

THE UNIVERSITY OF MANITOBA

MINERALIZATION IN THE CANOE LAKE
STOCK, LAKE OF THE WOODS - SHOAL
LAKE AREA, NORTHWESTERN ONTARIO

by

SUSAN WENDY CAMPBELL

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ABSTRACT

The Canoe Lake stock illustrates distinct petrological, structural, and mineralization features for an Archean intrusion. Some of the results from this study differ from previously and concurrently investigated plutons in the Lake of the Woods area.

The quartz diorite composition, multiple phase magmatic hydrothermal alteration, abundant felsic porphyry intrusive dikes, combined pre-hydrothermal curvilinear fractures and superimposed post-hydrothermal multi-directional, straight to curved fractures, disseminated and hydrothermal vein sulphides, and minor peripheral gold mineralization characterize the Canoe Lake stock.

This granitic mass is interpreted as a shallow, syntectonic pluton. The high degree of fracturing and copper-molybdenum-zinc mineralization indicate epizonal intrusion. The marginal cataclastic foliation and absence of a penetrative regional foliation in the stock suggest syntectonic emplacement with the central portions of the body remaining mobile throughout the major period of deformation.

Porphyry type copper mineralization pervades the Canoe Lake stock. A complex zonal alteration pattern is centered near Squaw Lake and includes potassic, phyllic, and propylitic halos. The sulphides are also zoned outward from chalcopyrite and molybdenite to pyrite and chalcopyrite, and

finally to pyrite and sphalerite.

The processes of crystallization, fracturing, hydrothermal alteration, and mineralization are interpreted to overlap in time. Any ore grade mineralization which may have been formed has possibly been removed by an extreme depth of erosion.

GENERAL DISCUSSION

INTRODUCTION

Statement of Problem

Porphyry type copper and molybdenum mineralization in the Canoe Lake stock was investigated. Petrological, chemical, and structural features of the pluton are of significance in describing this mineralization.

Area of Study

The Canoe Lake stock is an oval-shaped intrusion extending about 6 miles northeast-southwest and just over 3 miles northwest-southeast. It comprises an area of 19 square miles.

The stock is located on the large peninsula separating Shoal Lake from Lake of the Woods and Labyrinth Bay. The centre of the intrusion is approximately 8 miles south of the Trans-Canada Highway and 21 miles directly southwest of Kenora, Ontario (see Figure 1).

The physiography encompasses typically rugged Precambrian Shield terrain with hills and ridges interrupted by low-lying swamps and glacial drift deposits. Variation in relief across the exposed extent of the stock averages 100

Figure 1. Index map showing the location of the Canoe Lake stock. (Refer to the dashed outline within the square).

feet. The maximum relief in the Canoe Lake - Love Lake area is 200 feet.

Access

The Canoe Lake stock is accessible by water and is exposed along a portion of the shores of Echo Bay, Bag Bay, Helldiver Bay, Canoe Lake, and Squaw Lake. These bodies of water can be reached from the town of Clearwater Bay, situated on the Trans-Canada Highway, approximately 8 miles northeast of the centre of the stock. Boat launchings, boat rentals, and a marina are available at Clearwater Bay. A public boat launching is also available at Clytie Bay, located near the western extremity of the Canoe Lake stock.

Inland parts of the intrusion are accessible by numerous overgrown logging trails. Most of these trails originate near Gold Point Camp, situated on Shoal Lake. Boat rentals are available at this camp.

Scope and Significance of the Study

A detailed examination of the Canoe Lake stock was carried out during June and July, 1972.

Field work was conducted by pace and compass traversing and five days of shoreline mapping. Three hundred and twenty-seven outcrops were studied and stations averaged

1000 feet apart. A representative quartz diorite sample was taken from most of these stations.

Laboratory work included 150 thin section modal analyses, 30 chemical analyses (whole rock and trace elements), 35 specific gravity readings, 37 magnetic susceptibility determinations, and 12 sulphur isotope results. The chemical analysis data were processed with a Niggli norm program.

The significance of this study may be summarized by the following three statements.

1. The Canoe Lake stock is essentially unique compared to most granitic plutons in the Falcon Lake - Lake of the Woods region. It contains a porphyry copper and molybdenum deposit in the Squaw Lake area and similar but much lower grade mineralization throughout the rest of the intrusion. Extreme hydrothermal alteration and intense fracturing are associated with this mineralization. Gold occurrences are present in the Bag Bay area of the stock.

2. Numerous plutons in the Falcon Lake - Shoal Lake area have been previously studied by Vagt (1968). They include the Winnetka Lake stock, Granite Lake porphyry, High Lake porphyritic granodiorite and grey granodiorite, Snowshoe Bay granodiorite, and the Indian Reserve granodiorite. Therefore this study adds to a larger scale investigation of granitic plutons within this portion of the Kenoran block (Wilson et al., 1972).

3. The study of the Canoe Lake quartz diorite precedes a detailed examination of the nearby Aulneau pluton by the Centre for Precambrian Studies at the University of Manitoba. Thus, results of this investigation will be available for comparison with data retrieved from the Aulneau Dome.

Previous Geologic Work

The Canoe Lake stock lies within a larger area of Lake of the Woods, geologically mapped by Lawson (1885) of the Geological Survey of Canada.

The Ontario Department of Mines has been involved in a number of geologic studies in the Shoal Lake - Lake of the Woods area from 1910 to the present. Parsons (1911) investigated the gold fields in Lake of the Woods, Manitou, and Dryden. Greer (1931) mapped the geology of the Shoal Lake (West) region and Thomson (1936, 1937) studied the gold deposits in Shoal Lake. Brief mention of granitic plutons was made by Goodwin (1970) in his study of Archean meta-volcanics in the Lake of the Woods - Manitou Lake - Wabigoon region of western Ontario. Davies (1969, 1970) geologically mapped the North Shoal Lake area (East Sheet) and the Western Peninsula area (West Sheet), respectively. His two preliminary maps contain most of the exposed extent of the Canoe Lake stock.

The Canoe Lake quartz diorite has not been studied

in detail.

in detail prior to the present research.

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GEOLOGY OF THE MINERALIZED STOCK

Regional Geologic Setting

The study area lies within the Kenoran block

(Wilson et al., 1972) of the Precambrian Superior Province of northwestern Ontario. This block is composed of belts of intricately interlayered metavolcanic and metasedimentary rock sequences. Scattered mafic and ultramafic rocks and numerous granitic plutons have intruded the greenstone sequences (Wilson et al., 1972).

The metavolcanic rocks include mafic, intermediate, and felsic flows and pyroclastics; the metasedimentary rock units are siltstones and shales, sandstones, and conglomerates. The mafic and ultramafic intrusions range from diorite to peridotite. Most of the granitic plutons have a calc-alkaline composition.

The metavolcanic-metasedimentary belts have been completely deformed into folds with east-west trending axial planes. Superimposed deformation resulted from later granitic intrusions. For the most part, metamorphism has progressed to the greenschist facies.

Wilson et al. (1972) mention that embryonic porphyry copper deposits exist at High Lake, Squaw Lake, and at a few other locations in northwestern Ontario.

Local Geology

The Canoe Lake stock is in contact with mafic metavolcanic rocks, including basalt and andesite, along the east, south, and southwest contacts. To a lesser extent, mafic

and ultramafic intrusive rocks are found along the border zone in the Bag Bay and south Squaw Lake areas. Metasedimentary rocks, mostly volcanic conglomerates, occur along the northwest contact near Canoe Lake. The north contact at Echo Bay places the stock against various felsic metavolcanic rocks. All layered rocks which are host to the intrusion have been metamorphosed up to the greenschist facies.

A distinct feature of the geology in the study area is the abundance of late felsic intrusive rocks, ranging in composition from quartz-feldspar porphyry to fine-grained granodiorite. These dikes and irregularly shaped intrusions occur near the contact areas and pervade the entire stock.

The sharp margins, minor offshoots from the quartz diorite, presence of distinct inclusions, and texture of the rock substantiate an igneous origin for the Canoe Lake granitic mass (Turner and Verhoogen, 1960).

THE CANOE LAKE STOCK - HOST TO PORPHYRY
TYPE COPPER-MOLYBDENUM-ZINC MINERALIZATION

PETROGRAPHY OF THE HOST INTRUSION

General Statement

The Canoe Lake stock is a massive, homogeneous, single phase quartz diorite intrusion. Its texture is medium-

grained, hypidiomorphic-granular, and ranges from equigranular to seriate porphyritic with large quartz eyes scattered through the rock. The quartz diorite ranges from light red and grey-red to grey and grey-green. Concentrations of quartz eyes and color differences are irregular across the intrusive body. The pre-alteration mineral composition was 45 to 70 percent plagioclase (andesine), 15 to 50 percent quartz, as much as 15 percent hornblende, and a maximum of 15 percent biotite. Minor accessory minerals include rutile, sphene, apatite, and traces of magnetite and ilmenite. Minor hematite is commonly present as stringers crosscutting grains or surrounding grain boundaries.

Closely associated in time are younger felsic intrusions. These quartz porphyry, feldspar porphyry, quartz-feldspar porphyry, and fine-grained granodiorite dikes and irregularly shaped intrusions dissect the stock and diminish in number as they extend into the adjacent rocks. The feldspar porphyry contains altered plagioclase (originally andesine), hornblende, and biotite phenocrysts in a quartzofeldspathic groundmass. Quartz, altered andesine, hornblende, and biotite are the main constituents in the quartz-feldspar porphyry dikes. The matrix of these porphyries is also quartzofeldspathic. Both the plagioclase and quartz phenocrysts in the younger felsic intrusions range from 0.5 to 3.0 mm. across and in some places the quartz grains reach about 5.0 mm..

Mineralogy - Modal Analyses

Procedure and Accuracy of Modal Analysis

One hundred and fifty thin sections from the Canoe Lake stock were point counted, using a Carl Zeiss Point Counter and Research Microscope. One slide was counted from a representative sample from each station and 1000 counts were performed. Thin sections were mounted on 27 mm. by 46 mm. petrographic slides and the section usually covered most of the slide. A grid was superimposed on the section such that counts were made every 0.33 mm. in lines parallel to the long dimension of the slide and every 1.0 mm. in lines parallel to the short dimension. The point counting procedure was continued until the original mineral count reached 1000. Alteration minerals were counted twice; once as the mineral they replaced, and once as the alteration product. The modal analysis results are given in Appendix I.

According to Solomon and Green (1966) the analytical error in point counting is twofold: the counting error involves areal measurements and the sampling error involves the specification of volumetric relationships. Hasofer (1963) derived an equation for the analytical error in point counting and from his equation Solomon and Green (1966) devised a chart for the number of counts versus the variance of the percentage estimate for an individual mineral. Table 1 shows

Table 1. Modal analysis analytical error for the major mineral constituents.

Mineral	Grain Radius (R) mm.	R/a Value	% Range	σ^2/p	Lowest Percentage		Highest Percentage	
					σ	σ^2	σ	σ^2
Plagioclase	1.0	1.82	45 - 70	0.65	5.41	29.25	6.75	45.50
	2.0	3.64		0.96	6.57	43.20	8.20	67.20
	3.0	5.45		0.99	6.67	44.55	8.32	69.30
Quartz	1.0	1.82	15 - 50	0.65	3.12	9.75	5.70	32.50
	2.0	3.64		0.96	3.79	14.40	6.93	48.00
	3.0	5.45		0.99	3.85	14.85	7.04	49.50
	4.0	7.27		1.00	3.87	15.00	7.07	50.00
	5.0	9.09		1.00	3.87	15.00	7.07	50.00
Hornblende	1.0	1.82	1 - 15	0.65	0.81	0.65	3.12	9.75
	2.0	3.64		0.96	0.98	0.96	3.79	14.40
Biotite	1.0	1.82	1 - 15	0.65	0.81	0.65	3.12	9.75
	2.0	3.64		0.96	0.98	0.96	3.79	14.40

a = 0.55 mm.

Number of counts = 1000

the analytical error for the four main primary minerals in the Canoe Lake stock.

Figure 2 illustrates the distribution of control points for the contoured modal percentage diagrams.

Plagioclase

Hypidiomorphic plagioclase grains are mainly 1.0 to 3.0 mm. across. Twinning is common with dominantly combined Albite and Carlsbad and to a lesser extent Pericline twinning. Both zoned and unzoned plagioclase is present in the stock and often the zoning is strained and shows geometric irregularities. The original plagioclase is inferred to be andesine, because of the associated mineral composition and the degree of alteration to which the quartz diorite has been subjected. The composition decreased in calcic content to oligoclase and albite as a result of various stages of hydrothermal alteration.

Modal analyses illustrate a range in volume percent of fresh and altered plagioclase from 45 to 70 percent. Figure 3 shows the contoured plot of modal percent plagioclase. A distinct linear trend is developed in the contour levels in a northeast direction, paralleling the length of the Canoe Lake stock. Two main bands of high plagioclase content (more than 60 percent) are discernible in the diagram; one band runs along the southern contact, while the other stretches from Bag Bay through the centre of the stock to Squaw Lake.

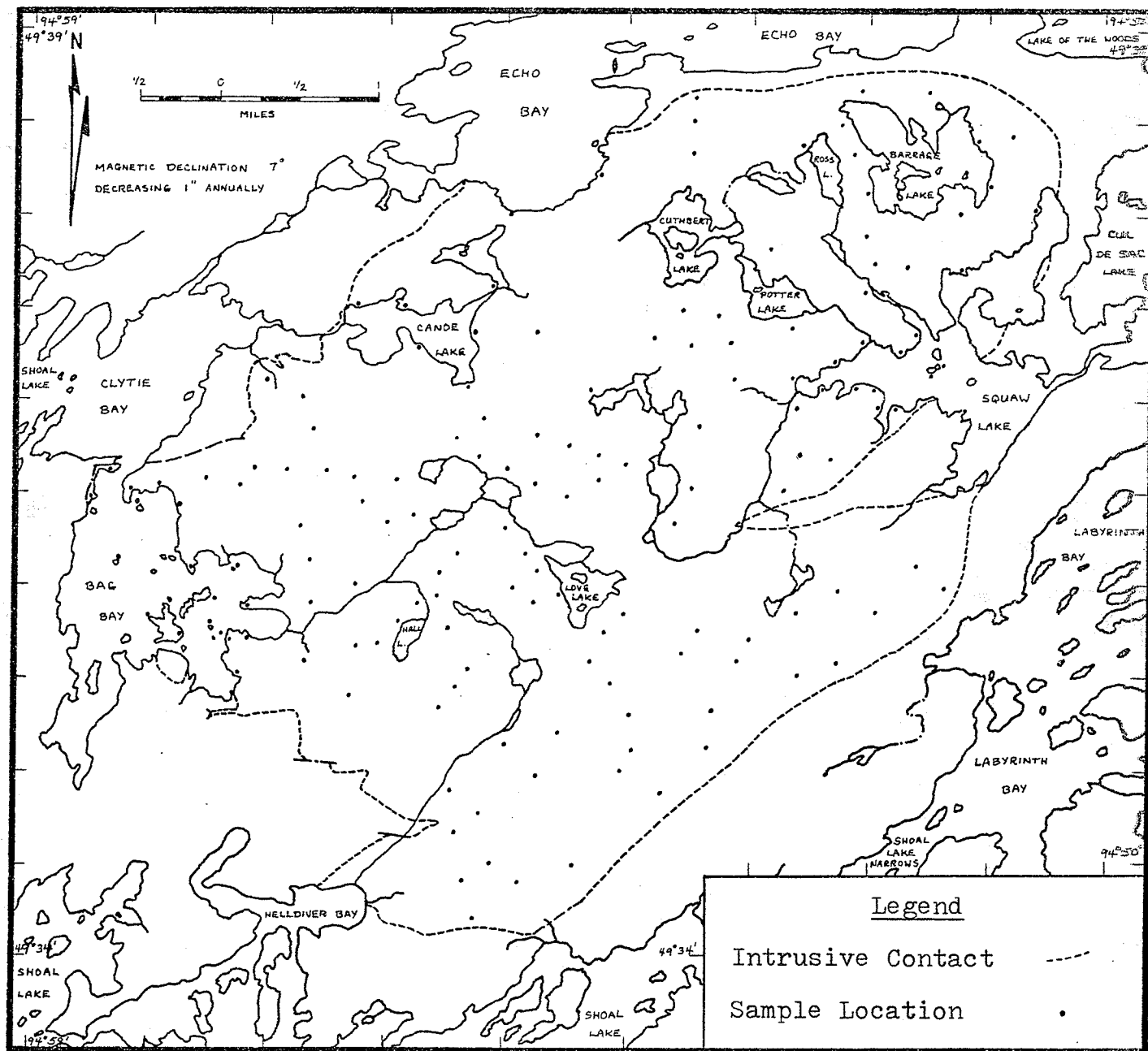


Figure 2. Distribution of the control points for the contoured modal analyses plots.

Another less distinct high percentage trend runs northeast through parts of Cuthbert, Ross, and Barrage Lakes.

Quartz

Allotriomorphic quartz ranges from small interstitial grains averaging 1.0 to 1.5 mm. to large rounded quartz eyes measuring 3.0 to 5.0 mm. across. These quartz eyes are aggregates of a number of quartz grains and show overgrowth effects. Strain extinction in quartz is commonly present, although the degree of strain varies. The quartz eyes yield a pseudo-porphyritic texture to the rock.

Figure 4 illustrates a contour plot of modal percent quartz. The volume percent ranges from 15 to 50 percent across the Canoe Lake stock. The northeast trend of the contour pattern is less distinct for quartz than it is for plagioclase, but an approximate correlation exists between low quartz and high plagioclase content. This is to be expected in a crystallizing magma, which is becoming increasingly enriched in silica during the course of solidification. The author attempted to show this relationship more clearly by plotting modal percent quartz versus percent plagioclase. This plot shows a distinct inverse relationship between quartz and plagioclase content; the scatter of points forms a wide band with negative slope on the graph (see Figure 5).

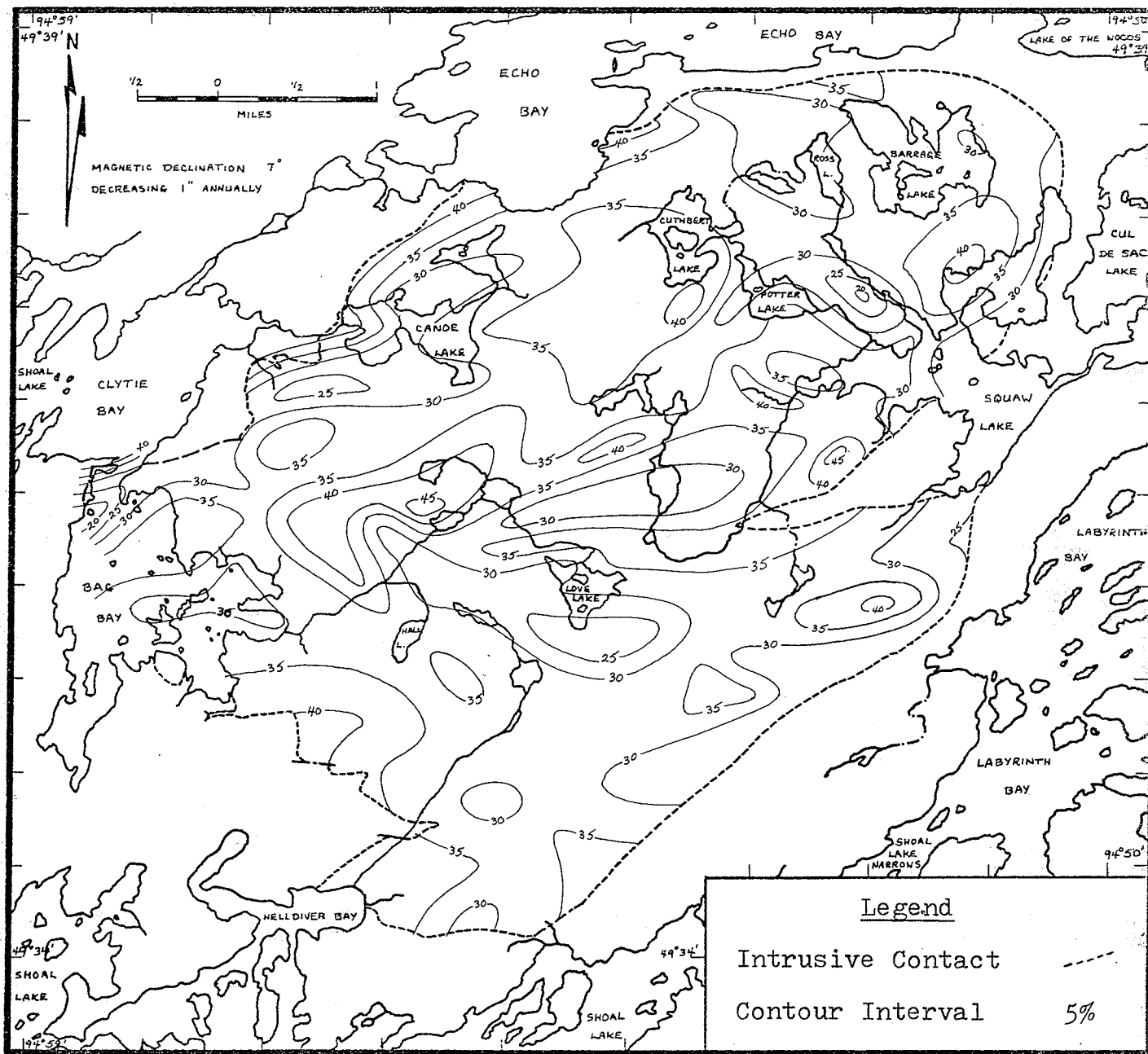


Figure 4. Contour plot of modal percent quartz.

