba, high in V and normal in Cr, Zr, Ni, Cu, Co, Zn, Pb, Ga, Sn and Ag contents. Compared with thirteen New Zealand and Japanese andesites (Taylor and White 1966), Keewatin andesite is low in Sr, high in Ba, Zr, Ni and normal in Cr, V, Cu, Co, Pb, Sn, Ga and Ag contents. Compared with average high calcium granite (Turekian and Wedepohl 1961), Keewatin rhyolite is very low in Sr and Pb, high in Ni, Co and Sn and normal in Ba, Cr, Zr, V, Cu, Zn, Ga and Ag contents. In summary, on this basis, Keewatin volcanic rocks are consistently low in Sr, notably low in Pb with respect to rhyolite, generally high in Ni, and comparable with respect to ten other minor elements.

Minor element contents by sections and areas are generally consistent one to the other the differences expressing local variations in mafic-felsic proportions.

The plot of individual Cu contents in the 427 samples taken in the region reveals certain anomalous lithic zones, particularly in Lake of the Woods area. The highest Cu content determined in the region (1,100 ppm in sample K-25) is in an isolated sample of ultramafic intrusion on the east-central shore of Shoal Lake. In the Lake of the Woods area high Cu contents were determined in samples K-51, 53, 55 and 61, all southwest of Luella Island and in samples K-89, 90, 92, 93 and 94 west of Crescent Island to the south. Both groups of samples occupy relatively high stratigraphic positions in the Keewatin sequence. Three isolated high Cu samples were taken in the Sioux Narrows area (K-172, 176 and 185). Cu contents are consistently low to normal at Kakagi Lake (exc. K-242) and Rowan Lake. A few isolated high Cu contents were determined along the southeast shore of Eagle Lake (K-292, 300, 307 and 317) and in eastern Wabigoon Lake area (K-345, 356 and 375). At Manitou Lake moderately high Cu contents were determined in samples K-409, 411, 413 and 415 all situated at and near the east-central shore.

In calculating average minor element compositions of volcanic classes by areas (Table 4) 69 anomalously high determinations were omitted from the calculations. The number of determinations omitted, grouped by element, is as follows: 33 Sn, 14 Pb, 7 Ba, 4 Ga, 3 Cr, 3 Cu, 2 Sr, 1 Ni and 1 Ag.

The omitted samples (all belonging to the K-series) are next arranged by volcanic classes and grouped by elements. Basalt: Cr-46, 67; Pb-253, 263; Sn-253, 263; Sn-180, 253, 263, 264, 310, 321, 415. Andesite: Pb-273, 306, 311, 369, 420, 421; Sn-94, 95, 97, 131, 231, 258, 273, 311, 306, 369, 372, 374, 322, 416, 420; Ba-77, 121, 422. Dacite: Sn-156, 224, 281, 268, 284; Pb-224, 284; Ba-38. Rhyodacite: Sr-127, 130; Ba-122, 324; Cu-122, 324; Sn-130, 270; Pb-119, 270. Rhyolite: Pb-113, 414; Sn-256, 260, 261, 414; Ba-137, 148; Cr-137; Ga-260, 261, 271, 395; Ag-331; Ni-137.

Considered by areas the anomalously high determinations are numerically grouped as follows: Shoal Lake - 1 Ba, 2 Cr, 1 Cu; Lake of the Woods - 5 Ba, 6 Sn, 2 Pb, 1 Cr, 2 Sr and 1 Cu; Sioux Narrows - 1 Sn; Kakagi Lake - 4 Sn, 2 Pb and 3 Ga; Eagle Lake - 13 Sn, 6 Pb and 1 Ga; Wabigoon Lake - 1 Ba, 5 Sn, 1 Pb and 1 Ag; Manitou Lake - 1 Ba, 2 Ni, 4 Sn, 3 Pb. Thus anomalously high determinations of the following elements by areas are present: Lake of the Woods - Ba, Sn; Eagle Lake - Sn, Pb; Wabigoon - Sn. Of these the greatest number (13) of anomalously high determinations are of Sn at Eagle Lake.

METALLOGENIC RELATIONS

General Statement

Mineralization is varied and widespread. At least 212 mineral occurrences are known (Map No. 2115) including gold-silver (153), copper (17), nickel-copper (9), iron (4), talc (5), molybdenum (5), antimony (3), zinc-lead (4), pyrite (4), fluorite (2), lithium (1) and beryllium (1).

Mining operations in the region began in the early 1850's. Although some spectacular lodes have been discovered the total production has been small. There is no regular production at present.

Production Record

The production record is 164,502 ounces gold, 23,636 ounces silver, and 1,886,246 pounds copper; all from 536,198 tons milled. This has come from 37 properties brought to production or pre-production stage. The names of the properties and their production record are listed in Table 4 of P.R. 1965-2.

Of the total mineral production, 90 percent is accounted for by 9 main producers, as follows: Wendigo, Sultana, Straw Lake Beach, Mikado, Regina, Laurentian, Cedar Island, Duport, and Kenricia mines (see Map No. 2115). Of the remaining 28 properties, together accounting for less than 10 percent of the regional production, one milled more than 10,000 tons, 5 milled between 5,000 and 10,000 tons, 3 between 1,000 and 2,000 tons, and the remaining 20 each milled less than 1,000 tons. Thus, the preponderance of production from a small number of mines is evident; in this regard, the Wendigo mine alone accounts for one-half the regional production. Most other occurrences are small showings that have warranted only very brief surface examination. Potential nickel and iron producers occur in the area.

Description of Main Occurrences

Most occurrences consist of quartz veins and associated minerals. The mineralogy of the veins is generally simple. Many contain small amounts of metallic constituents. Pyrite is most common. One or more of pyrrhotite, chalcopyrite, galena and sphalerite may be present. The sulphides occur both in quartz and impregnating wallrocks. Where present, gold occurs mainly in native state and locally as tellurides (altaite and tetradymite). Calcite, ankerite and siderite are commonly present.

Notes on seven main occurrences, listed from west to east across the region, are given in P.R. 1965-2 to which the reader is referred.

Relation to Stratigraphy

Known mineral occurrences in the region have the following preferential lithic associations: 1) gold-silver and copper mineralization with volcanic rocks; 2) nickel-copper mineralization with mafic igneous rocks; and 3) iron mineralization with fine-grained sedimentary rocks.

The following table shows lithic associations of 196 mineral occurrences in the region.

		Number	Percent
Mineral occurrences in mafic volcanic rocks	-	80	41
Mineral occurrences in felsic volcanic rocks	-	72	37
Mineral occurrences in igneous rocks, sediments, etc.	-	44	22
		196	100

Thus the large majority (78 percent) of mineral occurrences are directly associated with volcanic rocks. The remainder are associated with gabbroic intrusions, banded iron formation and, to lesser extent, granitic and metamorphic rocks.

The distribution of known mineral occurrences and main felsic volcanic bands is illustrated in Map No. 2115. The clustering of most occurrences at and near the main felsic-mafic stratigraphic contact is apparent. Thus this felsic-mafic contact zone, used in the broad stratigraphic sense, constitutes a favourable metallogenic target for gold-silver and copper occurrences.

The distribution of past producers also points to significant volcanic stratigraphic control of gold-silver and copper mineralization. Of 21 past producers 8 are associated directly with felsic volcanic rocks and 17 with subjacent mafic volcanic rocks. Of the 17 past producers in mafic volcanic rocks, 9 are stratigraphically close to overlying felsic volcanic rocks and 4 lie at the contact of granite stocks (Canoe Lake stock and Regina Bay stock) which may be reasonably interpreted as coeval with felsic volcanism.

Still further support is provided in the distribution and production record of the 9 main past-producers which together account for 90 percent of the production. Their production records and lithic associations are as follows:

	Tons Milled	Gold (oz.)	Silver (oz.)	Copper (lbs.)	$
(a) Felsic volcanic association					
Kenricia	22,344	2,533	521		97,518
Straw Lake Beach	33,662	11,568	1,049		429,477
Laurentian	33,716	9,513	296		189,157
Duport	1,287	4,672	1,143		163,871
	91,009	28,286	3,009		880,023
(b) Mafic volcanic association					
Wendigo	206,054	67,423	14,762	1,886,246	2,516,076
Sultana	77,481	15,977	4		431,138
	283,535	83,400	14,766	1,886,246	2,941,214
(c) Granite stock association					
Mikado	57,813	28,335	41		421,070
Regina	36,828	7,812	1,460		299,553
Cedar Island	17,050	4,941	3,884		174,146
	111,691	41,088	5,385		894,768
Grand Total	476,235	152,774	23,160	1,886,246	4,716,005

Thus most production has come from deposits associated with subjacent mafic volcanic rocks and most of this from Wendigo mine. Of particular significance in this regard is the stratigraphic proximity of mineral deposits of (b) group to overlying felsic volcanic rocks. Thus Wendigo mine is situated 2,600 feet stratigraphically below (north of) the felsic volcanic contact. Sultana deposit is located only 600 feet stratigraphically below (east of) the felsic contact. Thus, both deposits belong to the mineralized felsic-mafic volcanic stratigraphic zone as defined.

Attention is drawn again to the three main producers of granite stock association, namely, Mikado and Cedar Island mines at Shoal Lake and Regina mine at Sioux Narrows. Although emplaced in mafic volcanic rocks, both the Canoe Lake granite stock at Shoal Lake and the Regina granite stock at Regina Bay are closely associated with stratigraphically overlying felsic extrusive piles and may well represent coeval intrusive equivalents of the overlying felsic extrusives.

Thus, a close spatial relationship of significant gold-silver and copper mineralization in this region to a specific felsic-mafic stratigraphic zone is apparent. In summary, significant deposits lie directly in Lower Keewatin felsic volcanic rocks (mainly gold and silver), in subjacent Lower Keewatin mafic volcanic rocks (copper, gold and silver), or marginal to nearby presumed coeval granitic stocks (mainly gold and silver). The main concentrations of felsic volcanic rocks and accompanying mineralization are considered to reflect proximity to Keewatin volcanic centres.

In contrast, examination of mineral distribution pattern (Map No. 2115) shows an absence of correlation either to main shear zones or to main batholithic margins. From this it would appear that mineral emplacement was not guided by obvious structural controls or related to major granite intrusions.

In summary, gold-silver and copper mineralization appears to be intimately related to Keewatin felsic-mafic volcanic stratigraphy, nickel-copper mineralization to mafic igneous intrusions stratigraphically deep in the volcanic pile, and iron mineralization to fine grained sedimentary facies, stratigraphically high in the Keewatin assemblage.

Recommendations

The above analysis of metallogenic relationship to Keewatin stratigraphy serves to draw particular attention to specific parts of the stratigraphic succession. Genetic considerations aside, most known gold-silver and copper occurrences, including all past producers, are located at or near a particular stratigraphic zone which encompasses Lower Keewatin felsic volcanic and subjacent mafic volcanic rocks, the latter including possibly coeval granite stocks. The favourable stratigraphic zone is well developed at Shoal Lake, Lake of the Woods, Kakagi Lake, Straw Lake, Upper Manitou Lake, and to a lesser extent, Wabigoon and Eagle Lakes. But particular attention is directed to the Shoal Lake-Lake of the Woods area - that part of the region rich in felsic volcanic rock extending from the interprovincial boundary at Shoal Lake on the west to Bigstone Bay and Andrew Bay in Lake of the

Woods on the east. Additional nickel and iron occurrences are likely to be associated respectively with mafic igneous rocks in central-eastern parts and sedimentary rocks in eastern and northeastern parts of the region.

A serious hindrance to conventional exploration techniques in this region is that much of the indicated favourable host rock lies under lake water. It is a fact that the larger lakes in the region, such as Shoal and Lake of the Woods in particular and also Kakagi and Upper Manitou Lakes, cover the largest masses of felsic volcanic rocks and immediately subjacent mafic volcanic rocks. This obstacle may be alleviated though not completely overcome by resort to indirect methods of geophysical and geochemical prospecting.

In conclusion, although other parts of the region should not be overlooked, the best chances for uncovering new deposits are indicated to lie in the favourable zones delineated above. Particular attention in this connection is drawn to the Shoal Lake-Lake of the Woods part of the region in the search for gold-silver and copper occurrences.

SUMMARY AND CONCLUSIONS

1. This region is of particular interest in containing the original Keewatin assemblage as defined by A.C. Lawson in 1885. It is underlain by approximately equal parts granitic rocks and supracrustal rocks the latter belonging to the Keewatin Group.

2. The Keewatin Group is of diverse composition including a wide variety of volcanic and sedimentary rocks. Lithic parts are arranged in stratigraphic sequences, as follows in ascending order: mafic volcanics - felsic volcanics - sediments. Two such superimposed sequences are present in the western part but only one sequence together with thick overlying sediments to the east. Total stratigraphic thicknesses range from 21,800 to 28,500 feet and average 23,000 feet.

3. The structure is complex, the regional fabric reflecting superposition of dome patterns upon pre-existing east- to northeast-trending linear fold patterns. The domes are now occupied by granite masses and intervening troughs by

Keewatin supracrustal rocks. Several persistent schist zones may include some faulting.

4. Keewatin volcanic rocks classify readily on the basis of chemical composition in the basalt-andesite-dacite-rhyodacite-rhyolite series. The weighted abundances of volcanic rocks in the region are as follows, in percent: basalt - 55.7, andesite - 26.4, dacite - 11.5, rhyodacite - 1.8, rhyolite - 4.6. However Keewatin volcanic rocks are comparatively low in K_2O, Sr and, in the case of rhyolite, Pb and high in CO_2, H_2O and $FeO:Fe_2O_3$ ratio.