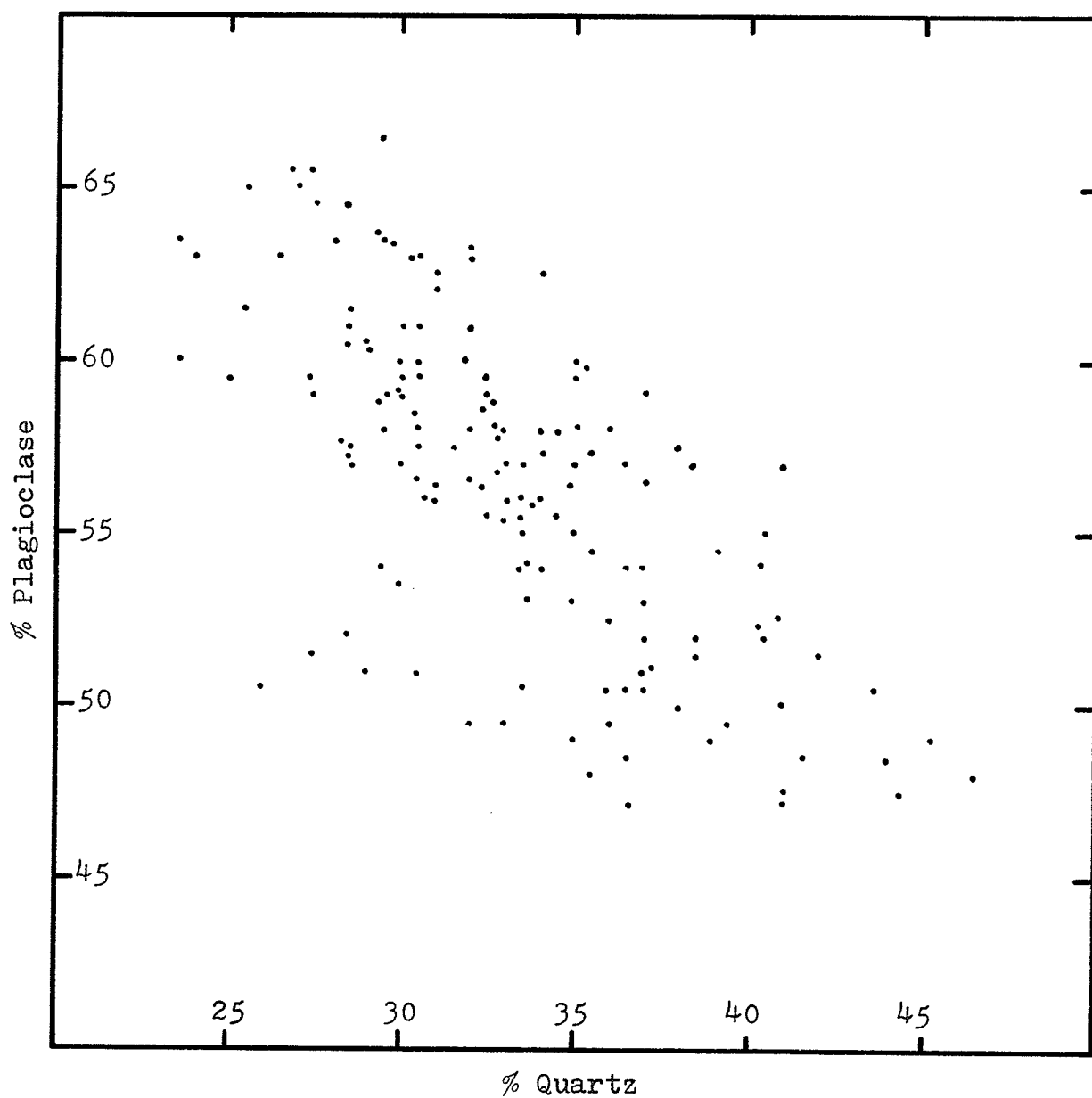


Figure 5. Graphical plot of modal percent quartz versus modal percent plagioclase. (150 points plotted)

Hornblende

Besides plagioclase and quartz the Canoe Lake quartz diorite was originally composed of as much as 15 percent green to green-brown hornblende. Chloritic pseudomorphs were identified as altered hornblende by the prismatic shape and six-sided basal sections. Where preserved, hornblende is hypidiomorphic and ranges from 1.0 to 2.0 mm. across. Primary hornblende was present in only two out of 150 counted thin sections.

Figure 6 is a contour plot of modal percent fresh and altered hornblende. Two contour highs (more than 10 percent) exist in the Bag Bay area and another in the Ross Lake area. It is interesting to note that the variation pattern for hornblende shows concentrations in the north and northwest portions of the stock, whereas high plagioclase content is mainly in the southeastern half of the intrusion.

Biotite

The other mafic mineral present in the Canoe Lake stock is biotite. Chloritic pseudomorphs and primary biotite appear as plates and irregular, elongated flakes measuring 1.0 to 2.0 mm. across. Primary biotite is mainly green-brown, varying to yellow-brown. Most of the biotite has been completely altered; it is preserved in only 29 of the 150

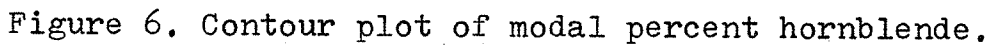


Figure 6. Contour plot of modal percent hornblende.

counted thin sections.

The quartz diorite intrusion has a fresh and altered biotite content of as much as 15 percent. Figure 7 is a contour plot of modal percent biotite showing an irregular variation pattern. The main trend of the contour values is northwest, although a faint northeast trend is also present, paralleling the contour patterns for plagioclase, quartz, and hornblende. Three areas of high biotite content (more than 10 percent) occur within the exposed portion of the intrusion; one high is centred near Ross Lake, and the other two are located in the Hall Lake - Love Lake region.

Accessories

Minor accessory minerals present in the Canoe Lake quartz diorite are sphene, sagenitic rutile in biotite and chlorite, apatite, zircon, and minor opaques (mainly magnetite with associated ilmenite and hematite). Microcline is another subordinate constituent of the quartz diorite intrusion, but its maximum concentration is less than 2 percent. This potassium feldspar is usually present in trace amounts in the thin sections.

Numerous sulphide minerals are also present in the Canoe Lake stock and they were included in the primary mineral count, although they represent products of a late magmatic hydrothermal stage. Pyrite is ubiquitous and the most abun-

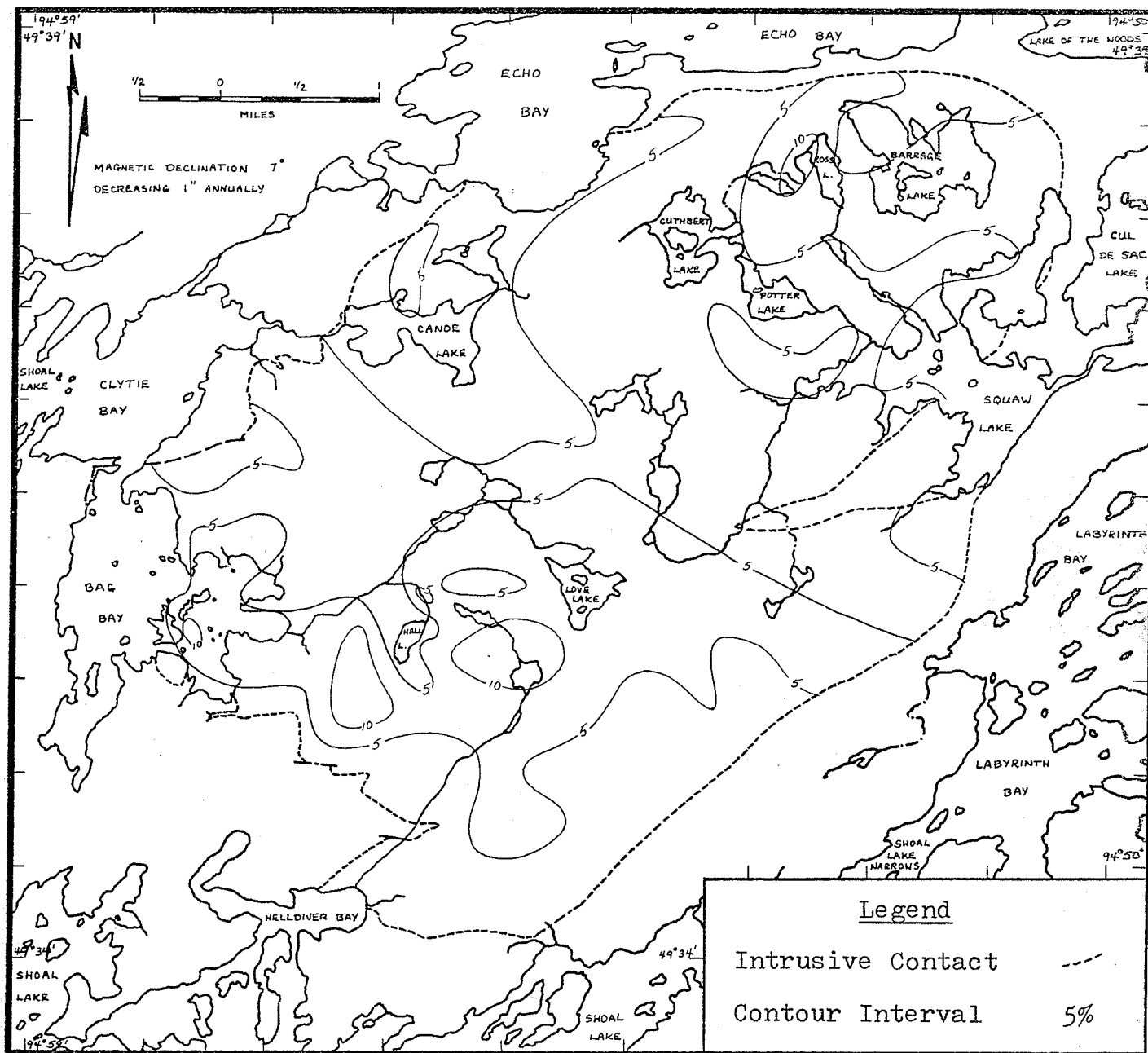


Figure 7. Contour plot of modal percent biotite.

dant sulphide in the quartz diorite. Chalcopyrite, molybdenite, pyrrhotite, and sphalerite are also contained within the stock.

Paragenesis of the Intrusion

Figures 8 and 9 illustrate triangular plots of quartz-plagioclase-microcline and quartz-plagioclase-total mafic minerals, respectively. Superimposing Bateman's (1961) compositional diagram on Figure 8 illustrates that the 150 modal analyses lie within a small part of the quartz diorite region. The plotted points depict a straight line crystallization trend moving from the plagioclase apex and terminating at nearly equal amounts of quartz and plagioclase. Figure 9 shows a much greater scatter of points when microcline is replaced by total mafic minerals. Although a distinct crystallization trend does not exist, the general crystallization path moves across the diagram away from the plagioclase apex and more toward the quartz apex than the total mafic minerals position.

These two figures and the previously mentioned contour diagrams suggest that crystallization was initiated in the peripheral and southeastern portions of the Canoe Lake stock as its present depth level. High concentrations of hornblende (more than 10 percent) in the north half of the intrusion indicate that the crystallization trend migrated rapidly

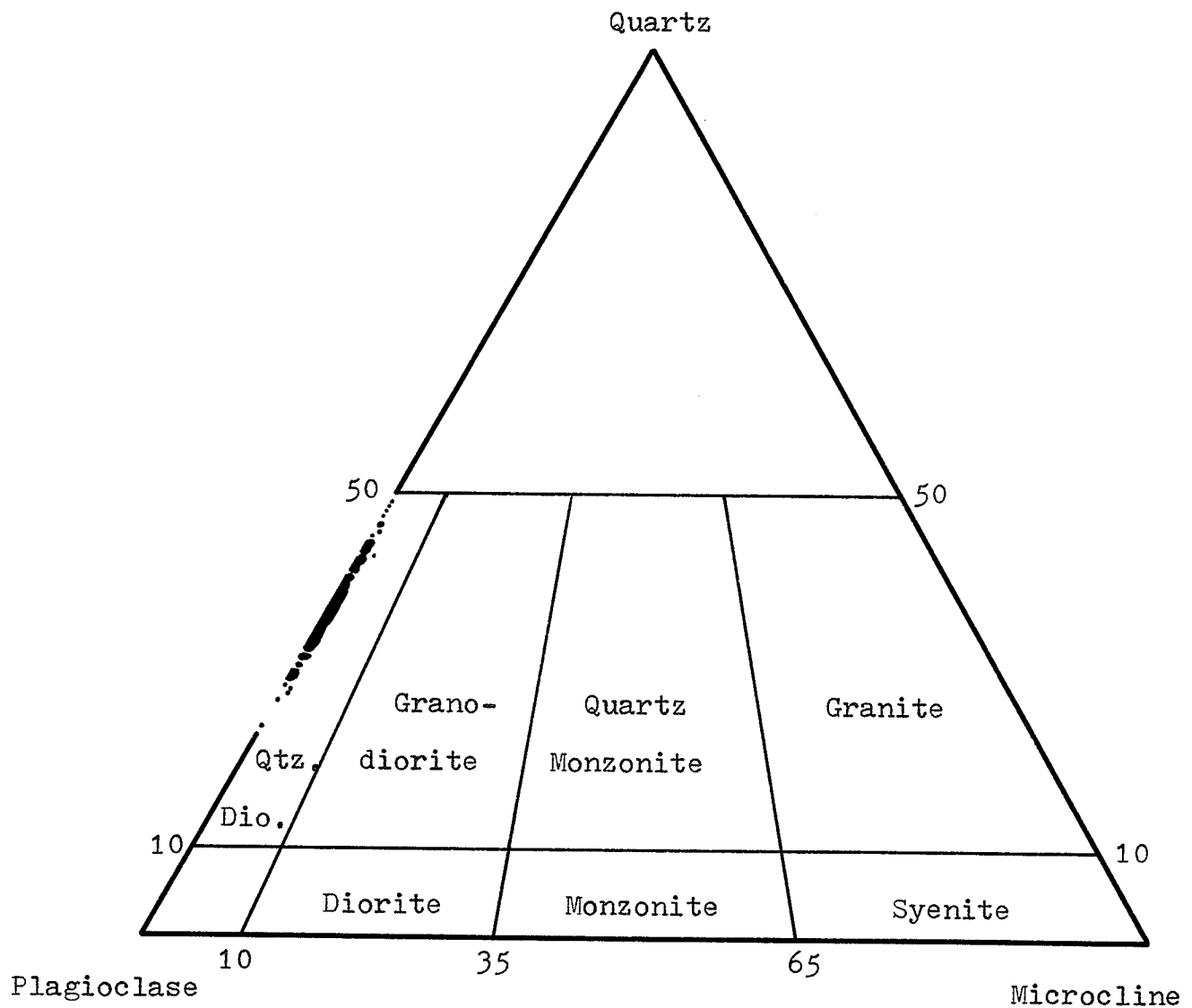


Figure 8. Quartz-plagioclase-microcline triangular diagram for the Canoe Lake stock, with Bateman's (1961) classification superimposed. (150 points plotted)

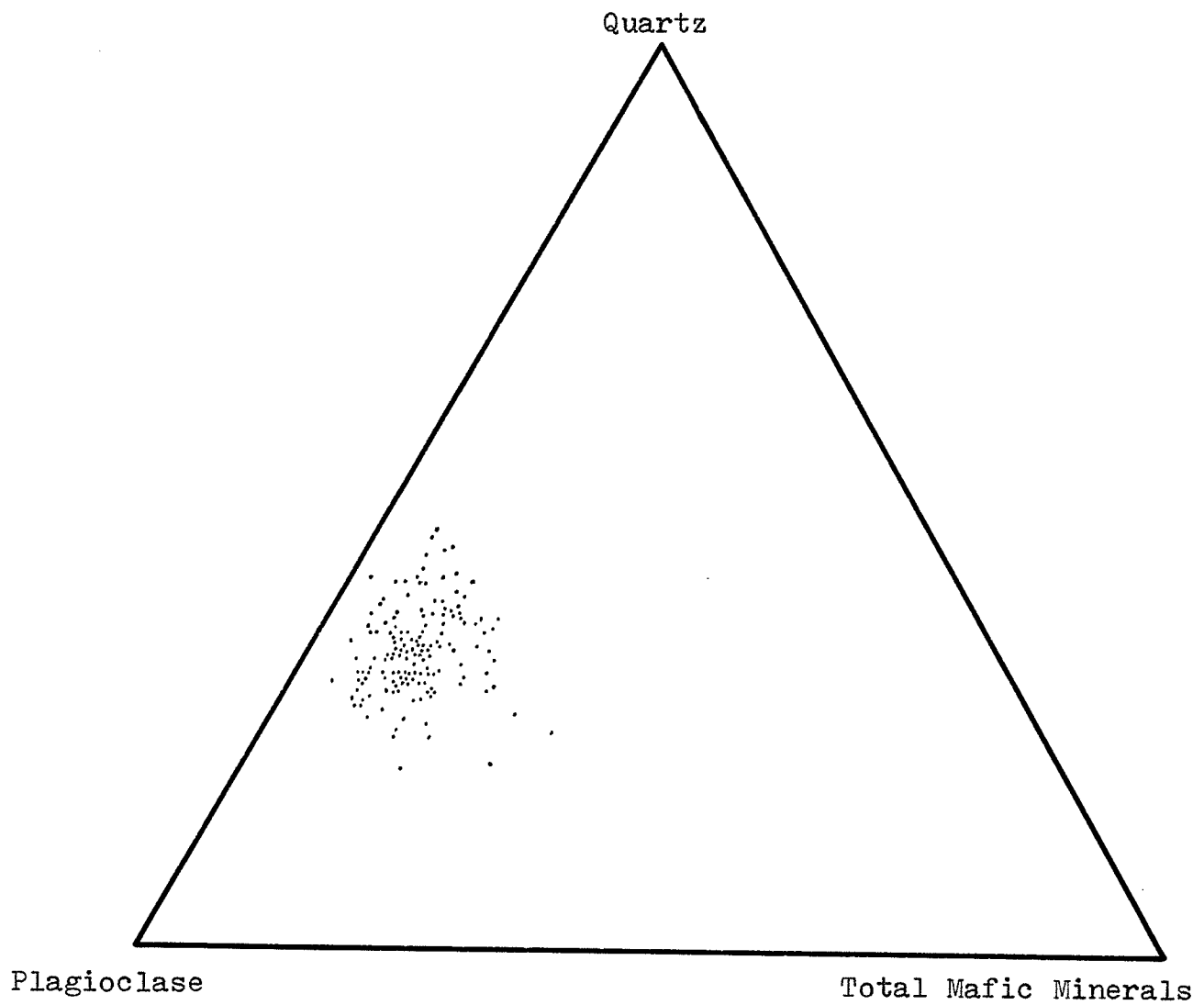


Figure 9. Quartz-plagioclase-total mafic minerals triangular diagram for the Canoe Lake stock. (150 points plotted)

toward this part of the stock after some initial separation of plagioclase. The following crystallization sequence is inferred for the Canoe Lake quartz diorite: plagioclase; plagioclase and successive hornblende; plagioclase, becoming more soda-rich, hornblende, and biotite; and quartz with contemporaneous crystallization of minor amounts of the other three minerals. The complexities of the four contour plots indicate a more intricate paragenesis than the simplified crystallization sequence described above.

ALTERATION OF THE HOST INTRUSION

General Statement

Definition of Hydrothermal

The word 'hydrothermal' has been used in a number of different contexts and in order to avoid obscurities the definition is stated below. The first sentence of the definition states the interpretation used in this study.

"Of or pertaining to heated water, to the action of heated water, or to the products of the action of heated water, such as a mineral deposit precipitated from a hot aqueous solution, with or without demonstrable association with igneous processes (also, said of the solution itself). 'Hydrothermal' is generally used for any heated water but has also been restricted to heated

water of magmatic origin."¹

Description of the Alteration

Hydrothermal alteration within the Canoe Lake stock is intense, complex, and has been progressive through a number of sequential stages. This succession of events is presumed to be closely related in time, such that the entire alteration process was essentially continuous and the various types of alteration in any one stage were simultaneous (Park and MacDiarmid, 1970).

It appears that the quartz diorite intrusion has been subjected to at least four overlapping stages of hydrothermal activity. The types of alteration, visible on a microscopic scale, are given in decreasing order of importance: sericitization, saussuritization, chloritization, carbonatization, and silicification. Silicification and chloritization are the two most prominent alteration types on a megascopic scale, occurring along fractures. Park and MacDiarmid (1970) state that the types of minerals of hydrothermal alteration depend on: (1) the composition and temperature of the metal-bearing fluids; and (2) the wall rock composition.

The younger felsic intrusions, genetically asso-

¹ Glossary of Geology, p. 344.

ciated with the Canoe Lake stock, have undergone the same alteration processes.

Alteration - Stage One

The first stage of hydrothermal alteration is marked by extremely fine-grained alteration products. Plagioclase has been replaced by minute flakes of sericite, which tend to concentrate in the cores or inner zones of zoned crystals or to be randomly distributed in unzoned plagioclase grains. Twinning features are only slightly obliterated. Small patches of carbonate or chlorite and fine-grained clinozoisite may or may not have been present in this stage of alteration.

A plot of total percent sericite and muscovite would represent all sericitization which has reached alteration stage one or any successive stage. This plot is depicted in Figure 10. Four major areas of high percentage sericite (more than 25 percent) are visible in the diagram: in the Bag Bay - Love Lake region, near Canoe Lake, in the Squaw-Cuthbert-Barrage Lakes area, and along the south contact of the stock. These areas of high sericitization correlate moderately well with high percentage plagioclase. A noticeable feature of Figure 10 is the northwest trend of the contour lines, as opposed to the northeast trend of the percentage plagioclase contours.

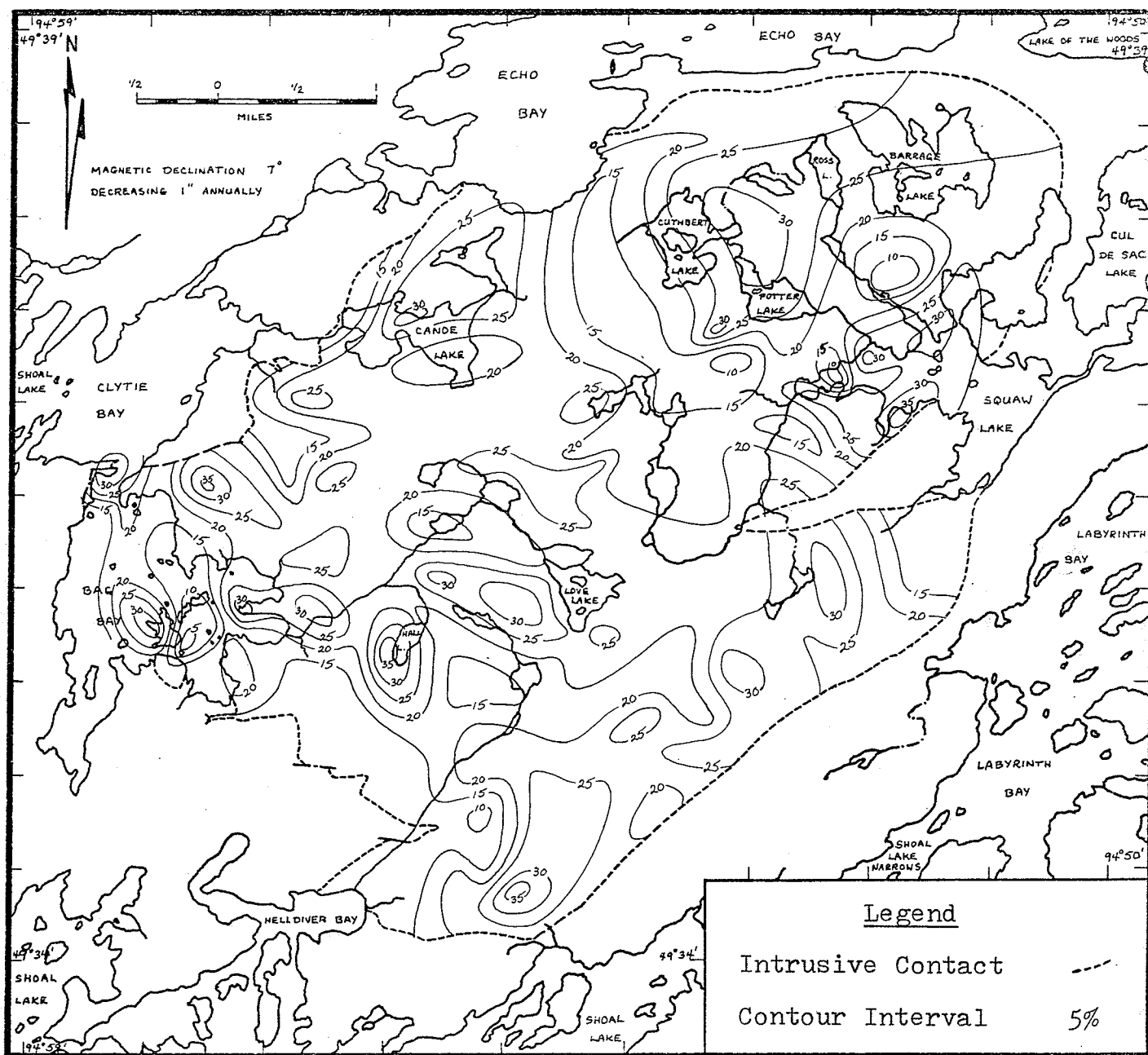


Figure 10. Contour plot of modal percent sericite for alteration stages one to four.

The mafic minerals were also subjected to minor alteration effects during stage one of the hydrothermal alteration process. Hornblende has been partially replaced by biotite and fine-grained epidote and carbonate. Biotite shows slight replacement by stringers of chlorite and scattered fine grains of epidote.

Alteration - Stage Two

During the second stage of hydrothermal alteration plagioclase was subjected to continued replacement by coarser-grained sericite, minor carbonate and chlorite patches, and fine-grained aggregates of clinozoisite.

Figure 11 represents a contour plot of stages two, three, and four sericitization in the Canoe Lake stock. The areas of high sericite (more than 15 percent) correlate with those of high total sericite in Figure 10, although they are more localized. This areal decrease in sericite concentration shows the progressive nature of the alteration.

Second stage hydrothermal alteration also produced continued effects on the mafic minerals. Hornblende grains contain biotite altering to chlorite, more fine-grained epidote, patches of carbonate, and minor leucoxene and quartz. Magnetite also made an appearance in hornblende at this alteration stage. Biotite was subjected to further chloritization with associated fine-grained epidote, minor leucoxene,

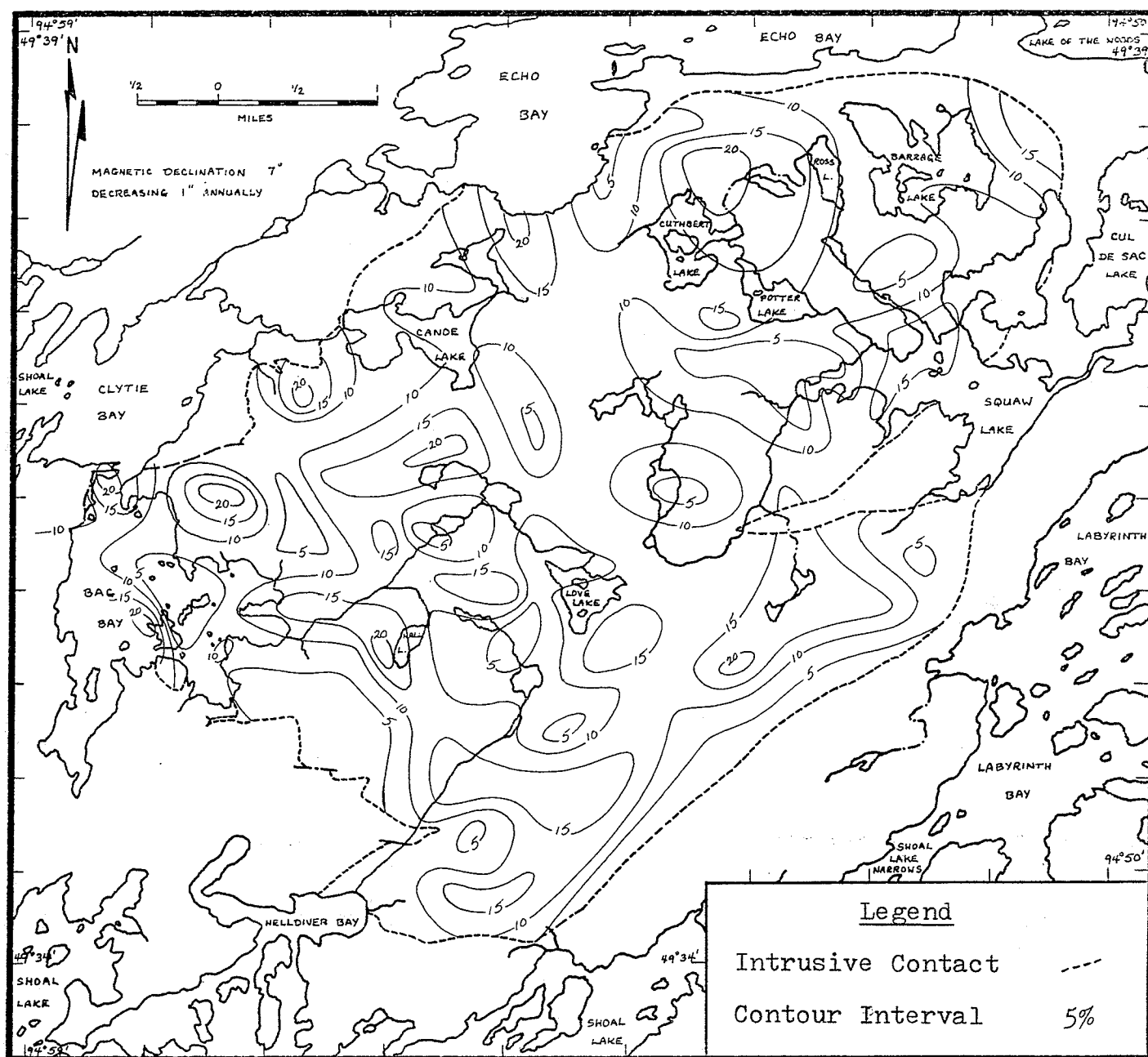


Figure 11. Contour plot of modal percent sericite for alteration stages two, three, and four.

and magnetite.

Alteration - Stage Three

Coarser-grained flakes of white mica or muscovite, randomly oriented in plagioclase grains, appear in this hydrothermal phase. Large carbonate and chlorite patches are also present and numerous aggregates of fine- to coarse-grained clinozoisite have been noted in the central portions of plagioclase grains. The twinning features are moderately to poorly preserved at this stage and in extreme cases the alteration products become nearly pseudomorphic after primary plagioclase.

Hornblende and biotite have been subjected to increased alteration during this third hydrothermal stage and in many places, pseudomorphs are all that remain of the original mafic constituents. Abundant chlorite, coarse-grained epidote, large carbonate patches (some with rhombohedral calcite crystals), clusters of blocky magnetite grains, clouds of leucoxene, and fine-grained quartz have adopted the hornblende crystal shape, while chlorite, epidote, minor magnetite and leucoxene, and rutile are pseudomorphic after biotite.

Alteration - Stage Four

This fourth alteration phase involved the last available hydrothermal solutions. The result is veins and stringers dissecting the quartz diorite stock on a megascopic to microscopic scale. The hydrothermal fracture fillings are mostly quartz and chlorite, while microscopic veinlets contain one or more of muscovite, chlorite, carbonate, epidote, and quartz. Figures 12a and 12b are photomicrographs of epidote and carbonate-chlorite-muscovite veinlets, respectively.

Stages three and four sericitization are combined in Figure 13 to show four areas of high sericite concentration (more than 10 percent). These localized highs represent the final result of progressive sericitization in the Canoe Lake intrusion. The four regions are Bag Bay, Canoe Lake - Love Lake, the south contact, and Squaw Lake.

Figures 14, 15, 16, and 17 illustrate contour plots of percent chlorite, clinozoisite, epidote, and carbonate, respectively, for the four stages of hydrothermal alteration combined. High contour values for chlorite and epidote correlate moderately well with contour highs for both of the primary mafic minerals. Clinozoisite appears more highly concentrated in the central portions of the Canoe Lake stock, which agrees with areas of high percentage plagioclase. The percentage carbonate contour diagram shows a rough correla-

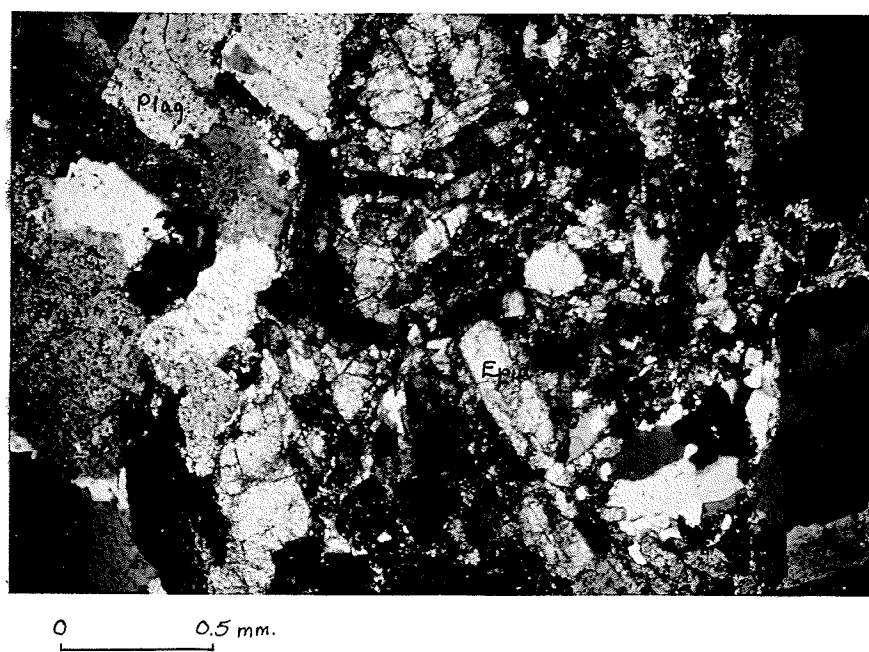


Figure 12a. Photomicrograph of an epidote vein resulting from hydrothermal alteration stage four.

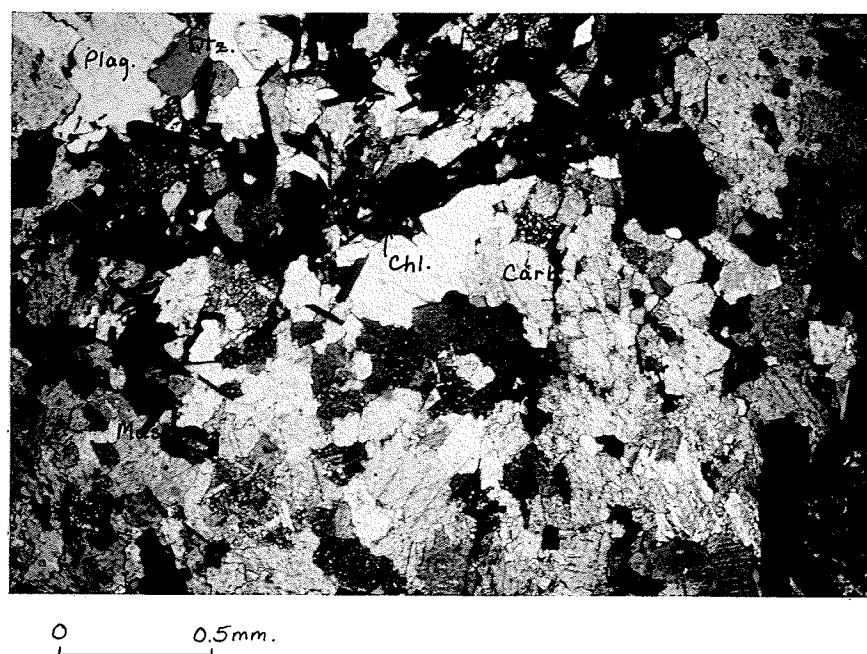


Figure 12b. Photomicrograph of a carbonate-chlorite-muscovite vein resulting from hydrothermal alteration stage four.

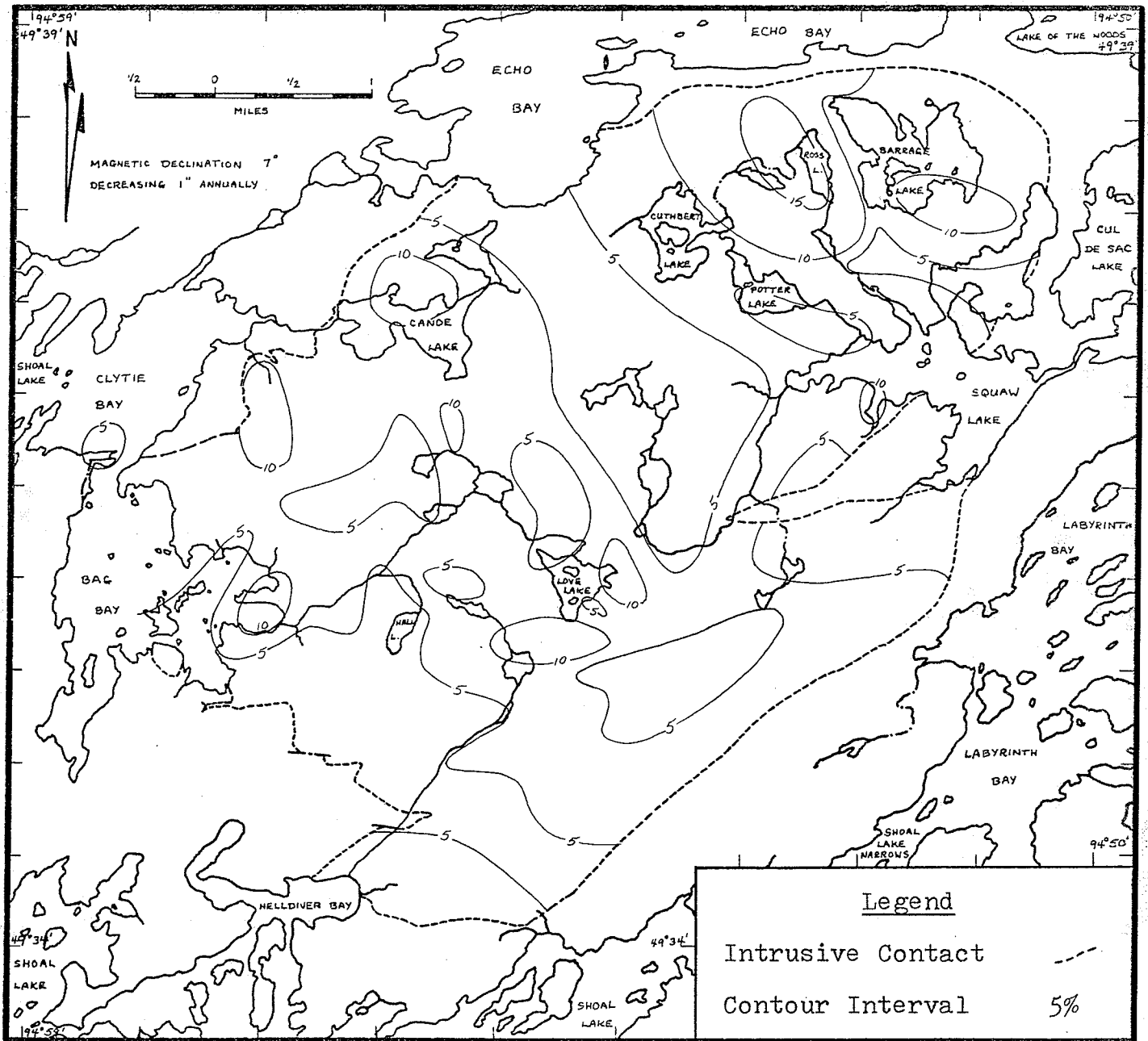


Figure 14. Contour plot of modal percent chlorite for alteration stages one to four.