5. The weighted average chemical compositions of individual volcanic sections and sequences by areas vary according to proportions of mafic and felsic components. The highest felsic proportions are in northern parts of the region particularly Lake of the Woods area. This is taken to indicate proximity to felsic eruptive vents.

6. Mineralization is varied and widespread. At least 212 mineral occurrences are known including gold-silver (153), copper (17), nickel-copper (9), iron (4), talc (5), molybdenum (5), antimony (3), zinc-lead (4), pyrite (4), fluorite (2), lithium (1) and beryllium (1). The production record of the region comprising gold, silver and copper has come from 37 properties. Ninety percent of this production is accounted for by 9 producers of which 6 are in the western part, 2 in the central part and one in the eastern part.

7. Significant gold-silver and copper mineralization, as known, is stratigraphically related to Lower Keewatin felsic volcanic rocks, to subjacent Lower Keewatin mafic volcanic rocks and to the margins of nearby, presumably coeval granitic stocks. Significant nickel-copper mineralization and iron mineralization in the form of banded iron formation are associated respectively with mafic igneous intrusions in stratigraphically lower and clastic sediments in stratigraphically higher Keewatin zones.

8. The above analysis of metallogenic relationships with accompanying geochemical data serves to draw attention to specific parts of the Keewatin stratigraphic succession. Within this context the favourable stratigraphic zone for gold-silver and copper mineralization is comparatively well-developed in the western or Shoal Lake-Lake of the Woods area.

9. Further assessment of available chemical and stratigraphic data may reveal additional relationships of economic significance. In this regard comparative studies of other Archean volcanic assemblages and continuous critical review are required to fully exploit a growing mass of volcanic-stratigraphic data.

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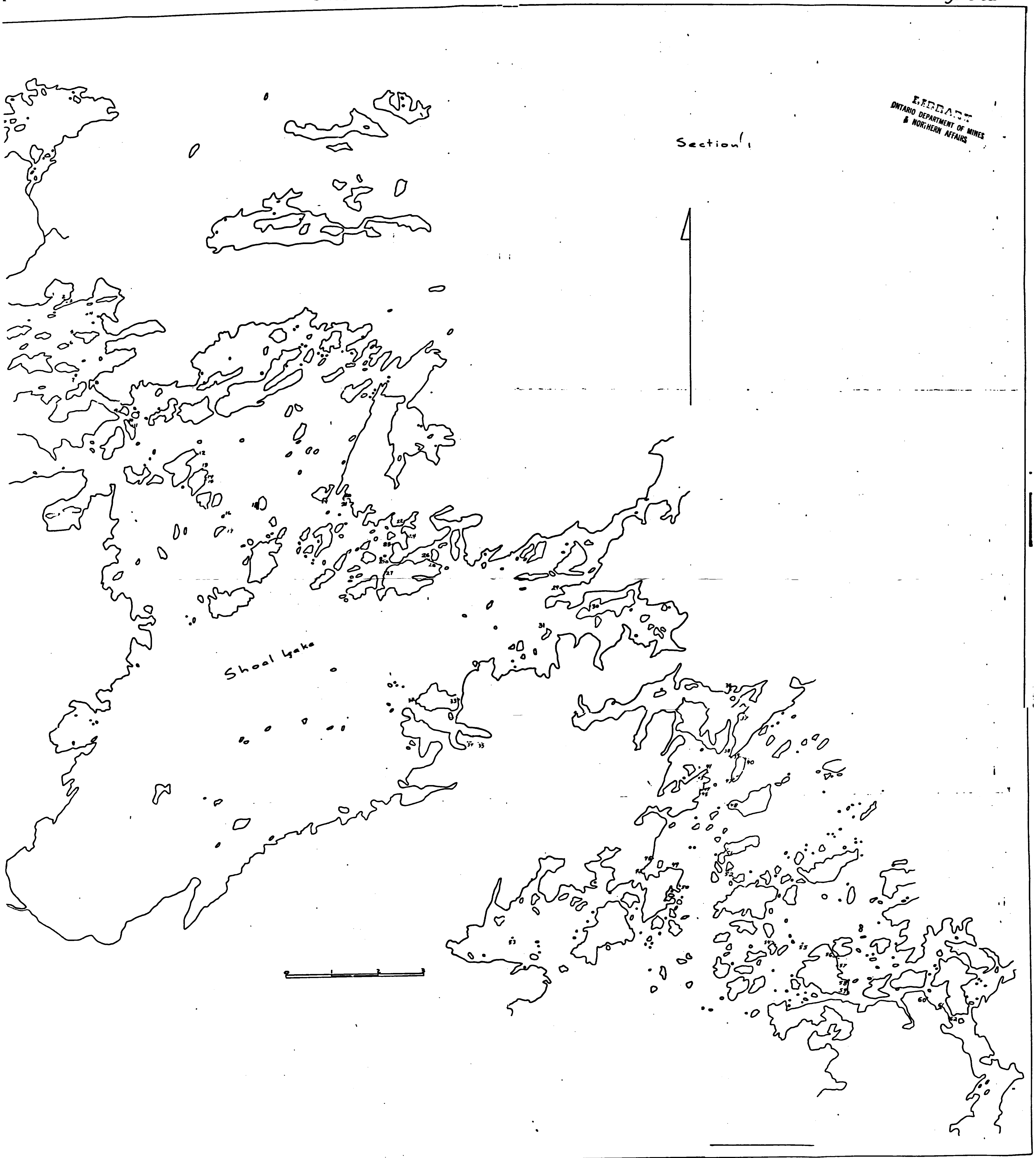
Shoal Lake

5742

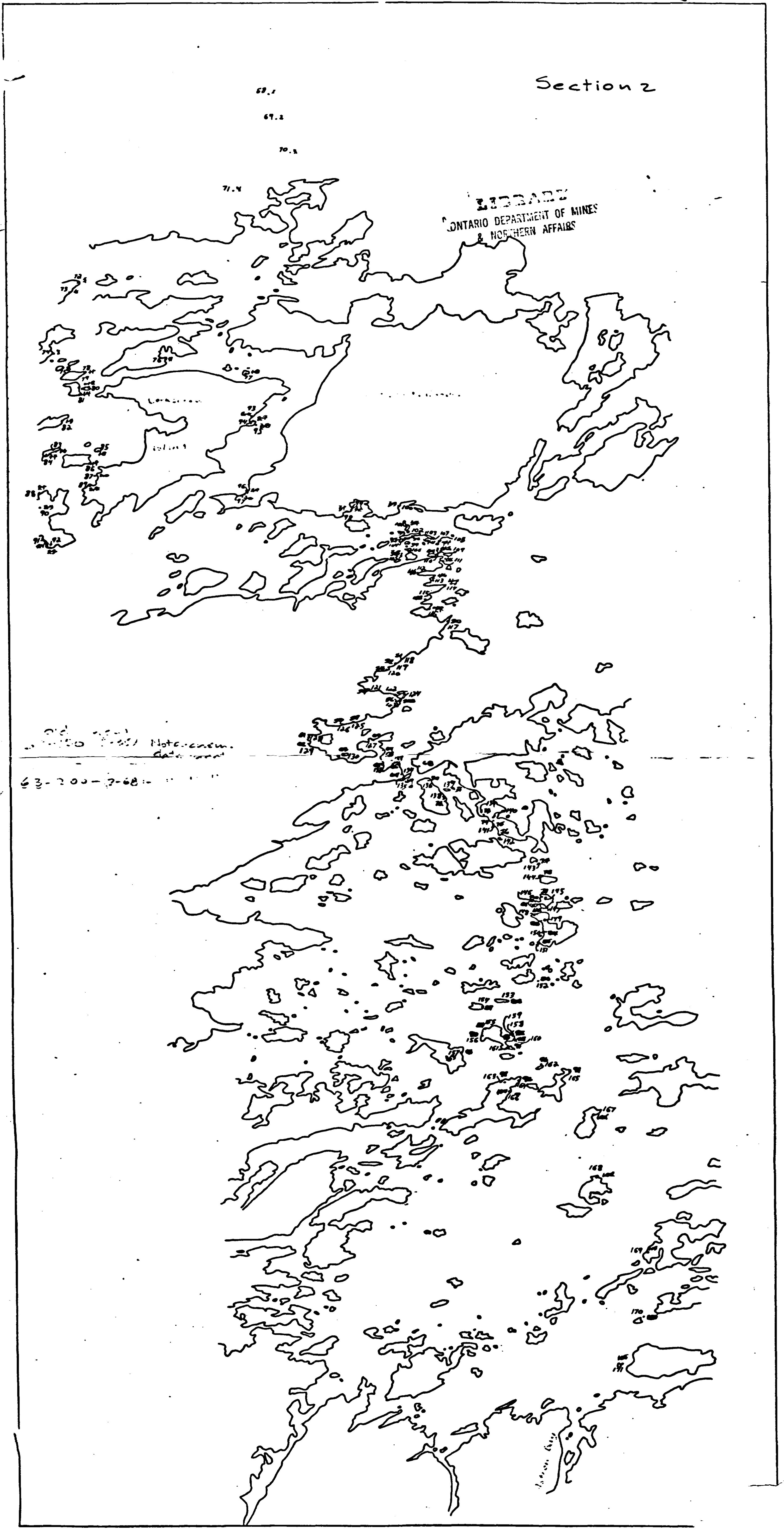
Figure 3a



Nos 1-62

Lake of the Woods - North Central

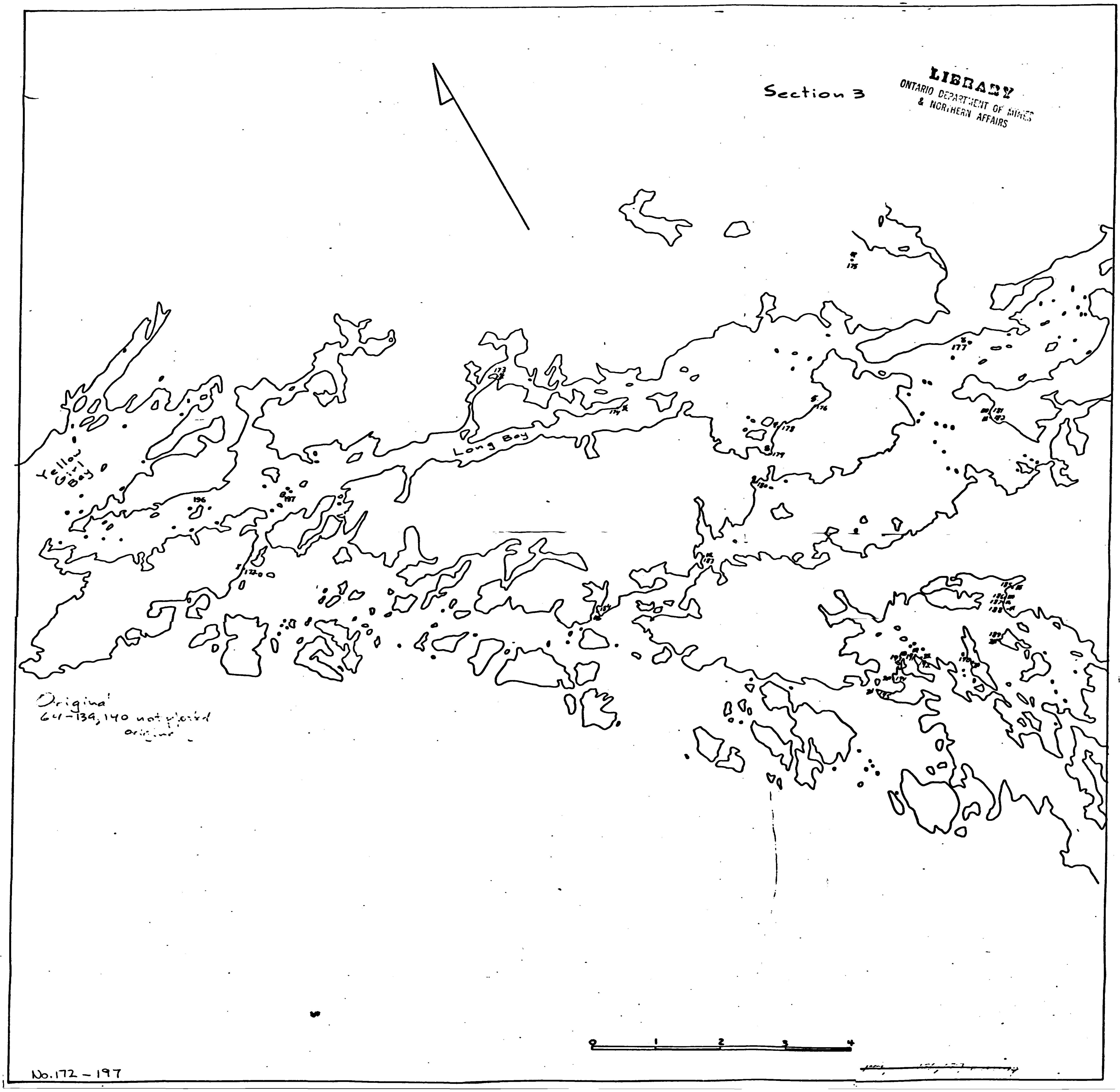
Figure 33.