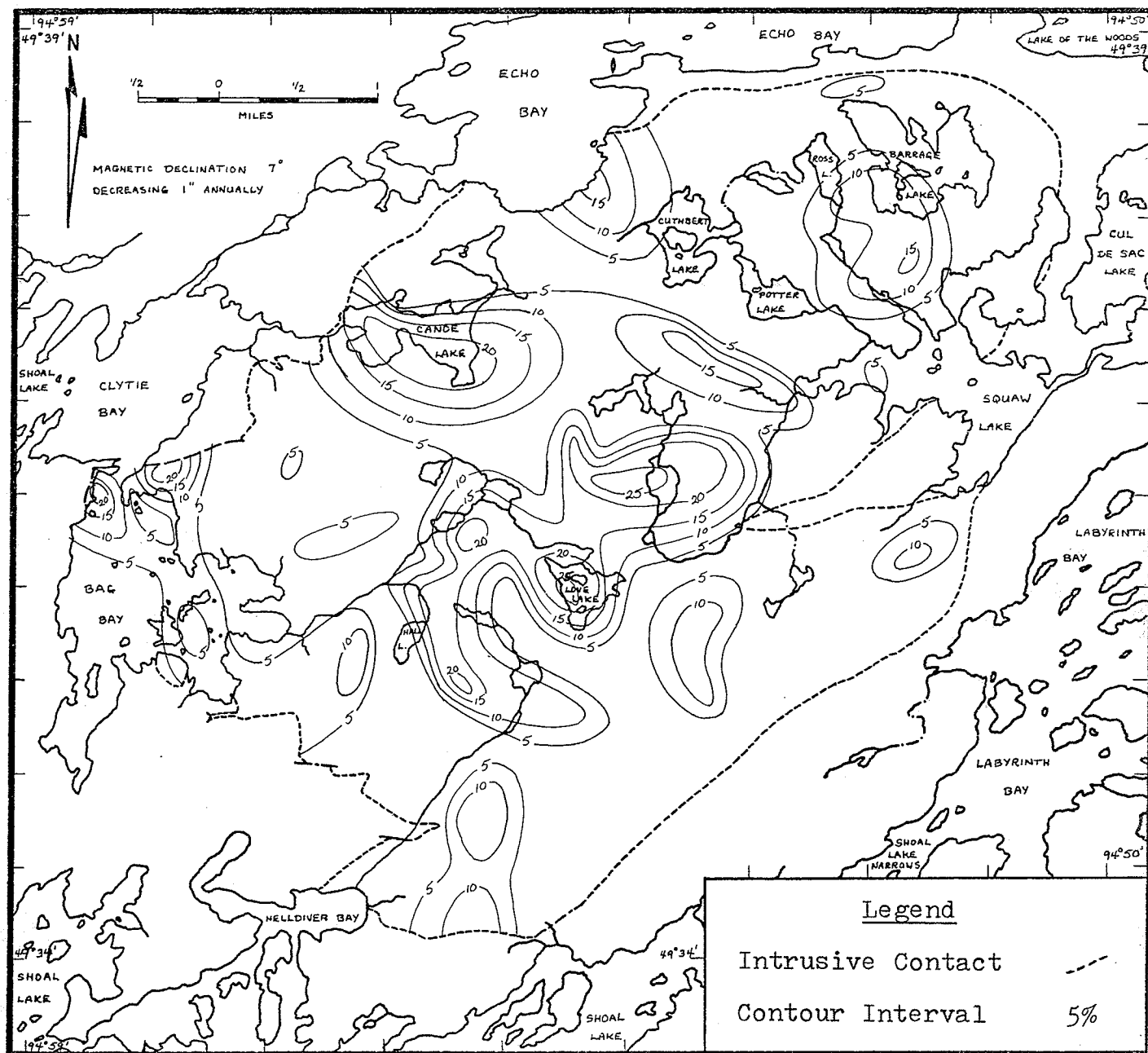


Figure 15. Contour plot of modal percent clinozoisite for alteration stages one to four.

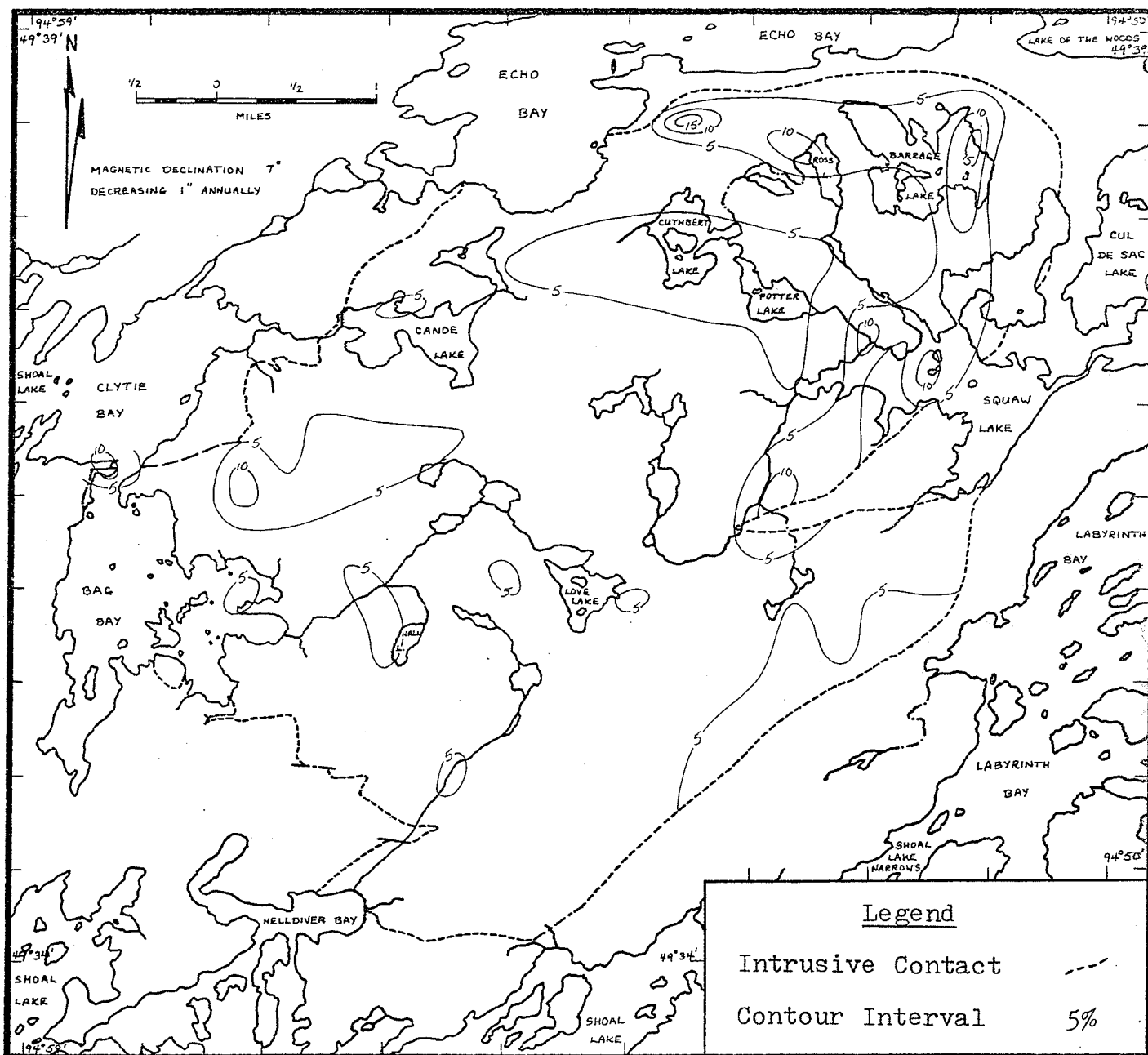


Figure 17. Contour plot of modal percent carbonate for alteration stages one to four.

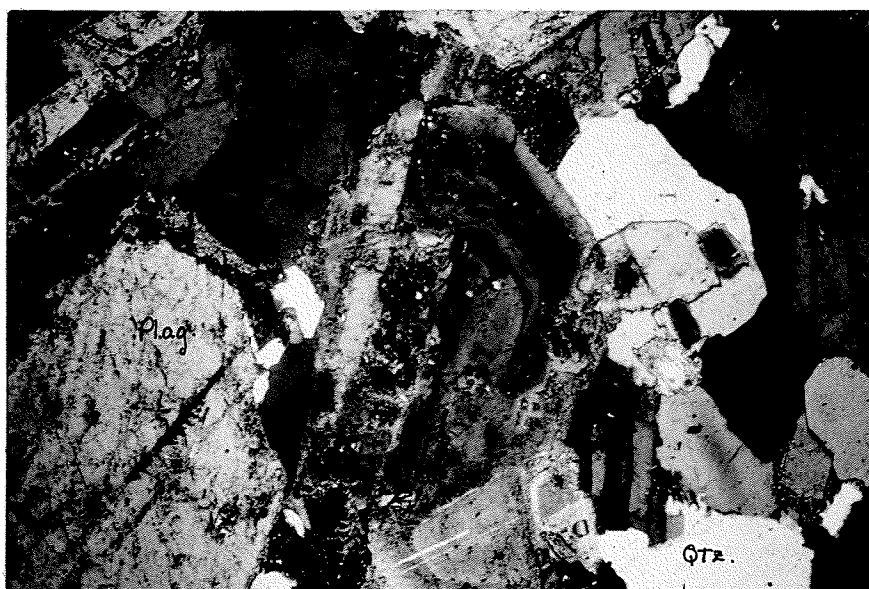
tion to the contour plots for plagioclase and hornblende.

Discussion

Distribution of Total Alteration

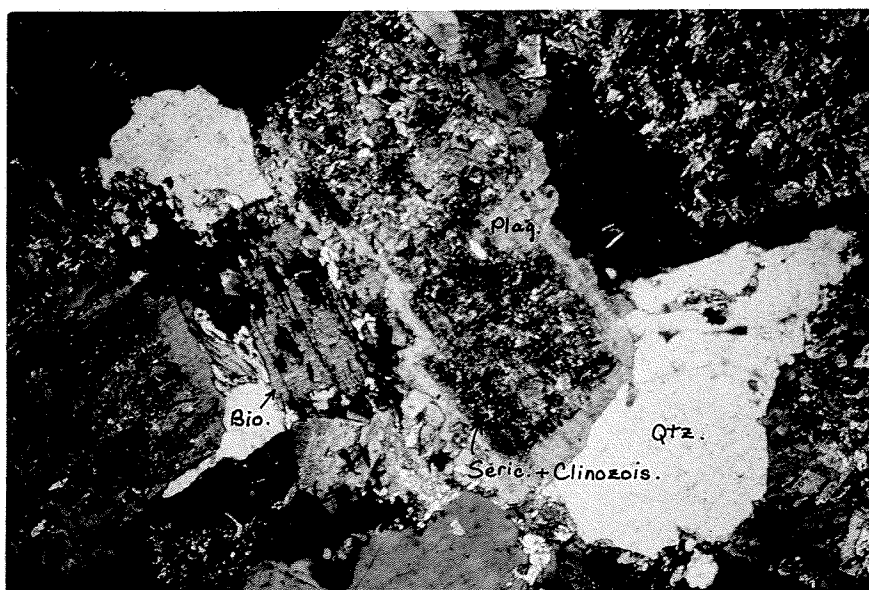
Total hydrothermal alteration in the Canoe Lake stock ranges from 20 to 65 volume percent, according to the modal analyses. The author has arbitrarily divided the degree of alteration into three categories: low degree, 20 to 35 percent; moderate degree, 35 to 45 percent; and high degree, 45 to 65 percent. Photomicrographs of the quartz diorite within each of the three alteration categories are shown in Figures 18a, 18b, and 18c.

Figure 19 shows a contour plot of percent total alteration. Two large areas of high alteration (more than 45 percent) are observed from the diagram; the first is in the Canoe Lake - Love Lake area, and the second is in the Ross Lake - Squaw Lake region. The most prominent feature of this contour diagram is the two-directional trend of the contour lines. A major northwest trend exists in areas of high alteration, which are separated by areas of a low to moderate degree of alteration. A northeast trend to the lines is present within these regions. This trend is better defined by the low contour values. The two contour trends are parallel to the strikes of the two sets of pre-hydrothermal fractures.



0 0.5 mm.

Figure 18a. Photomicrograph of quartz diorite showing the least degree of alteration and zoning in plagioclase.



0 0.5 mm.

Figure 18b. Photomicrograph of quartz diorite showing a moderate degree of alteration.

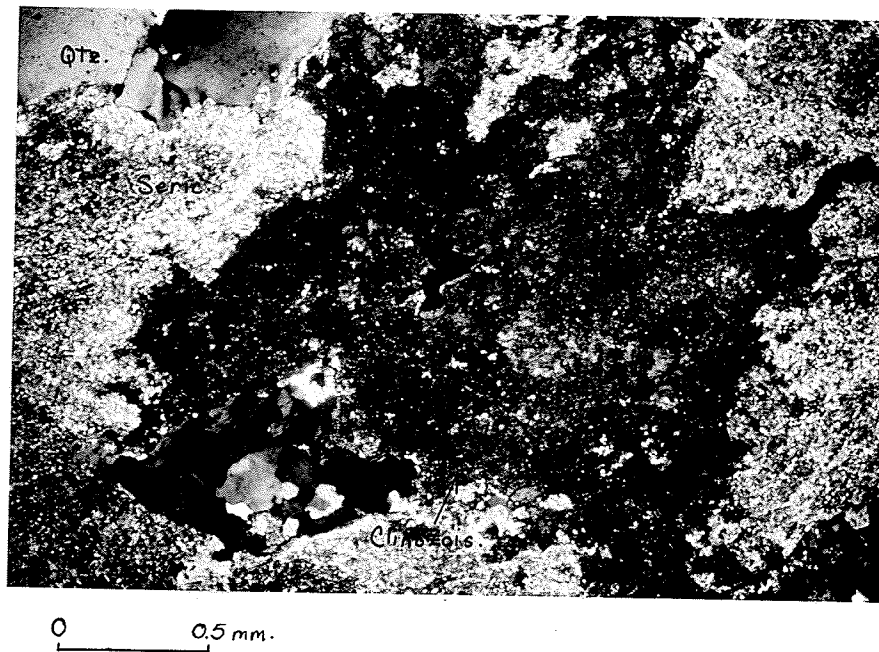


Figure 18c. Photomicrograph of quartz diorite showing the highest degree of alteration. Note the patch of zoisite.

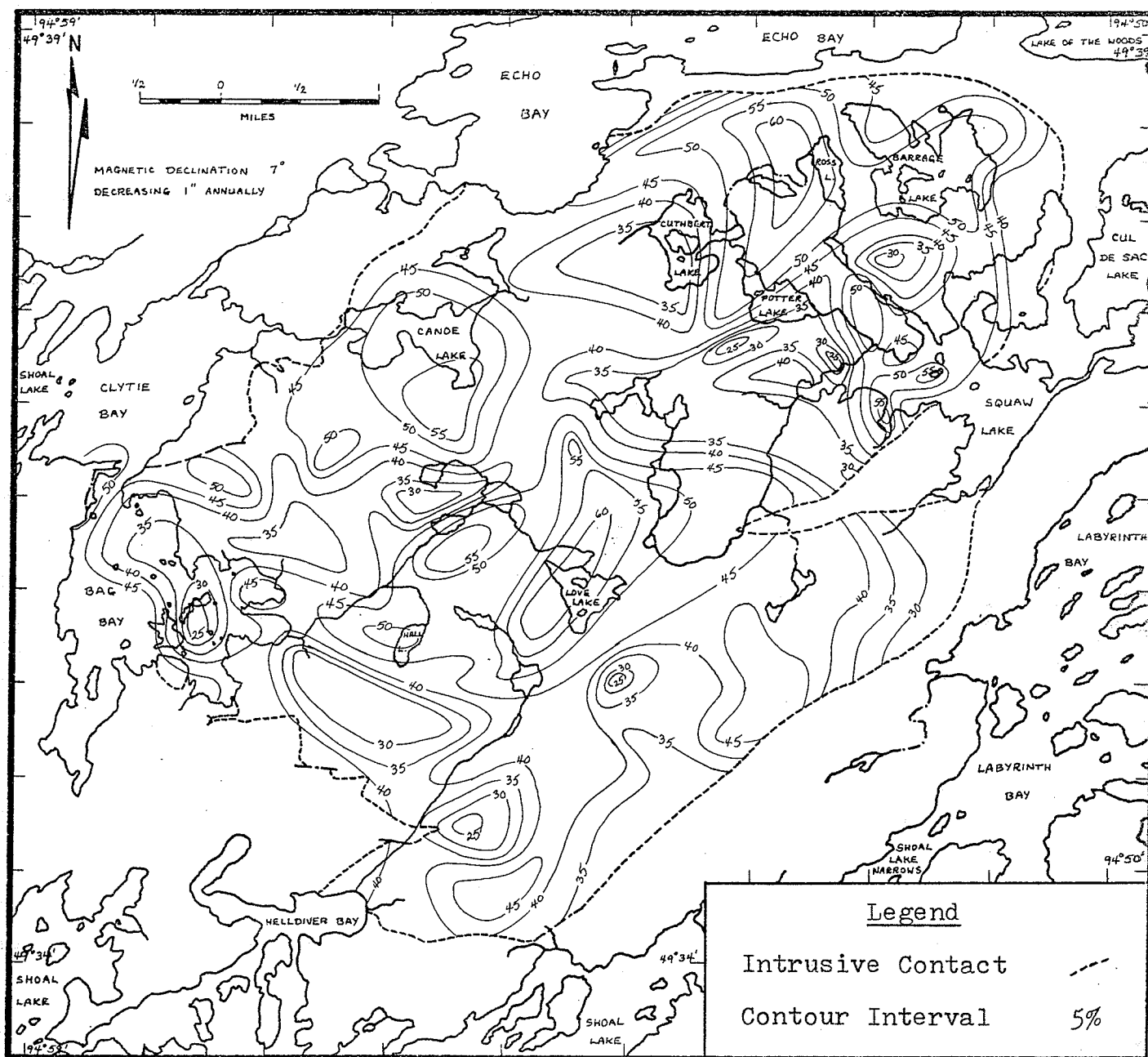


Figure 19. Contour plot of modal percent total hydrothermal alteration in the Canoe Lake stock.

These fractures acted as the channelways for the hydrothermal solutions.

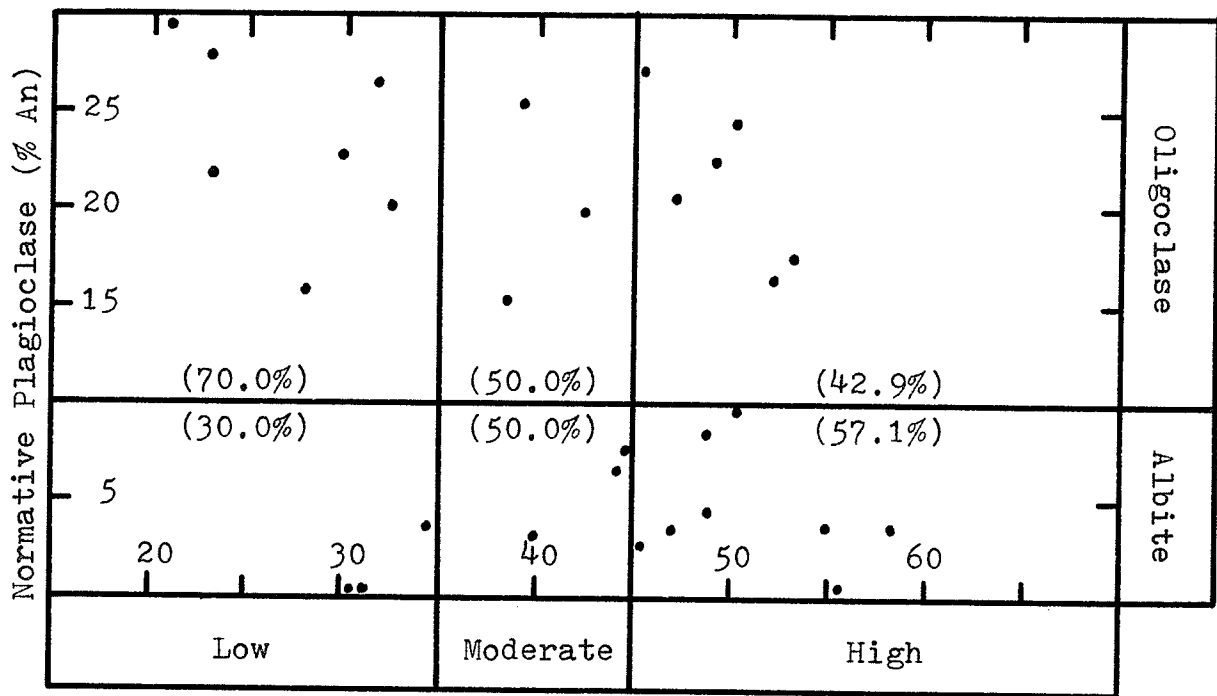
The normative plagioclase values, taken from the Niggli norm data in Appendix II, were plotted against percent total alteration. Figure 20 illustrates that plagioclase tends to be more albitic in areas of high alteration, whereas the andesine composition has been altered to oligoclase in areas of low alteration.