No 68 - 171

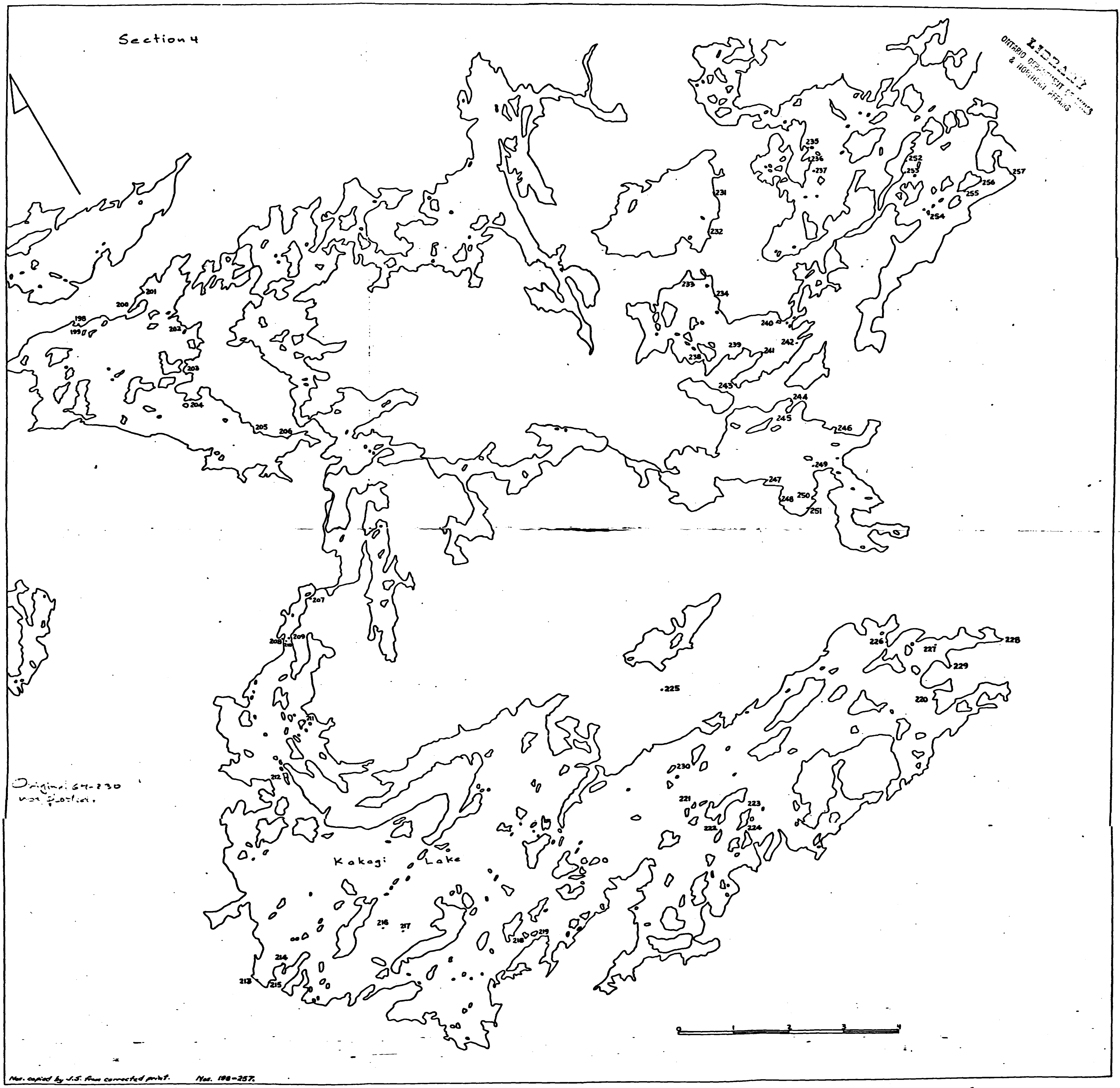
Sioux Narrows

Figure 3c.



Kakagi Lake

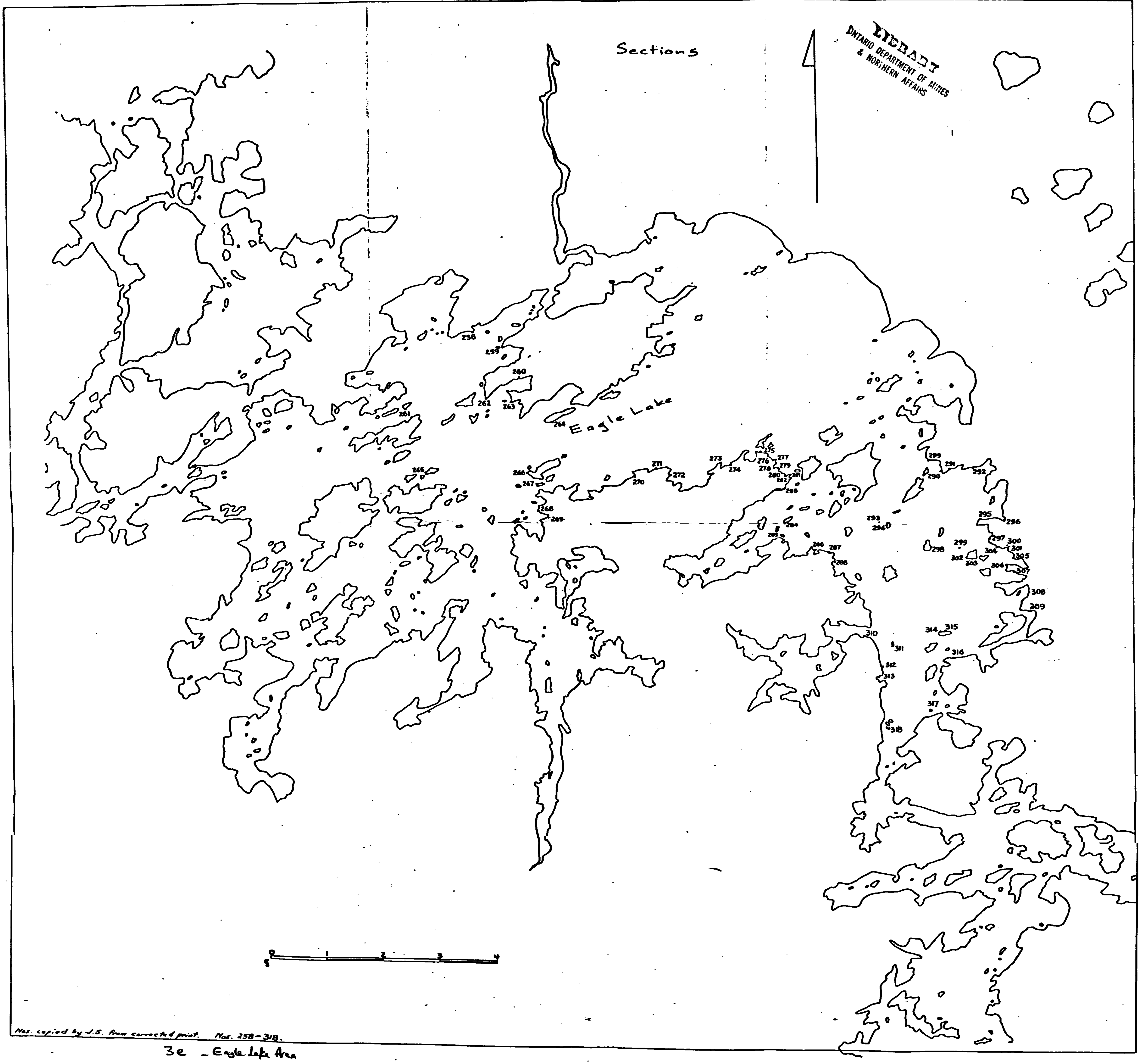
Figure 3d.