Late Magmatic Versus Metasomatic Alteration

At least the first stage of the hydrothermal alteration process is assumed to be late magmatic or deuteric. Perhaps the three successive phases are also late magmatic or perhaps the deuteric process is followed by metasomatism. This latter possibility requires the introduction of hydrothermal solutions from sources external to the Canoe Lake pluton. If metasomatism did occur, it raises the difficult question as to where the external sources were located.

Through careful field examination of hydrothermal veins, numerous thin section studies, and personal communication with Dr. A.C. Turnock, of the University of Manitoba, the author has concluded that the hydrothermal fluids were genetically associated with the granitic intrusion. Reasons for this decision are listed as follows:

1. Late magmatic felsic intrusions and quartz veins are



Percent Alteration by Volume and Degree of Alteration

Figure 20. Graphical representation of volume percent total alteration from modal analyses versus normative plagioclase from the Niggli norm program. (Percentages in parentheses indicate the percentages of albite and oligoclase in each of the three categories of alteration).

numerous in the Canoe Lake stock, indicating the abundant supply of water-rich fluids from the crystallizing granitic magma.

2. Thin section examination shows an almost continuous progression from one stage of hydrothermal alteration to the next stage. A more distinct break in the alteration pattern would be expected if metasomatic processes were superimposed on deuteric alteration effects.

3. The hydrothermal solutions responsible for the deposited mineralization in porphyry copper-molybdenum deposits are generally regarded as late magmatic in origin.

4. The steady trend lines for the major oxides and trace elements, when plotted on Larsen variation diagrams, suggest that the entire hydrothermal event was genetically related to the granitic pluton.

5. Sulphur isotope data from mineralized samples of the Canoe Lake quartz diorite indicate an igneous association for the sulphide minerals and therefore, for the hydrothermal solutions that transported the metals.

Burnham (1967) postulates two magmatic hydrothermal solution hypotheses. The first assumes the hydrothermal deposits and associated igneous rocks to be collinear descendants of magmas. In this theory most of the metal-bearing, water-rich fluids were derived from magmas during emplacement and crystallization. The second hypothesis assumes the hydrothermal solutions to be cognately related to the asso-

ciated igneous rocks through a common source. The first of these two processes is thought to best represent the hydrothermal alteration events in the Canoe Lake stock. The close association of pervasive and vein-type hydrothermal alteration, copper-molybdenum-zinc mineralization, and pre-hydrothermal fractures caused by cooling suggests the derivation of hydrothermal solutions during crystallization of the quartz diorite mass.

In describing the Santa Rita stock, Nielson (1968) derives the sequence of hydrothermal and mineralization events, which are similar to those present in the Canoe Lake stock. A solid shell is developed from early crystallization and then fractured with felsic dike emplacements. Remaining hydrothermal solutions migrated outward through fractures and deposited, in sequence, veinlets of pegmatite, barren quartz and molybdenite-bearing quartz, pyrite-chalcopyrite-molybdenite veins, and pyrite-quartz veins.

CHEMICAL TRENDS IN THE HOST INTRUSION

General Statement

Thirty representative samples were chosen for chemical analysis; 15 from the mineralized Squaw Lake area, and 15 from the remainder of the intrusion (see Figure 21). Whole rock and trace element analyses were run on each sample

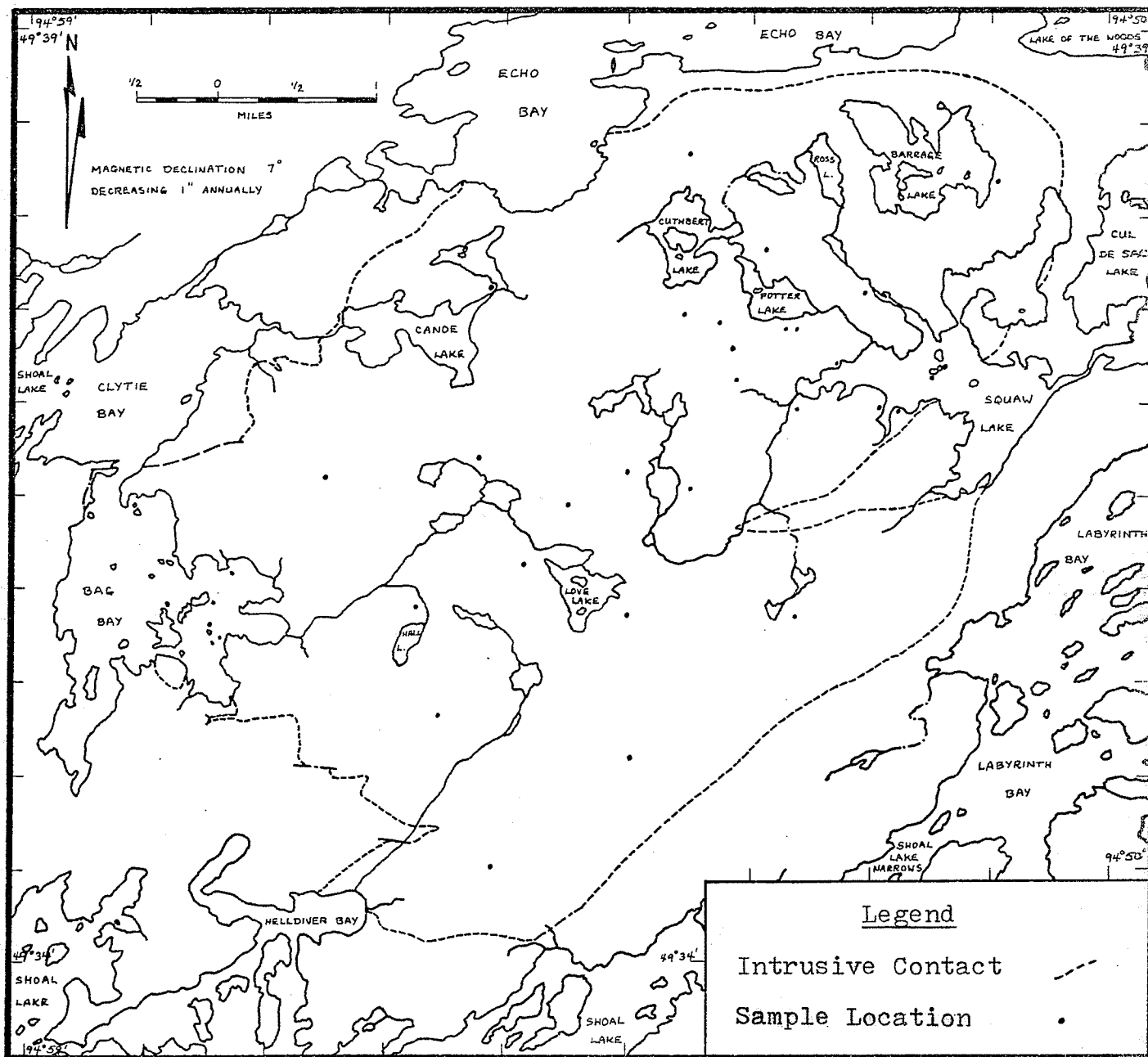


Figure 21. Distribution of the control points for the contoured chemical analyses plots.

(Tables 2a and 2b), and molybdenum was determined in samples 108-1B and 108-2A. A brief summary of the methods used in these chemical analyses is given in Table 3 and the precision and accuracy of the determinations for the various major oxides and trace elements are given in Tables 4a and 4b.

Contour plots of weight percent of the major oxides and trace elements were constructed and Larsen variation diagrams were plotted.

Discussion of Chemical Trends

Spatial Distribution of Chemical Data

The percentage contour diagrams for the major oxides are shown in Figures 22 to 33. SiO_2 and Al_2O_3 are concentrated within the central part of the Canoe Lake stock. These oxides have areal highs of more than 68.0 percent and more than 15.2 percent, respectively. Fe_2O_3 , FeO , K_2O , H_2O , CO_2 , TiO_2 , MnO , and P_2O_5 , in contrast, tend to be more highly concentrated away from the central area of the pluton. Both MgO and K_2O show major highs (more than 2.0 percent) near Love Lake (see Figures 25 and 28, respectively). Figures 26, 27, 29, and 30 illustrate concentrations of CaO , Na_2O , H_2O , and CO_2 , respectively, in the Squaw Lake region.

Contoured values for percent sulphur are depicted in Figure 34. Distinct concentrations (more than 0.20 per-

Table 2a. Whole rock chemical analyses - percentage values for the major oxides and sulphur.

Sample Number	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O
25-1	67.30	15.02	0.88	1.80	1.78	2.88	3.70	2.16
38-1	68.15	14.62	1.70	1.60	1.81	3.05	4.07	1.54
59-1B	66.20	14.50	1.34	2.12	1.46	3.28	4.78	1.51
61-4	66.85	14.35	3.24	2.16	1.70	1.20	5.33	0.94
62-1	66.45	15.18	1.09	2.12	1.96	2.69	4.73	1.38
67-1	70.90	15.39	0.42	1.08	0.85	3.41	5.18	0.37
93-3	68.05	15.53	0.49	1.92	1.30	3.00	3.88	1.66
97-1	65.45	15.27	2.07	2.08	1.90	4.04	5.00	1.02
103-1	66.60	15.12	0.28	1.96	1.39	3.08	4.03	1.91
108-1B	69.55	14.65	1.11	0.28	0.93	2.86	3.23	2.73
108-2A	71.00	14.26	1.72	0.14	0.64	1.59	4.60	1.86
110-1	69.60	15.49	0.53	1.22	2.02	3.95	4.50	0.24
111-2	67.90	15.20	0.67	1.72	1.38	3.25	4.45	1.48
112-1	67.90	14.64	0.67	1.84	1.25	3.70	4.32	1.37
117-2	70.95	15.11	1.13	0.72	1.03	3.68	4.83	0.53
128-1	69.90	15.39	1.35	1.28	0.95	2.95	4.50	1.64
132-1	69.35	15.38	1.14	1.36	1.09	3.31	5.05	0.95
139-1	66.60	15.16	1.49	1.92	1.83	2.91	4.83	1.66
150-1	67.65	15.05	1.53	1.08	1.44	2.30	5.00	2.07
171-1	67.20	14.59	1.37	0.76	1.09	3.29	5.13	2.24
194-1	67.90	15.01	1.46	1.02	1.96	2.92	5.23	1.89
206-1	65.80	15.26	1.71	1.52	2.52	2.26	4.38	2.68
242-1	68.65	14.91	0.68	1.32	1.83	2.88	4.70	1.60
267-1	67.75	15.64	1.95	1.68	1.26	3.65	4.53	1.66
294-1	71.60	14.96	0.83	1.12	0.70	2.88	5.23	0.93
296-1	70.15	15.49	0.51	1.68	1.13	2.68	5.15	1.07
299-1	67.60	15.18	1.77	1.08	1.41	2.75	4.78	1.88
307-1	69.60	15.56	0.77	1.44	1.51	2.66	4.86	1.12
312-1	68.90	15.44	1.50	1.12	1.50	3.29	4.43	1.78
326-1	67.90	15.31	1.58	1.72	1.78	3.15	3.87	1.95

Table 2a. (cont.) Whole rock chemical analyses - Percentage values for the major oxides and sulphur.

Sample Number	H ₂ O	CO ₂	TiO ₂	P ₂ O ₅	MnO	S	Total
25-1	1.86	1.99	0.45	0.13	0.03		99.98
38-1	1.53	1.22	0.48	0.13	0.03		99.93
59-1B	1.69	2.19	0.42	0.13	0.04	0.48	99.90
61-4	1.80	0.28	0.38	0.14	0.03	2.92	100.26
62-1	1.97	1.96	0.37	0.12	0.04		100.06
67-1	1.03	0.55	0.26	0.08	0.01	0.04	99.58
93-3	1.82	1.72	0.31	0.13	0.02		99.84
97-1	1.56	0.69	0.51	0.18	0.06		99.84
103-1	1.92	2.00	0.39	0.14	0.02		99.34
108-1B	1.40	2.76	0.28	0.08	0.03	0.27	100.14
108-2A	1.04	2.27	0.27	0.08	0.02	1.33	100.16
110-1	1.43	0.32	0.34	0.10	0.03	0.12	99.79
111-2	1.74	1.20	0.41	0.12	0.04	0.08	99.60
112-1	1.63	1.24	0.31	0.11	0.03	0.04	99.75
117-2	1.08	0.33	0.29	0.09	0.02	0.10	99.91
128-1	1.24	0.06	0.31	0.08	0.04	0.02	99.71
132-1	1.18	0.43	0.28	0.10	0.02		99.64
139-1	1.61	1.59	0.51	0.13	0.04		100.15
150-1	1.54	1.43	0.38	0.15	0.03		99.65
171-1	1.29	2.17	0.38	0.14	0.03		99.68
194-1	0.97	0.73	0.40	0.16	0.03		99.68
206-1	1.92	1.30	0.48	0.19	0.04		99.79
242-1	1.56	1.43	0.40	0.10	0.05		100.11
267-1	0.94	0.38	0.41	0.11	0.04		100.00
294-1	1.09	0.35	0.32	0.08	0.03		100.12
296-1	1.24	0.46	0.34	0.09	0.03	0.03	100.03
299-1	1.44	1.76	0.36	0.15	0.03		100.19
307-1	1.30	0.18	0.37	0.11	0.03		99.51
312-1	1.19	0.14	0.41	0.11	0.04		99.75
326-1	1.48	0.72	0.39	0.13	0.03		100.01

Table 2b. Whole rock chemical analyses -
ppm. values for the trace elements.

Sample Number	Rb	Ni	Cu	Co	Zn	Pb	Mo
25-1	49	14	19	7	37	5	
38-1	40	13	3	7	49	16	
59-1B	49	11	600		72	32	
61-4	31		3660	23	265	55	
62-1	43		48		86	25	
67-1	18	10	329	1	28	15	
93-3	68	12	15	4	42	25	
97-1	39	10	30	2	58	23	
103-1	50	2	4	2	39	25	
108-1B	85	6	435		30	27	950
108-2A	59	5	175	1	16	30	10
110-1	10	2	204	3	34	30	
111-2	47	4	224	4	67	50	
112-1	45	2	373	1	49	23	
117-2	21	10	1230		62	15	
128-1	33	5	146		30	13	
132-1	42	4	83	3	26	23	
139-1	38	14	32	4	55	19	
150-1	48	12	4	3	49	17	
171-1	49	15	7	9	42	13	
194-1	51	20		2	43	33	
206-1	52	31	12	7	52	28	
242-1	38	8		8	43	22	
267-1	45	8	1	6	43	13	
294-1	20	7	60	4	42	28	
296-1	33	5	94	4	40	16	
299-1	50	19	11	7	46	19	
307-1	33	11	11	9	46	19	
312-1	43	11	5	8	48	17	
326-1	57	11	7	7	46	17	

Table 3. Summary of methods used in the analytical laboratory
- Department of Earth Sciences, University of Manitoba.

Element	Method
Si Al Fe (Total) Mg Ca K Ti Mn	X-ray Fluorescence Spectrometry: Weighted sample plus $\text{Li}_2\text{B}_4\text{O}_7$ plus La_2O_3 heated in graphite crucible at 1050°C . for 1/2 hour. Resulting glass bead with H_3BO_3 (Total weight = 2.1000 grams) ground to -200 mesh and then compressed to 50,000 p.s.i.. Elements then simultaneously analyzed on multi-channel ARL X-ray Spectrometer.
Na_2O , Mg(Low) Cu, Ni, Co, Pb, Zn, Mo	Atomic Absorption Spectrophotometry: Rock dissolved with HF, H_2SO_4 , HNO_3 in platinum crucibles - Perkin Elmer 303. A.A.S.
P_2O_5	Colorimetry - solution as for Na_2O above: Absorption at $430\text{ m}\mu$ of molybdivanadophosphoric acid complex - Unicam Spectrophotometer.
FeO	Rock decomposed with HF and 1.4 H_2SO_4 solution titrated with $\text{K}_2\text{Cr}_2\text{O}_7$ using Sodium Diphenylamine Sulfonate as indicator.
H_2O (Total)	Determined by heating sample in stream of dry oxygen in induction furnace (Temp. $>1100^\circ\text{C}$.). H_2O collected on Magnesium Perchlorate and weighed.
CO_2	Determined simultaneously with H_2O . CO_2 collected on Ascarite and weighed.
S	Determined by heating sample in induction furnace with oxygen flowing through combustion chamber. SO_2 evolved is then titrated. Leco Induction furnace and automatic titrator.

Table 4a. Precision and accuracy
of the major oxides and sulphur.

Constituent	Concentration %	Instrument Precision		Accuracy of Replicates
		σ	Std. Dev.	
SiO ₂	59.60	0.12		0.20
Al ₂ O ₃	9.34	0.05		0.13
Fe ₂ O ₃ (Total)	10.08	0.017		0.03
MgO	4.04	0.04		0.10
CaO	10.22	0.02		0.07
K ₂ O	2.69	0.01		0.01
MnO	0.41	0.01		0.01
TiO ₂	0.48	0.02		0.02
Na ₂ O	4.20	0.01		0.05
H ₂ O (Total)	1.60	0.03		0.06
CO ₂	1.15	0.05		0.12
P ₂ O ₅	0.20	0.01		0.01
FeO	10.92	---		0.04
S	0.185	0.003		0.005

Table 4b. Precision and accuracy of the trace elements.

Constituent	Concentration ppm.	Instrument Precision	Accuracy of Replicates
		σ	Std. Dev. σ
Co	53	1.0	2.0
Cu	40	1.0	2.0
Ni	77	1.0	3.0
Pb	34	2.0	3.0
Rb	228	1.0	2.0
Zn	108	1.0	2.0
Mo	27	3.0	5.0

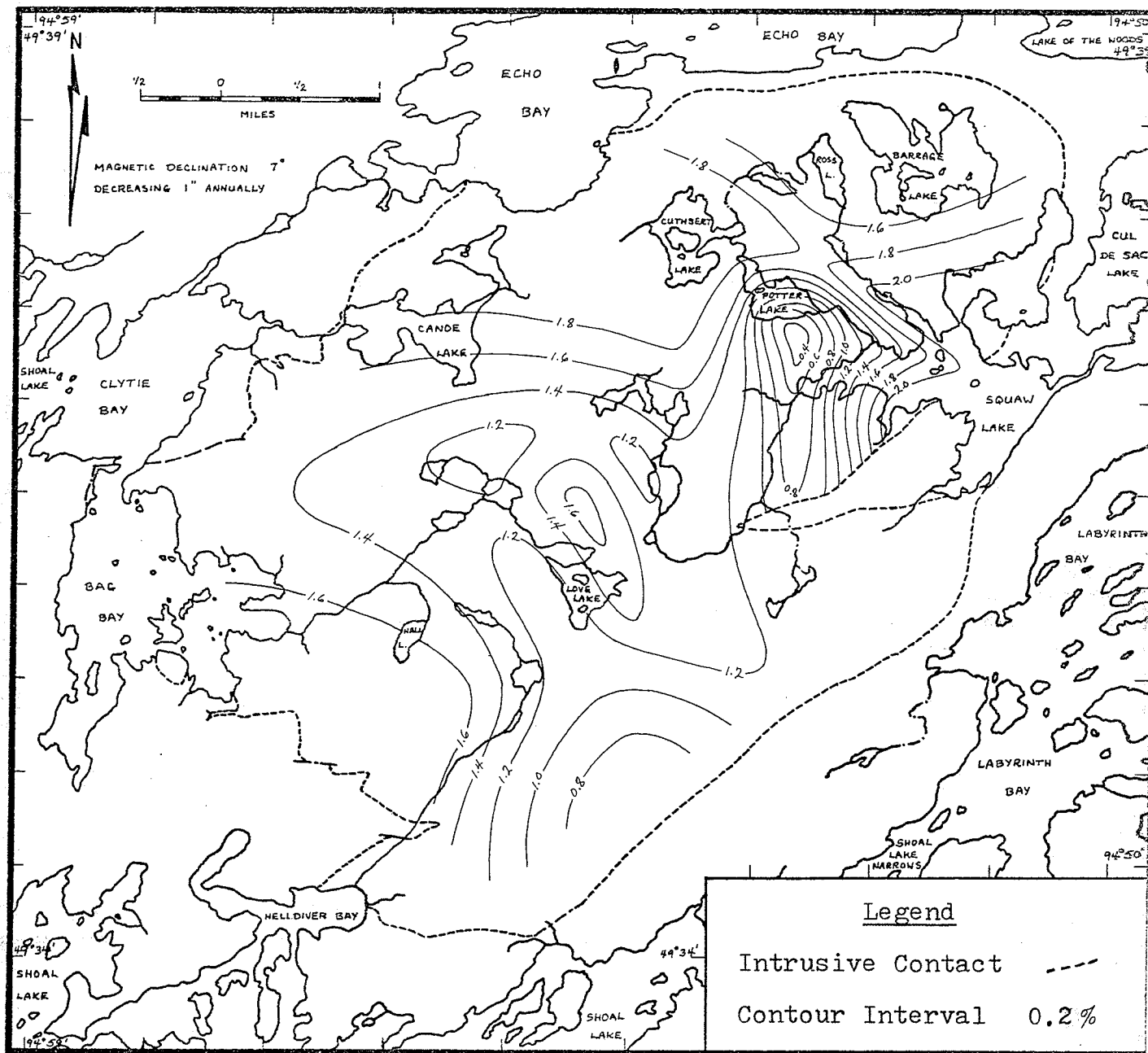


Figure 24b. Contour plot of weight percent FeO from the chemical analyses.