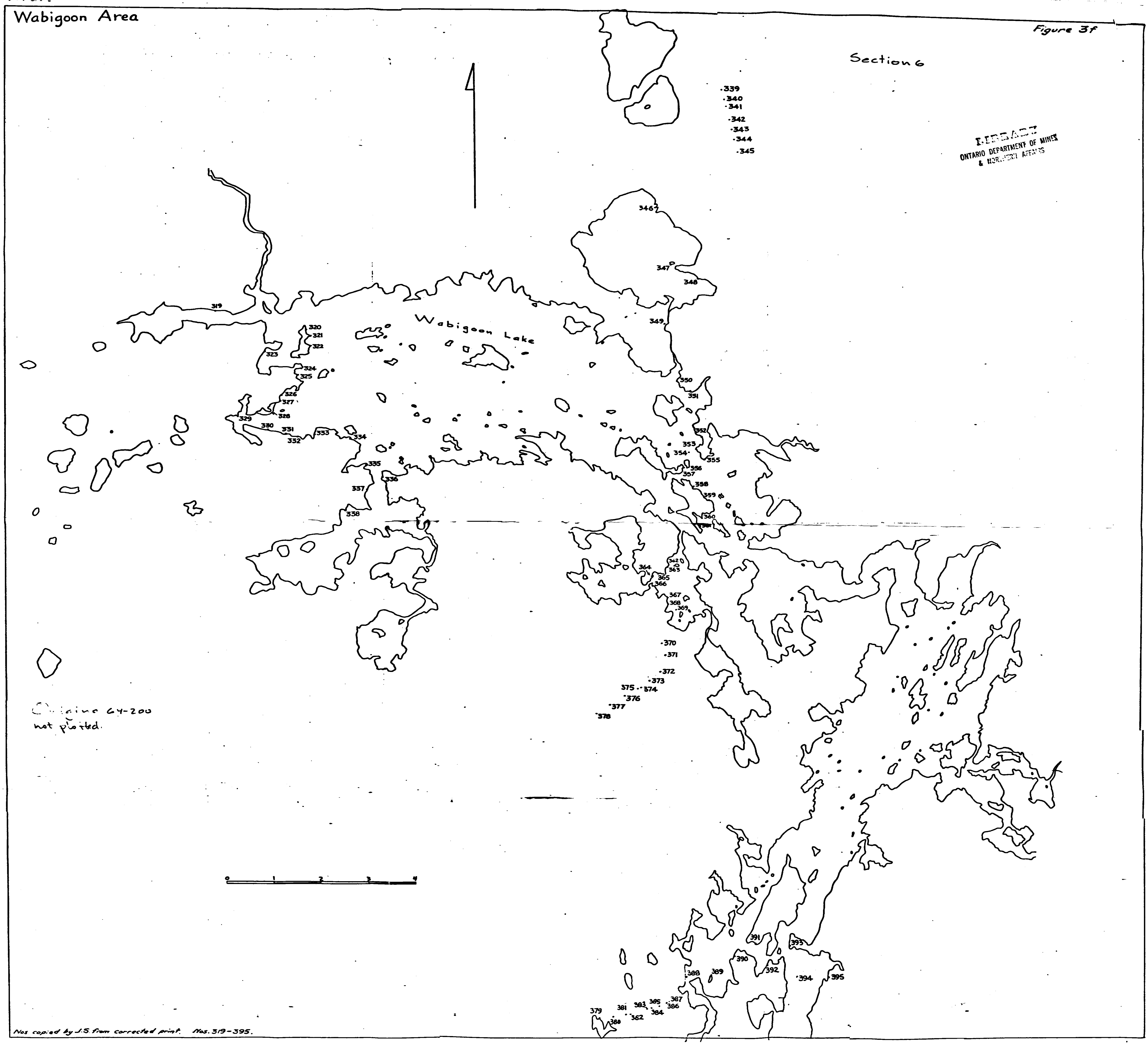
3D - Kakagi. L. Area

Eagle Lake

Figure 3e.



3e _ Eagle Lake Area


Wabigoon Area
Figure 3f
Section 6
Wabigoon Lake
ONTARIO DEPARTMENT OF MINES
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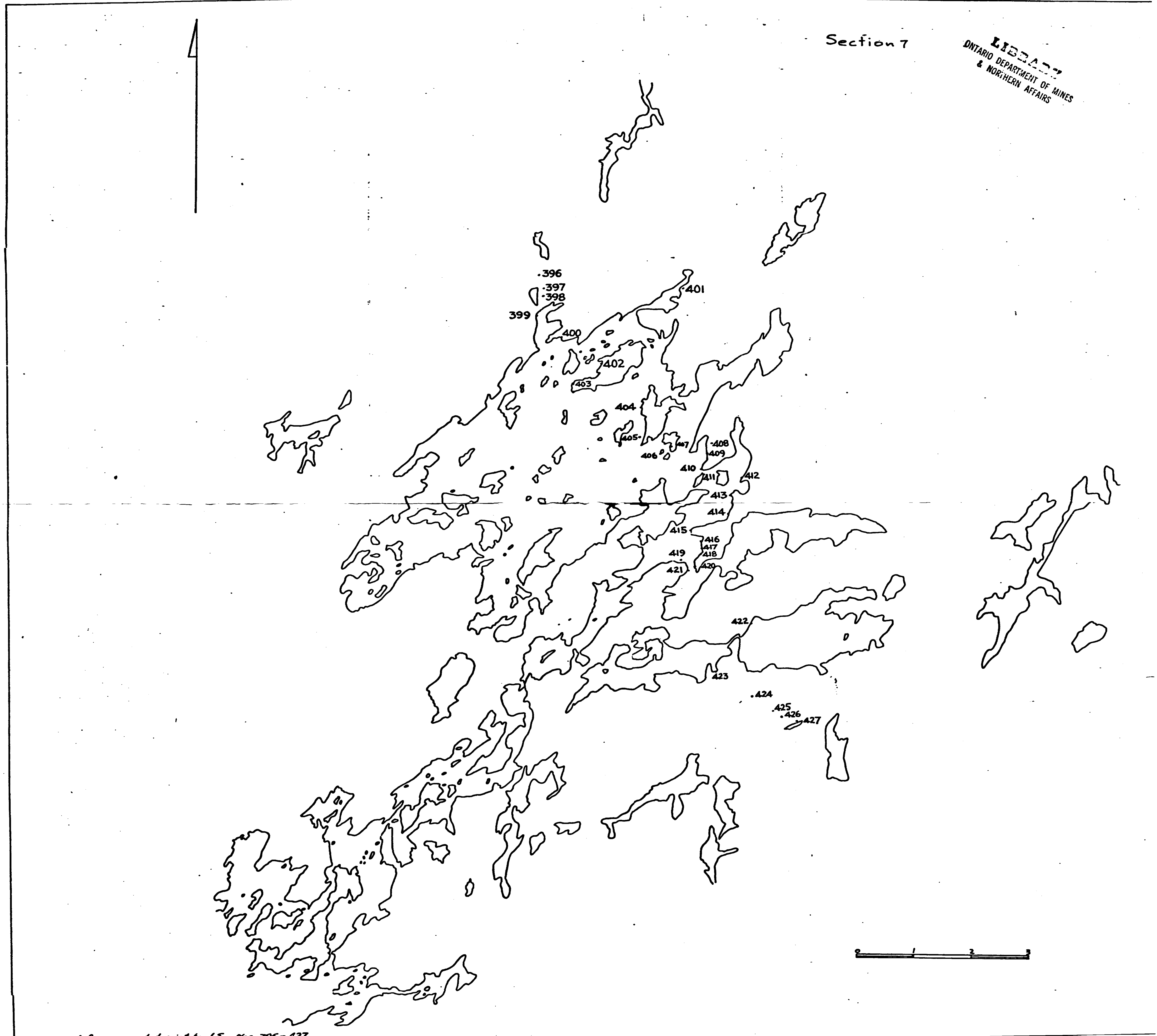
not plotted.
Nos copied by J.S. from corrected print. Nos. 319-395.