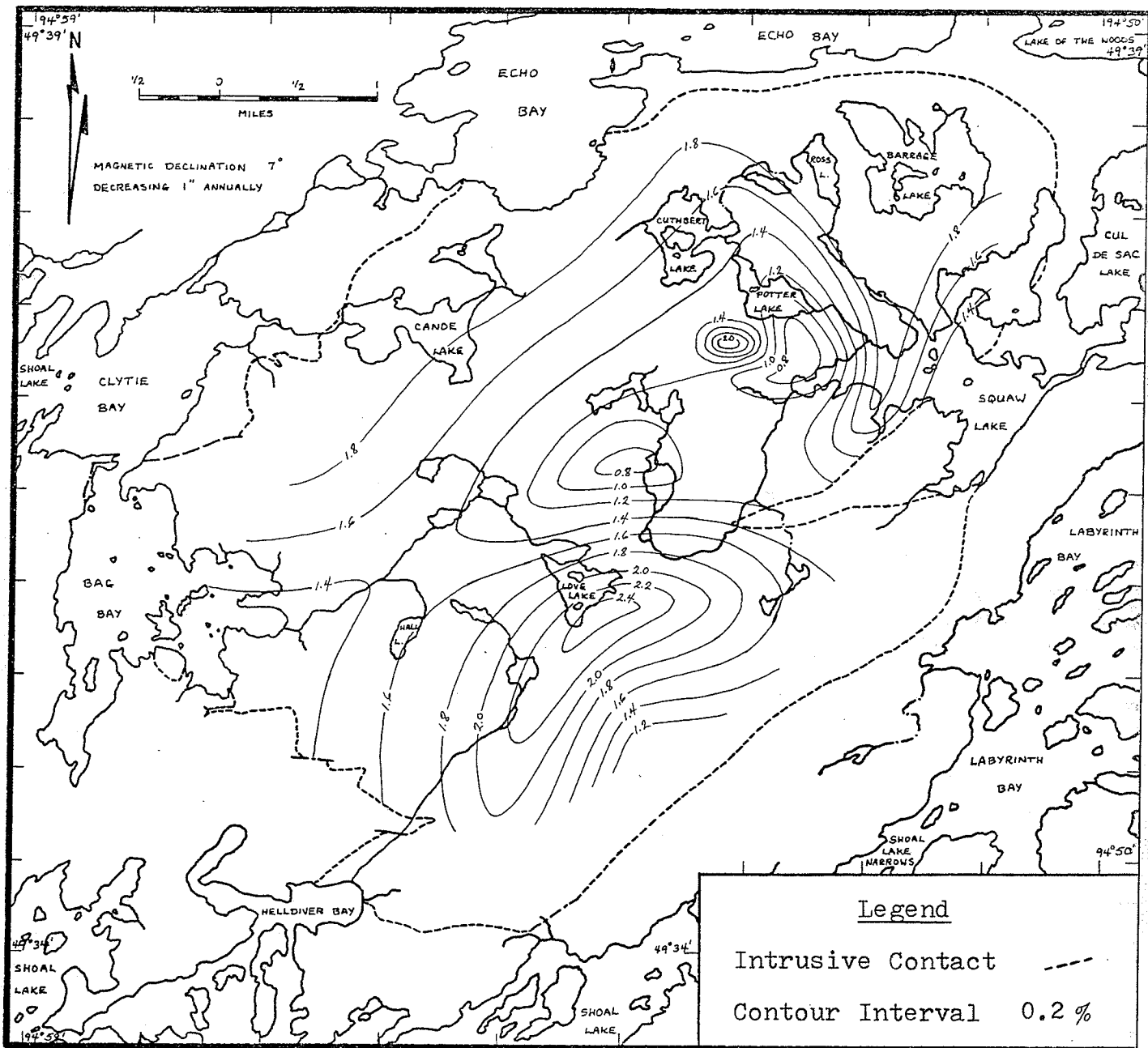


Figure 25. Contour plot of weight percent MgO from the chemical analyses.

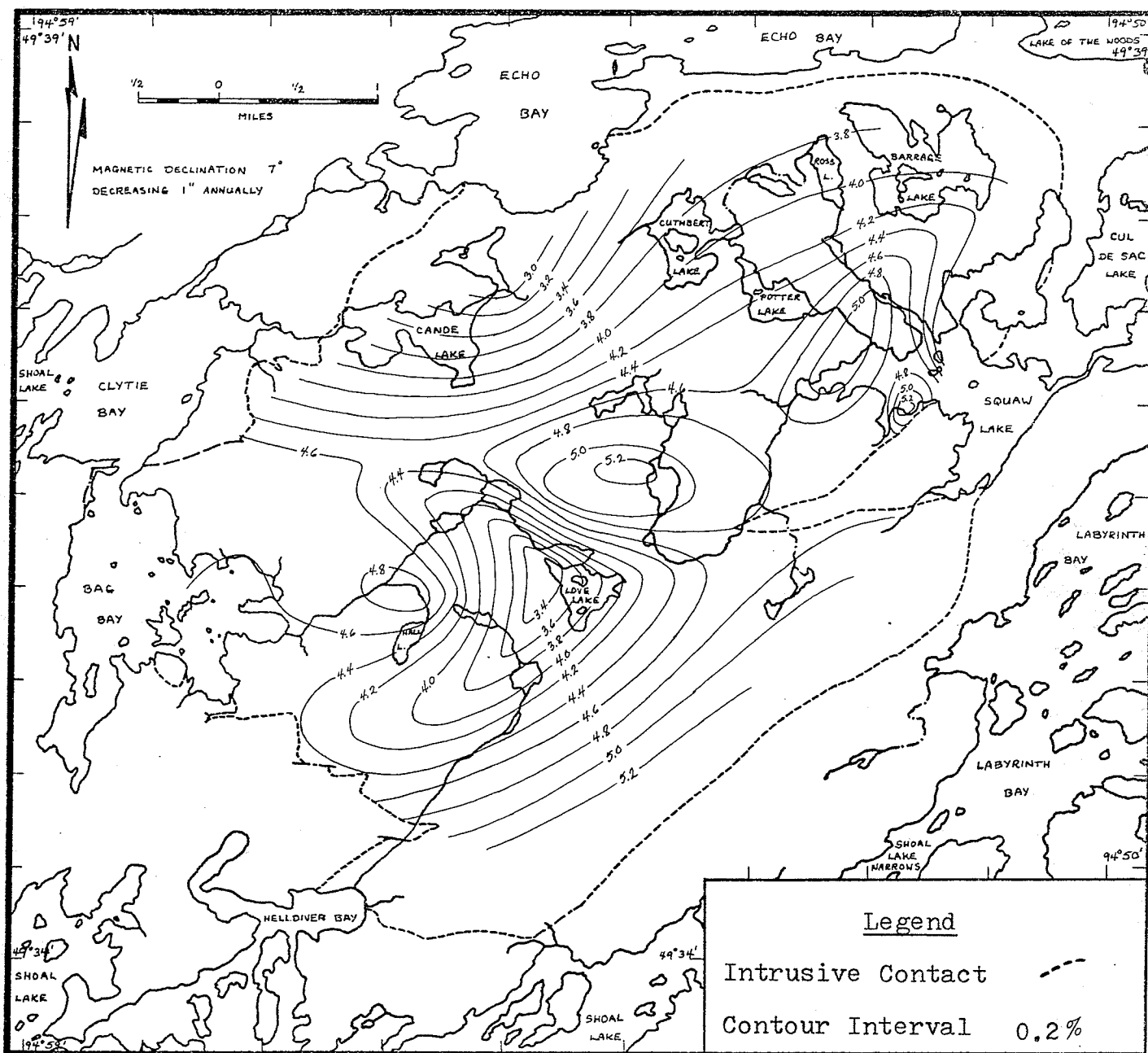


Figure 27. Contour plot of weight percent Na_2O from the chemical analyses.

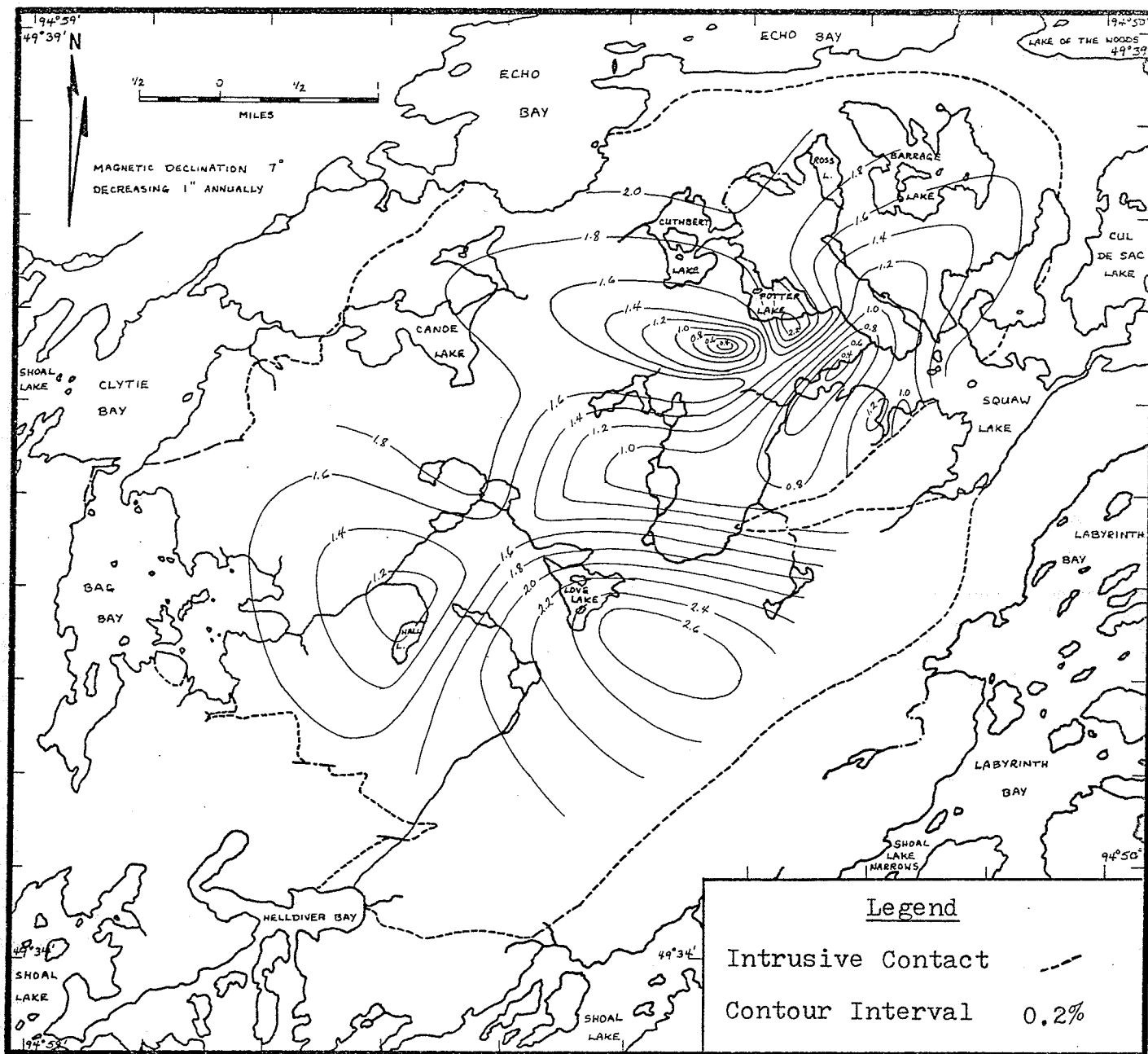


Figure 28. Contour plot of weight percent K_2O from the chemical analyses.

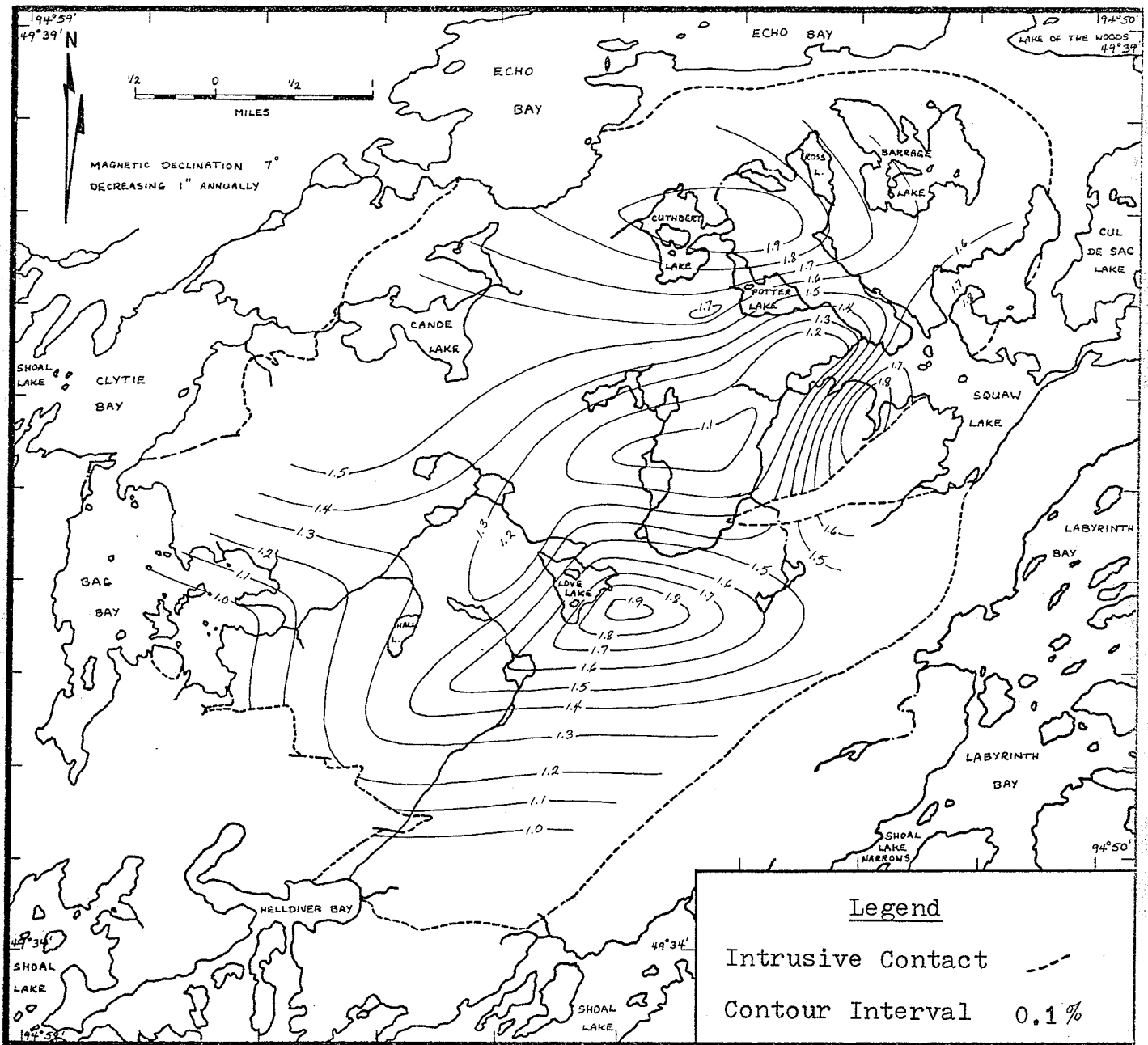


Figure 29. Contour plot of weight percent H_2O from the chemical analyses.

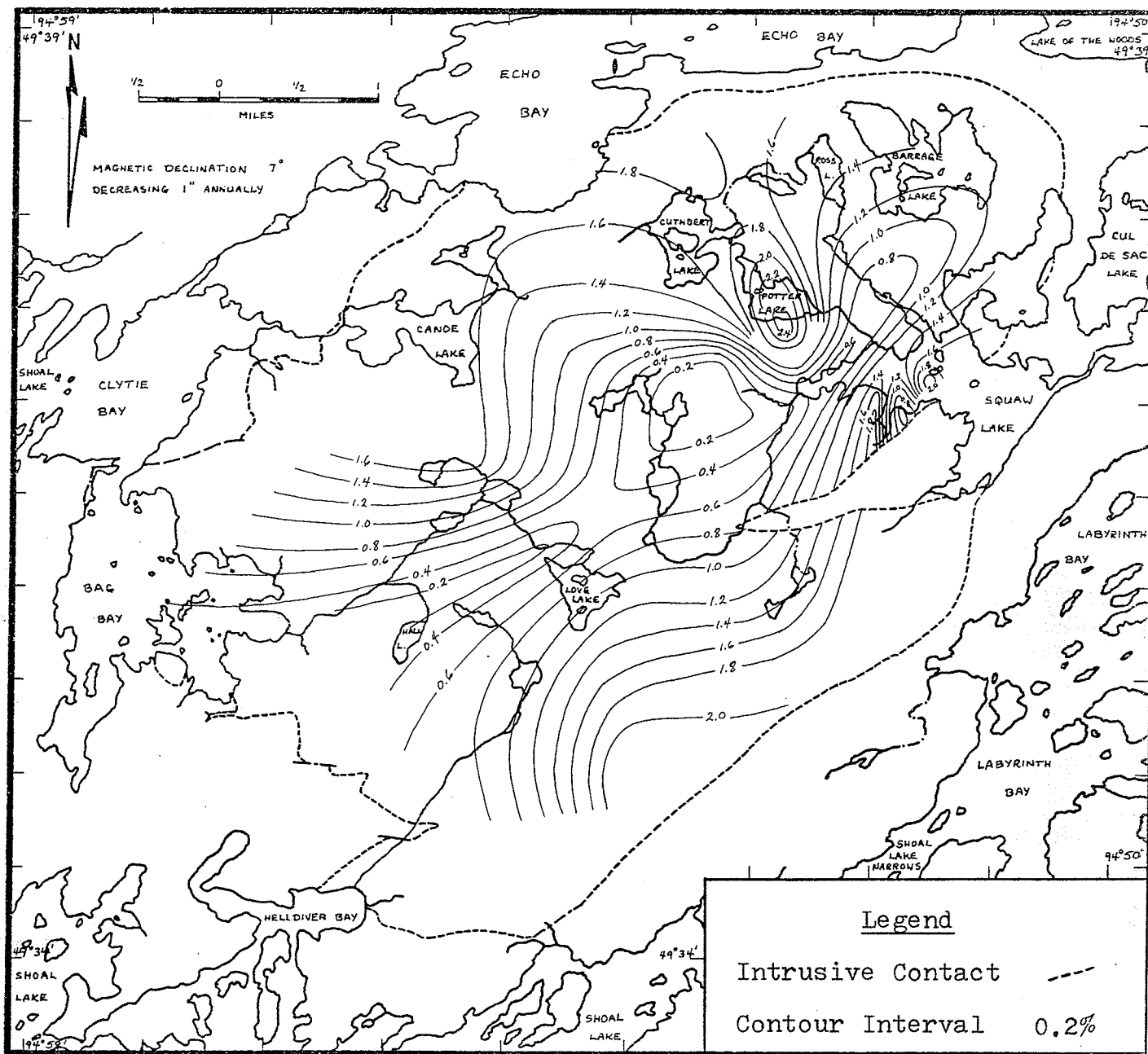


Figure 30. Contour plot of weight percent CO₂ from the chemical analyses.