Upper Manitou Lake

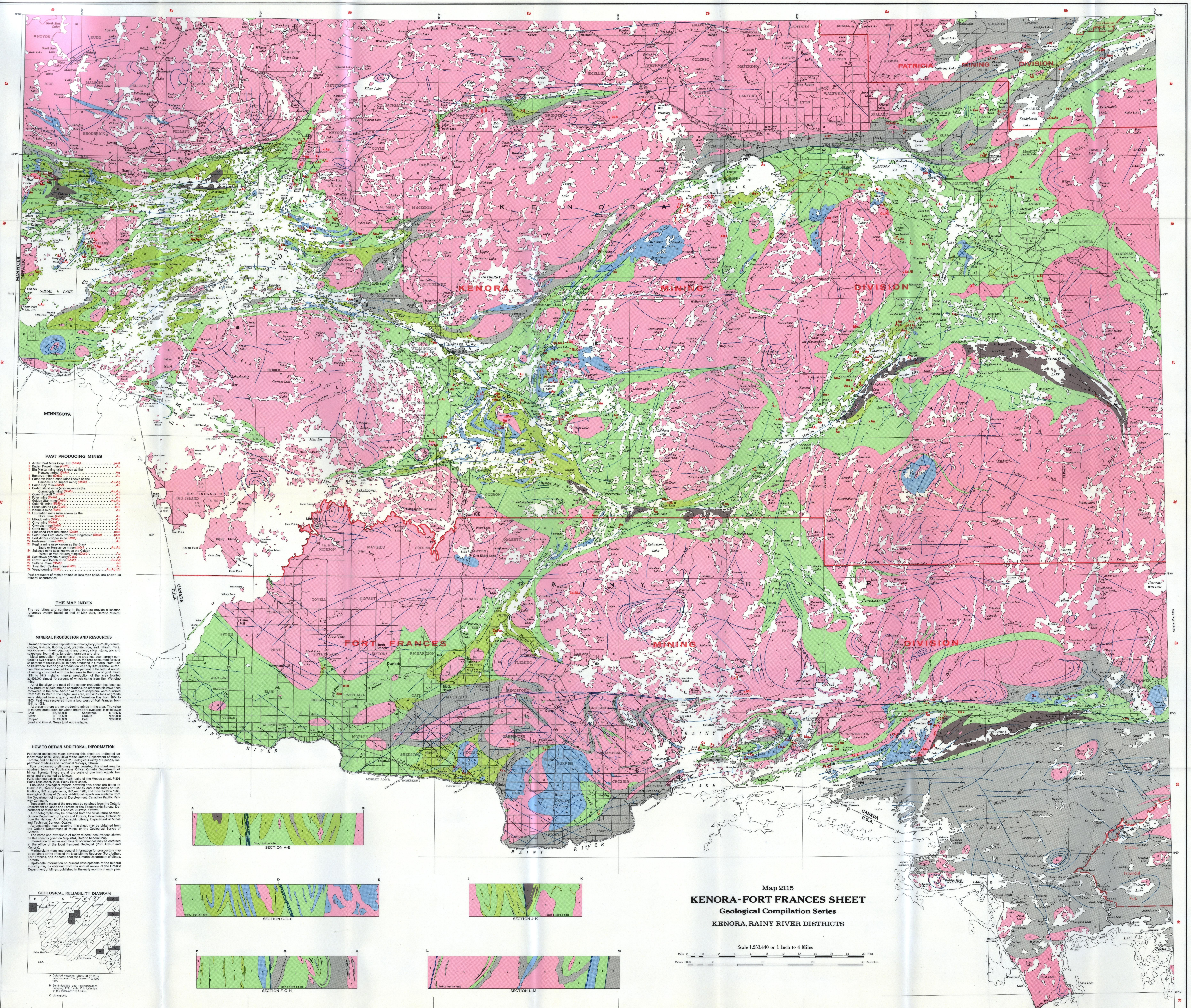
Figure 3g.

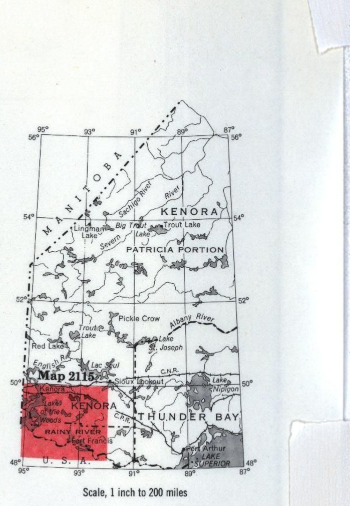


Nos. copied from corrected print by J.S. Nos. 396-427.

ONTARIO
DEPARTMENT OF MINES
HON. G. C. WARDROPE, Minister of Mines
D. P. Douglass, Deputy Minister   J. E. Thomson, Director, Geological Branch

Map 2115
Kenora-Fort Frances Sheet
Geological Compilation Series





Scale, 1 inch to 200 miles

N.T.S. reference 52C, 52D, 52E, 52F

LEGEND

CENOZOIC

PLEISTOCENE AND RECENT
Sand, gravel, clay.