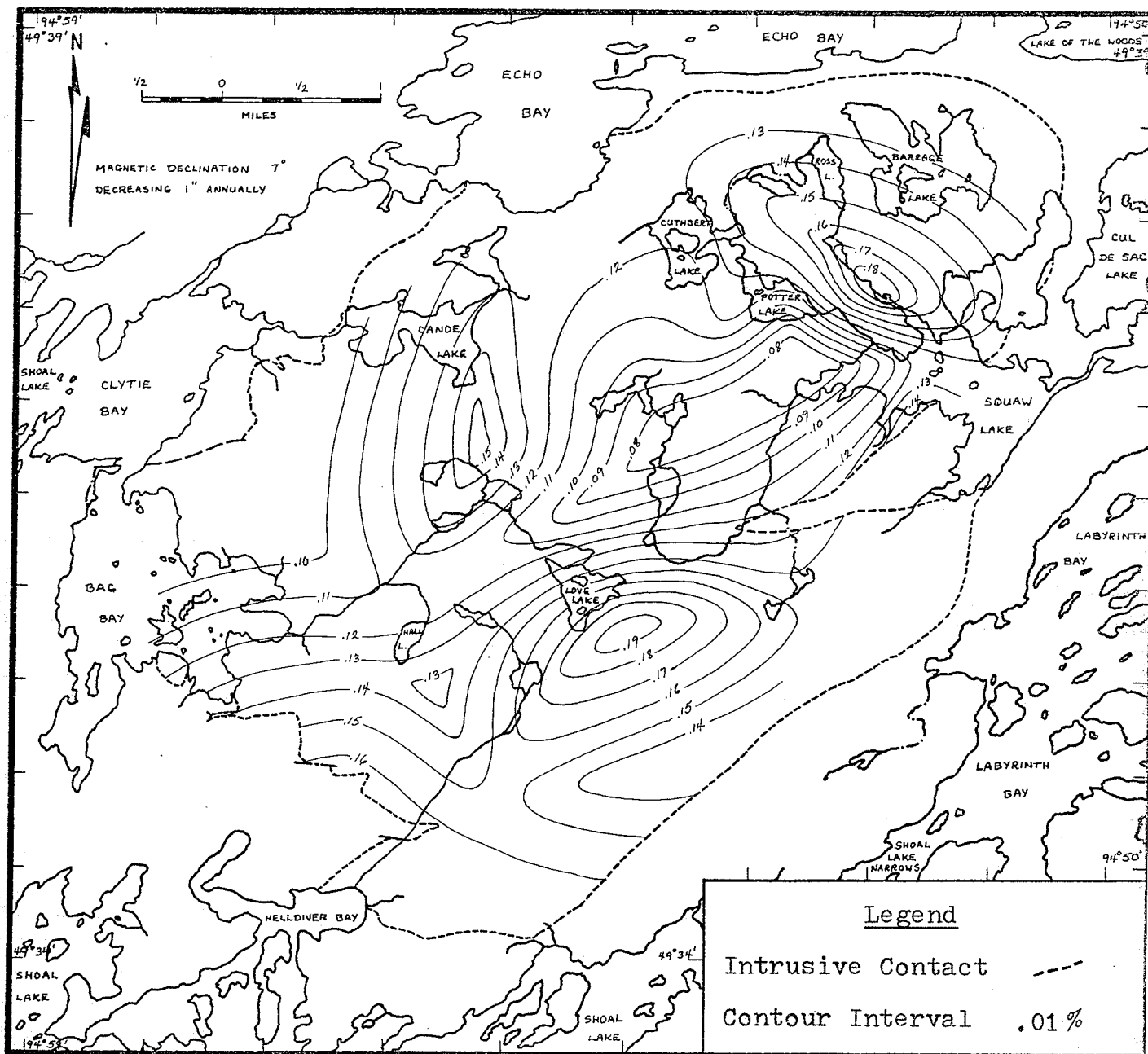


Figure 32. Contour plot of weight percent P_2O_5 from the chemical analyses.

cent) exist at Squaw Lake and Potter Lake, which coincide with the areas of most intense porphyry type copper mineralization.

Trace element contoured ppm. results are seen in Figures 35 to 40. Rubidium, copper, cobalt, and lead have major concentrations in the Squaw Lake area. Figure 36 illustrates a small high (more than 2.8 ppm.) for Ni near Love Lake. Major concentrations of Zn (more than 50 ppm.) are present near Canoe Lake, Love Lake, Potter Lake, and at Squaw Lake.

Larsen Variation Diagram Results

Plots of weight percent for the major oxides and trace elements against the corresponding Larsen index numbers diagrammatically show the trends during the crystallization of the quartz diorite stock (see Figures 41a, 41b, 41c, and 41d).

With progressive solidification the granitic magma was enriched in SiO_2 , and less distinctly, in K_2O and CO_2 . There occurred a major decrease in Fe_2O_3 and FeO , and a slight impoverishment in Al_2O_3 , CaO , TiO_2 , P_2O_5 , and MnO . Constituents that remained moderately steady in concentration during the crystallization process were Na_2O and H_2O .

Figure 42a, showing a plot of sulphur concentration versus Larsen index number, contains two points that

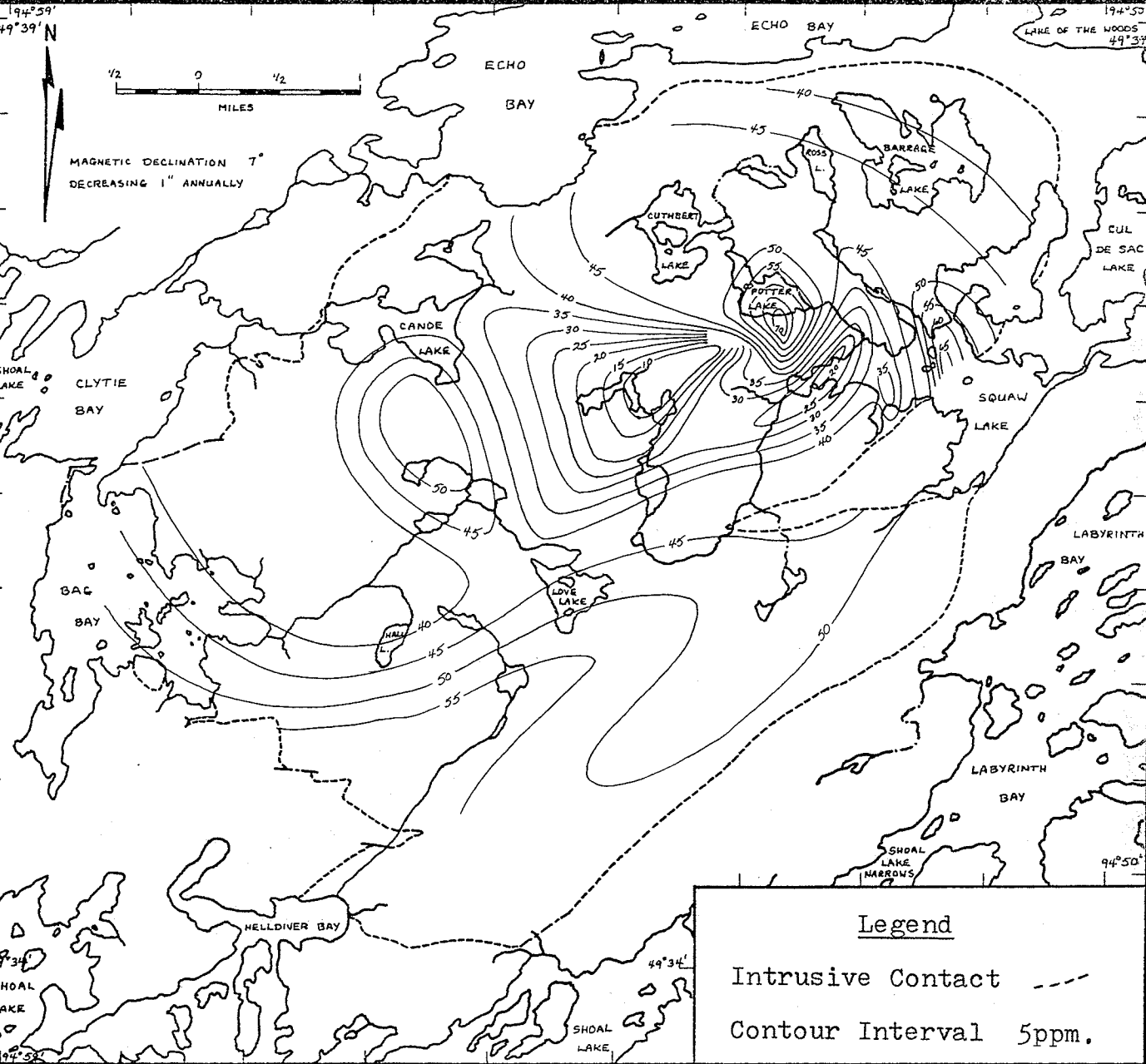


Figure 35. Contour plot of ppm. rubidium from the chemical analyses.

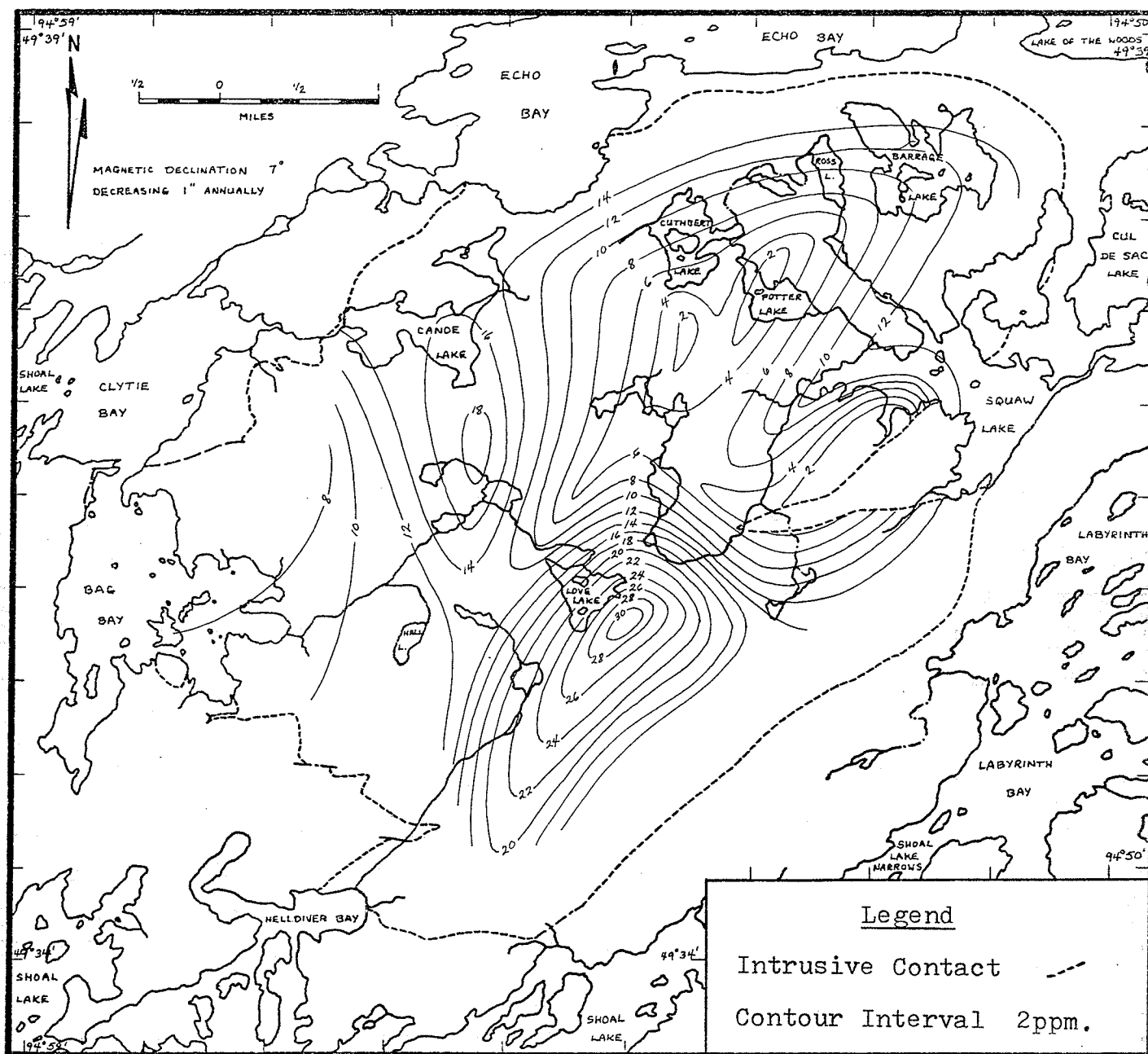


Figure 36. Contour plot of ppm. nickel from the chemical analyses.

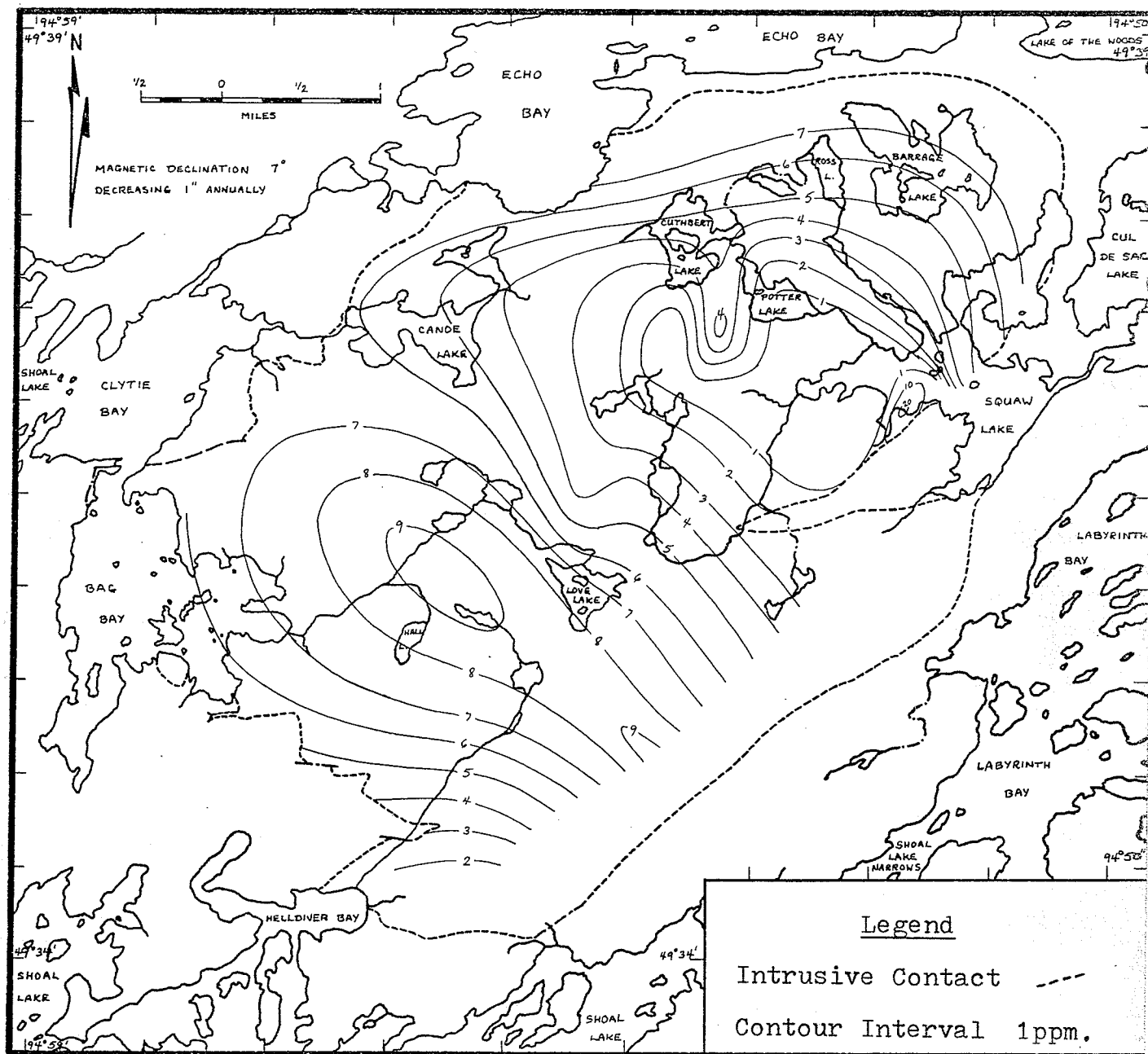


Figure 38. Contour plot of ppm. cobalt from the chemical analyses.

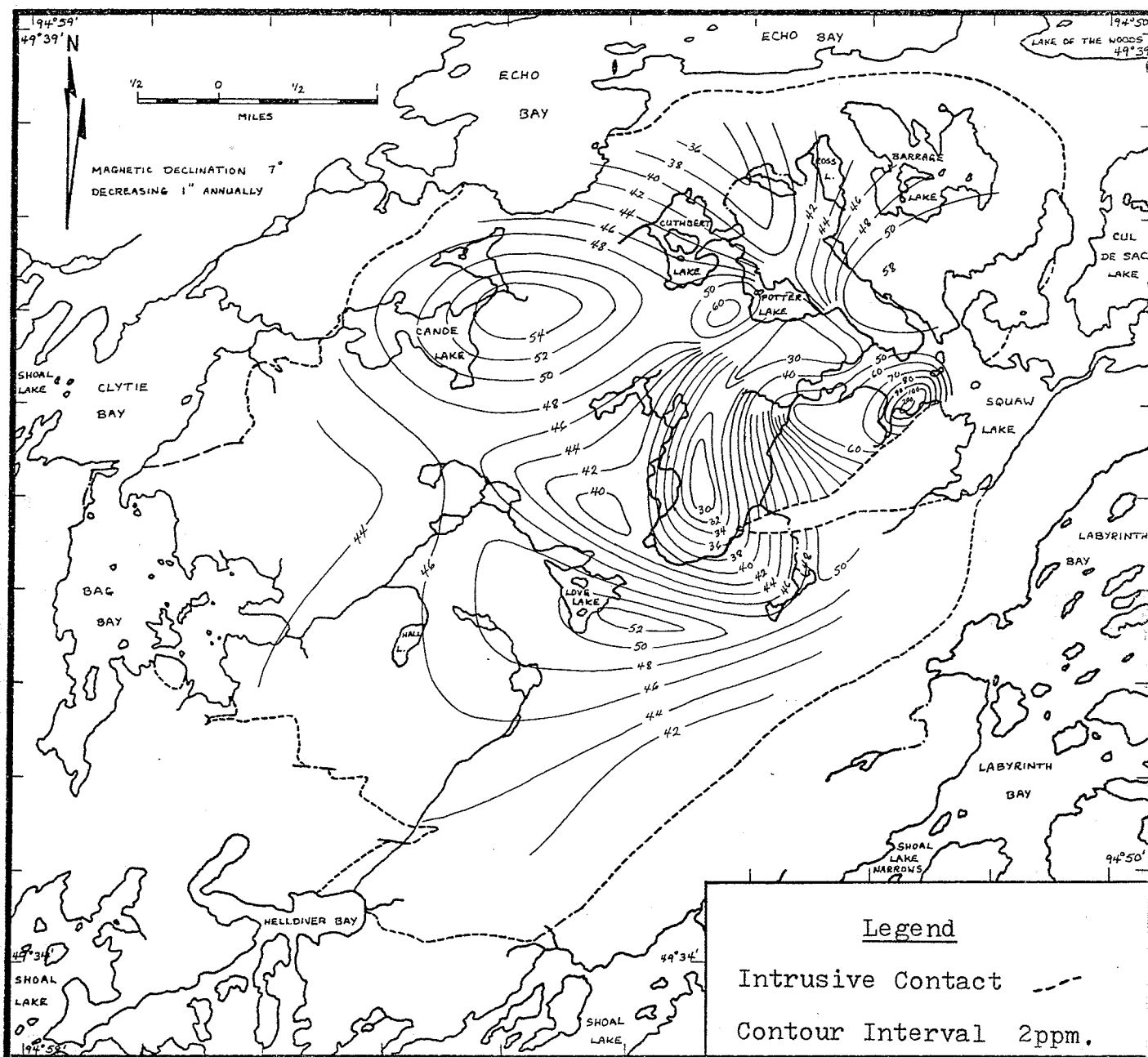


Figure 39. Contour plot of ppm. zinc from the chemical analyses.