UNCONFORMITY

PRECAMBRIAN
PROTEROZOIC
KEWEENAWAN

7 *Diabase.*

INTRUSIVE CONTACT

ARCHEAN

ACID IGNEOUS AND METAMORPHIC ROCKS [a]

6 *Undifferentiated.*
6a *Granite (gneiss), porphyritic granite (gneiss), quartz and feldspar porphyries, syenite, aplite, pegmatite.*
6b *Strongly foliated gneiss, migmatite, including areas containing abundant inclusions of metavolcanics or metasediments or both.*
6c *Monzonite, syenite.*

INTRUSIVE CONTACT

BASIC AND ULTRABASIC IGNEOUS ROCKS

5 *Undifferentiated.*
5a *Gabbro, norite, diorite.*
5b *Peridotite, pyroxenite.*
5c *Anorthositic gabbro.*
5d *Highly altered gabbro (amphibolite).* [b]

INTRUSIVE CONTACT

METASEDIMENTS [c]

4 *Undifferentiated.*
4a *Conglomerate, arkose, greywacke, slate, etc.*
4b *Intermixed metavolcanics and metasediments.*

Iron formation.

METASEDIMENTS [d]

3 *Greywacke, slate, arkose, mica schists and gneisses.*

Iron formation.

METAVOLCANICS [e]

2 *Undifferentiated.*
2a *Rhyolitic and dacitic tuff, agglomerate and flows.*
2b *Dacitic agglomerate with dark matrix.*
2c *Acid tuff and sedimentary rocks.*

1 *Undifferentiated.*
1a *Basaltic and andesitic massive lava, pillow lava, tuff, agglomerate, hornblende and chlorite schist.*
1b *Metavolcanics with interbedded metasediments.*
1c *Border phase of metavolcanics injected by granitic rocks.*

Iron formation.

S *Sulphide mineralization*

a *Some granitic rocks are pre-Metasediments* [c] *in age.*
b *Highly altered gabbro is probably of the same age as the basic volcanic rocks (1).*
c *Formerly classified as Timiskaming, Manitou and Seine.*
d *Formerly classified as Keewatin, Couchiching.*
e *Formerly classified as Keewatin.*

The letter "G" preceding a rock unit number, for example "G6a", indicates interpretation from geophysical data or air photographs in large drift-covered or unmapped areas.

SYMBOLS

Geological boundary.
Synclinal axis.
...
Surveyed line.
Line of section.

MINERAL OCCURRENCES

REFERENCE

Ag...... *Silver*	Ni...... *Nickel*
Au...... *Gold*	Pb...... *Lead*
be...... *Beryl*	peat..... *Peat*
Bi....... *Bismuth*	py...... *Pyrite*
Cs...... *Cesium*	Sb...... *Antimony*
Cu...... *Copper*	st....... *Stone, granite*
Fe...... *Iron*	talc..... *Talc, soapstone*
fel...... *Feldspar*	Ti...... *Titanium*
fl....... *Fluorite*	tour.... *Tourmaline*
gf....... *Graphite*	U....... *Uranium*
Li....... *Lithium*	W...... *Tungsten*
mi...... *Mica*	Zn...... *Zinc*
Mo..... *Molybdenum*	

MAP COMPILATION SOURCES

Geological compilation by J. C. Davies, Resident Geologist, Kenora and A. P. Pryslak, 1963-1965.

Geology from published and unpublished maps of the Ontario Department of Mines; Geological Survey of Canada; Department of Industrial Development, Canadian Pacific Railway Co.; and from unpublished maps of mining companies.

Cartography by F. W. Dawson, D. W. Robeson, Ontario Department of Mines 1965, 1966.

Base maps compiled from maps of the Forest Resources Inventory, Ontario Department of Lands and Forests, with additional information by the staff of the Ontario Department of Mines.

PAST PRODUCING MINES

[illegible]

THE MAP INDEX

[illegible]

MINERAL PRODUCTION AND RESOURCES

... from 1925 to 1927 in the Eagle Lake area, and 4,819 tons of granite were shipped from a quarry west of Vermilion Bay from 1954 to 1960. Peat was recovered from a bog west of Fort Frances from 1941 to 1952.

At present there are no producing mines in the area. The value of mineral production, for which figures are available, is as follows:

Gold	$5,305,000	Soapstone	$ 12,595
Silver	$ 11,500	Granite	$395,000
Copper	$ 197,000	Peat	$596,000

Sand and Gravel: Gross total not available.

HOW TO OBTAIN ADDITIONAL INFORMATION

Published geological maps covering this sheet are indicated on Index Maps (2082, 2083, 2084) of the Ontario Department of Mines, Toronto, and on Index Sheet 52, Geological Survey of Canada, Department of Mines and Technical Surveys, Ottawa.

Four uncoloured preliminary maps covering this sheet may be obtained from the Publications Office, Ontario Department of Mines, Toronto. These are at the scale of one inch equals two miles and are named as follows:
P.242 Manitou Lakes sheet, P.281 Lake of the Woods sheet, P.293 Rainy Lake sheet, P.309 Rainy River sheet.

Published geological reports covering this sheet are listed in Bulletin 25, Ontario Department of Mines, and in the Index of Publications, 1961, supplements, 1961 and 1963, and Indexes 1964, 1965, Geological Survey of Canada. Additional reports are available from the Department of Industrial Development, Canadian Pacific Railway Company.

Topographic maps of the area may be obtained from the Ontario Department of Lands and Forests or the Topographic Survey, Department of Mines and Technical Surveys, Ottawa.

Air photographs may be obtained from the Silviculture Section, Ontario Department of Lands and Forests, Downsview, Ontario or from the National Air Photographic Library, Department of Mines and Technical Surveys, Ottawa.

Aeromagnetic maps covering this sheet may be obtained from the Ontario Department of Mines or the Geological Survey of Canada.

The name and ownership of many mineral occurrences shown on this sheet is given on Map 2024, Ontario Mineral Map.

Information on mines and mineral occurrences may be obtained at the office of the local Resident Geologist (Port Arthur and Kenora).

Mining claim maps and general information for prospectors may be obtained at the office of the local Mining Recorder (Port Arthur, Fort Frances, and Kenora) or at the Ontario Department of Mines, Toronto.

Up-to-date information on current developments of the mineral industry may be obtained from the annual review of the Ontario Department of Mines, published in the early months of each year.

GEOLOGICAL RELIABILITY DIAGRAM

SECTION A-B

SECTION C-D-E

SECTION J-K

SECTION F-G-H

SECTION L-M

Map 2115
KENORA-FORT FRANCES SHEET
Geological Compilation Series
KENORA, RAINY RIVER DISTRICTS

Scale 1:253,440 or 1 Inch to 4 Miles

Published 1967