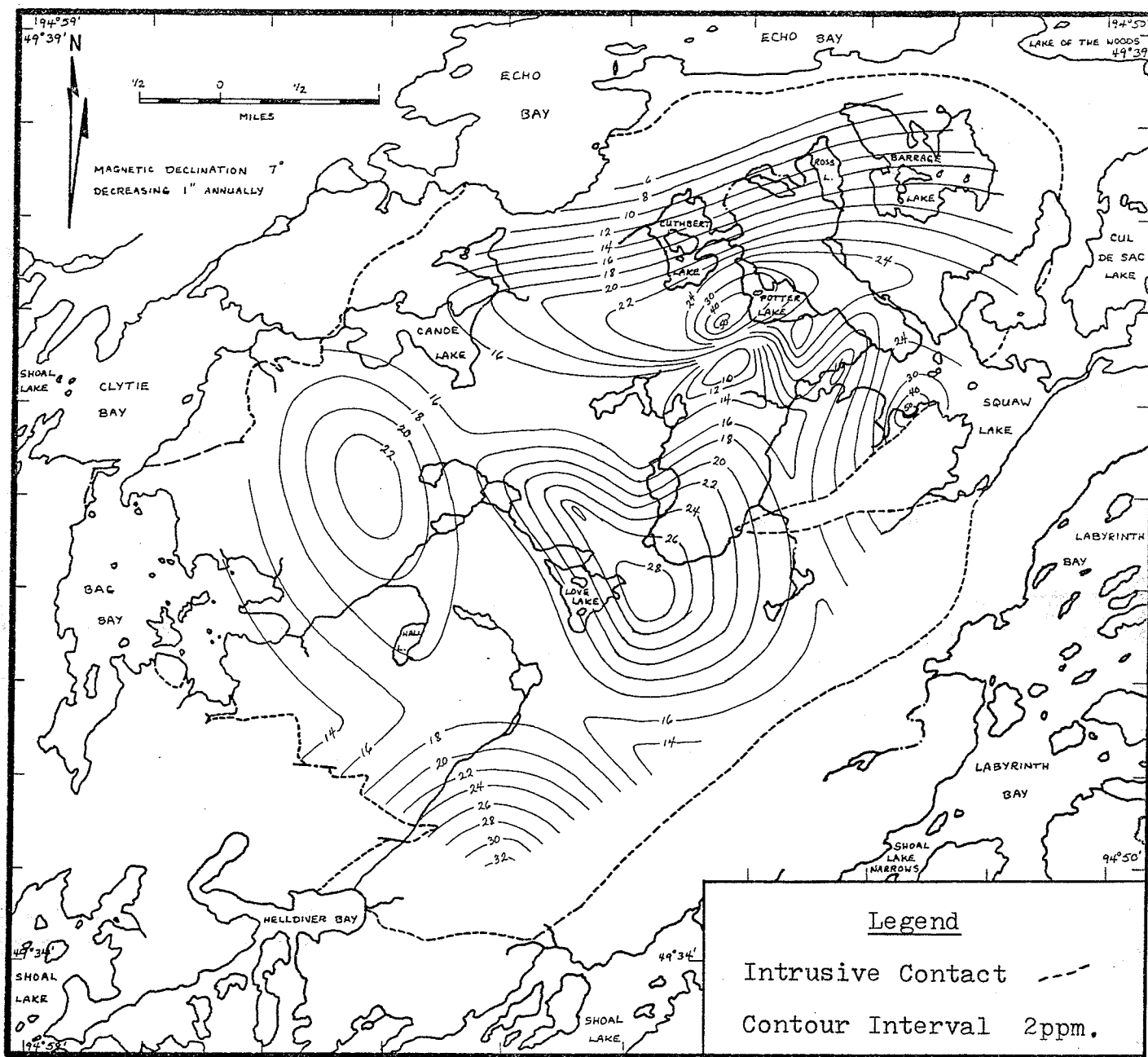


Figure 40. Contour plot of ppm. lead from the chemical analyses.

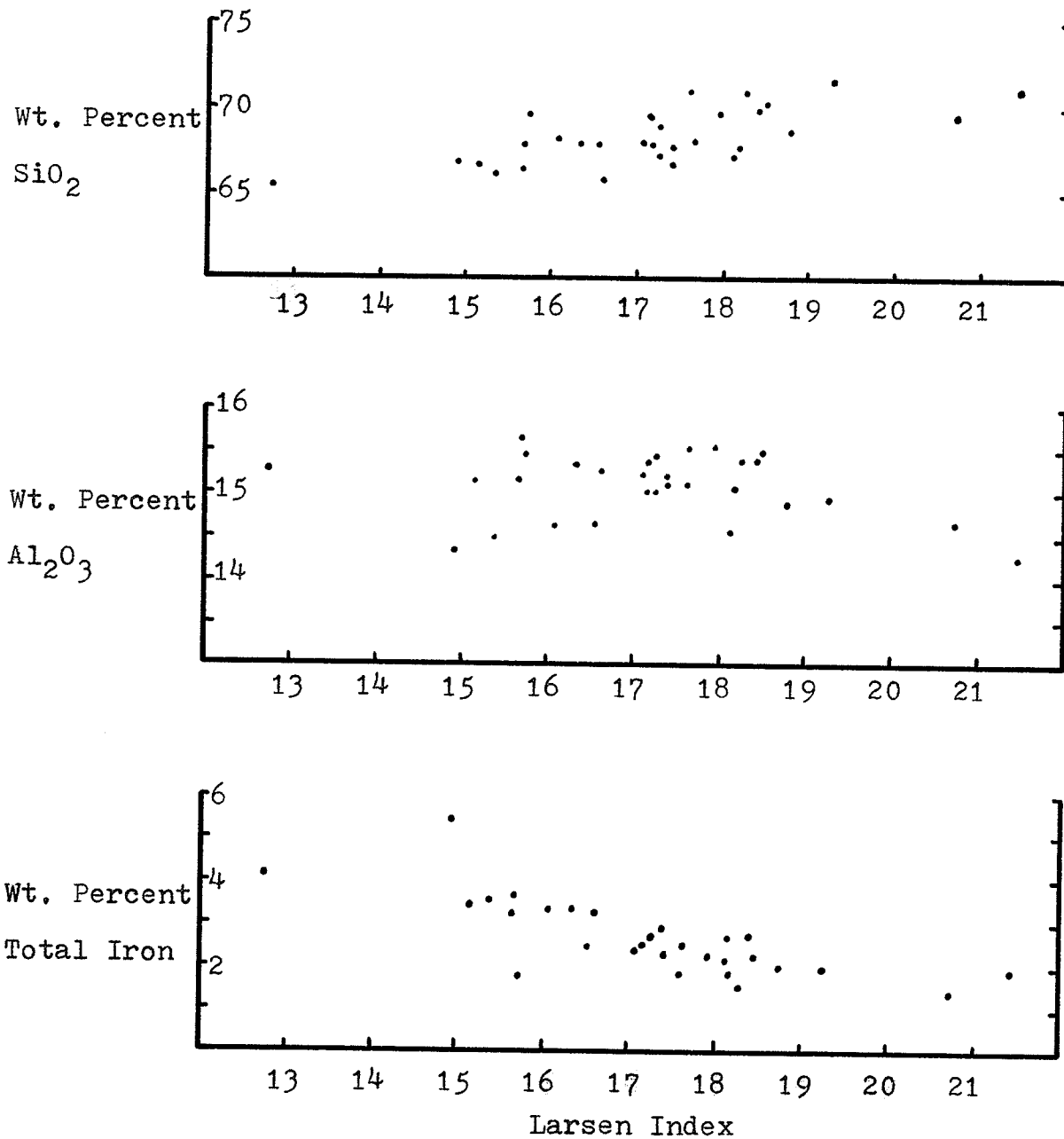


Figure 41a. Larsen variation diagrams for percent SiO₂, Al₂O₃, and (Fe₂O₃ + FeO). Larsen index number = $\frac{1}{3} \text{SiO}_2 + \text{K}_2\text{O} - \text{Total Iron} - \text{MgO} - \text{CaO}$.

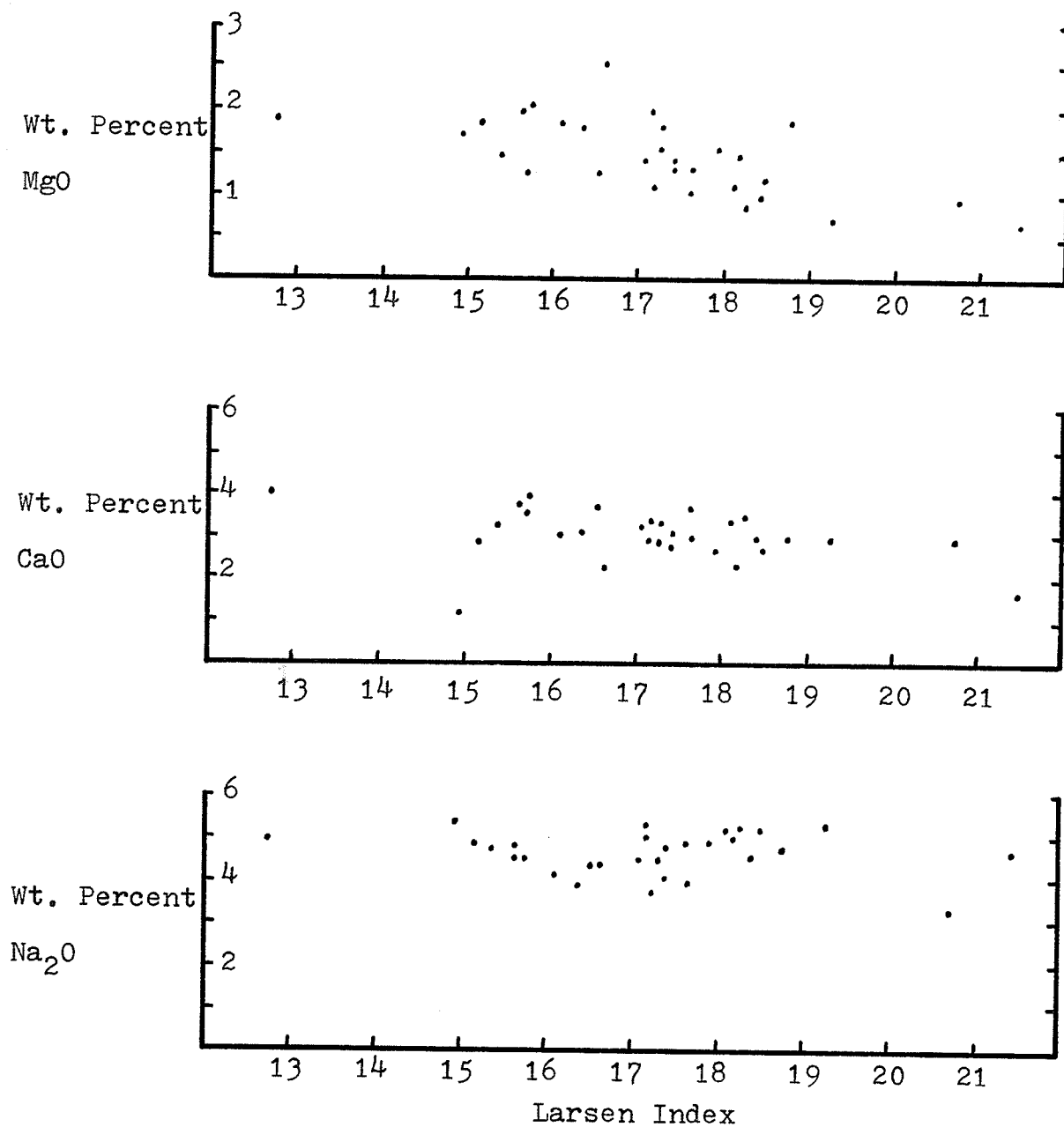


Figure 41b. Larsen variation diagrams for percent MgO, CaO, and Na₂O. Larsen index number = $\frac{1}{3} \text{SiO}_2 + \text{K}_2\text{O} - \text{Total Iron} - \text{MgO} - \text{CaO}$.

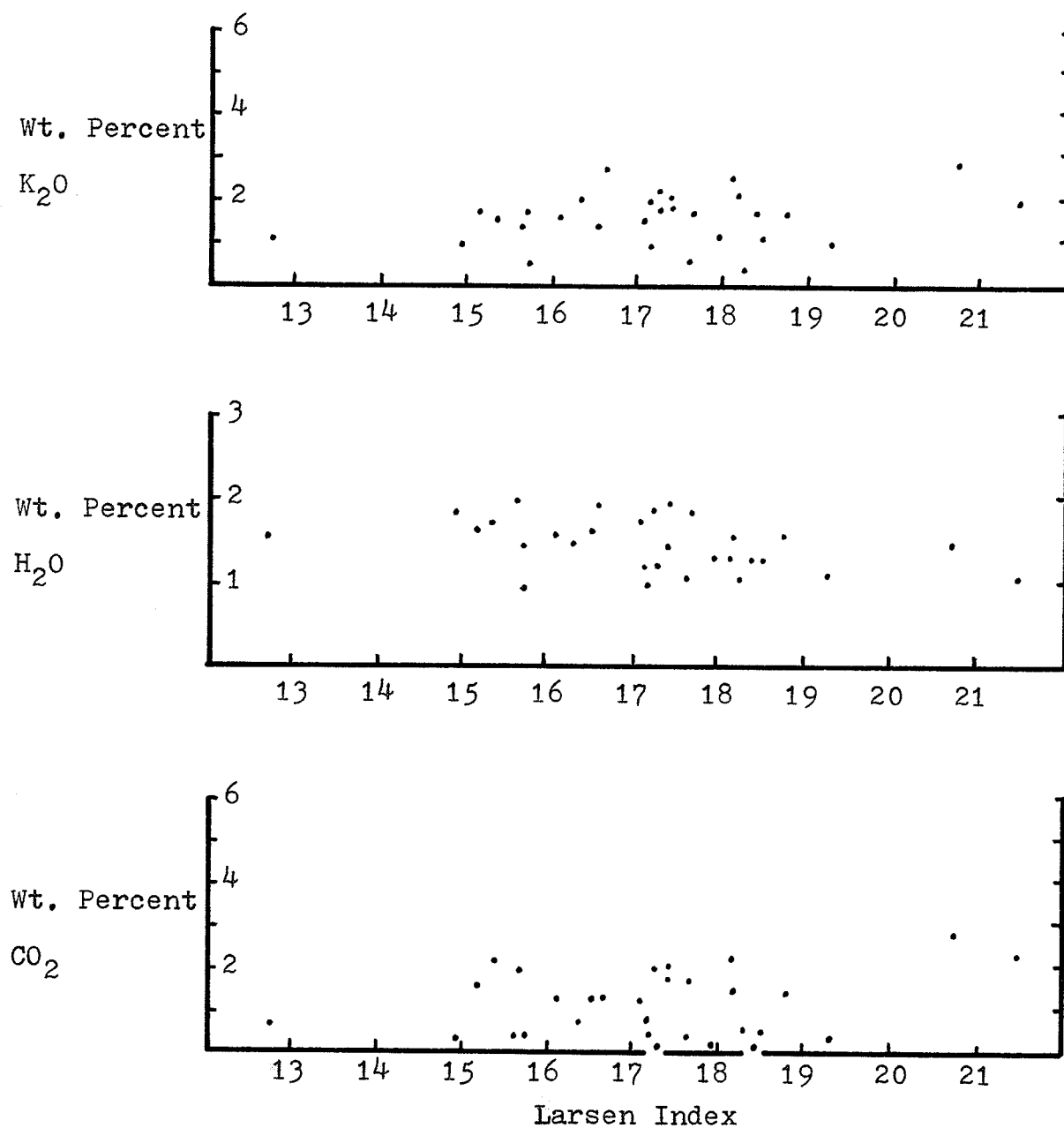


Figure 41c. Larsen variation diagrams for percent K_2O , H_2O , and CO_2 . Larsen index number = $1/3 SiO_2 + K_2O - \text{Total Iron} - MgO - CaO$.

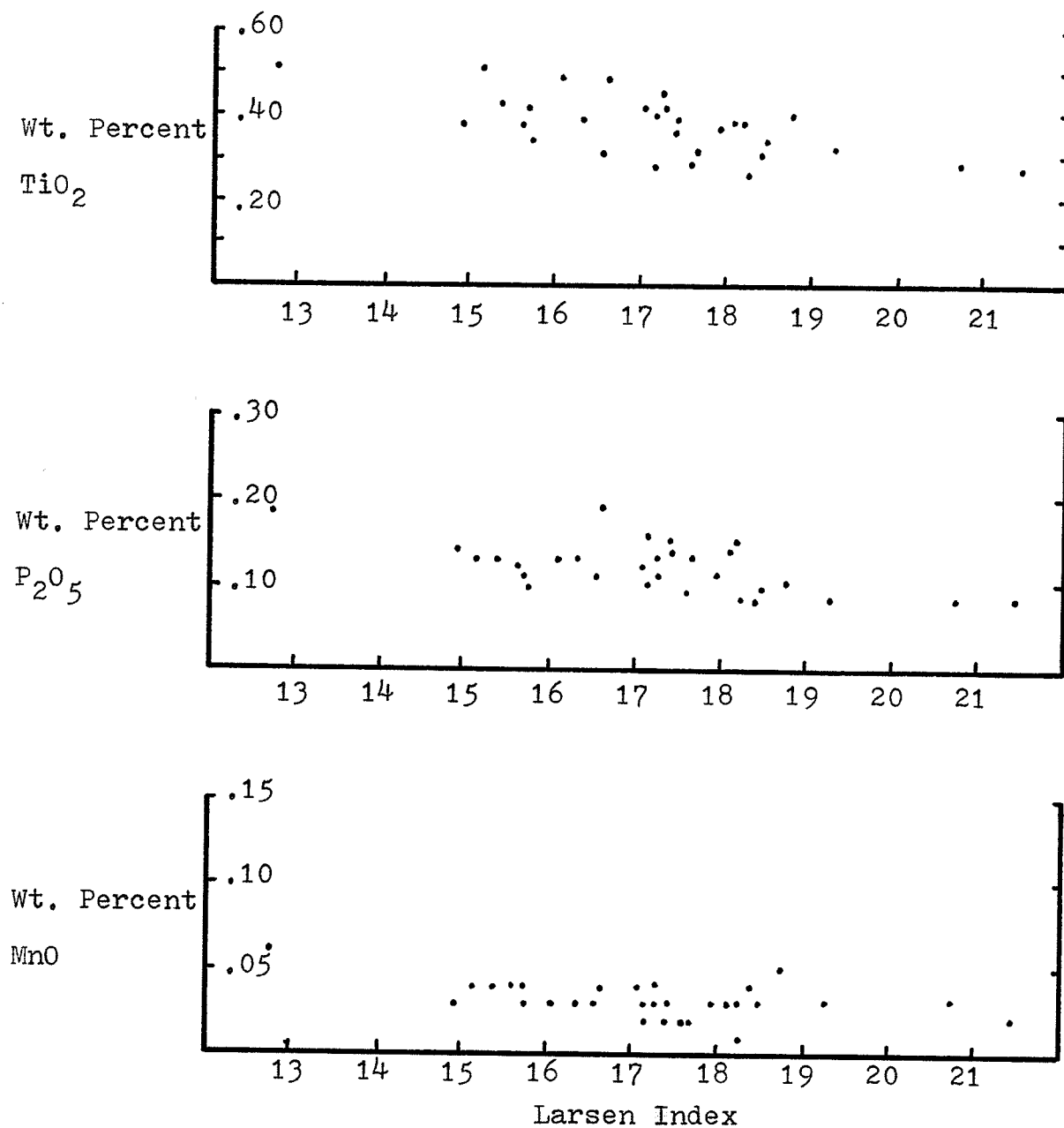


Figure 41d. Larsen variation diagrams for percent TiO_2 , P_2O_5 , and MnO. Larsen index number = $\frac{1}{3} \text{SiO}_2 + \text{K}_2\text{O} - \text{Total Iron} - \text{MgO} - \text{CaO}$.

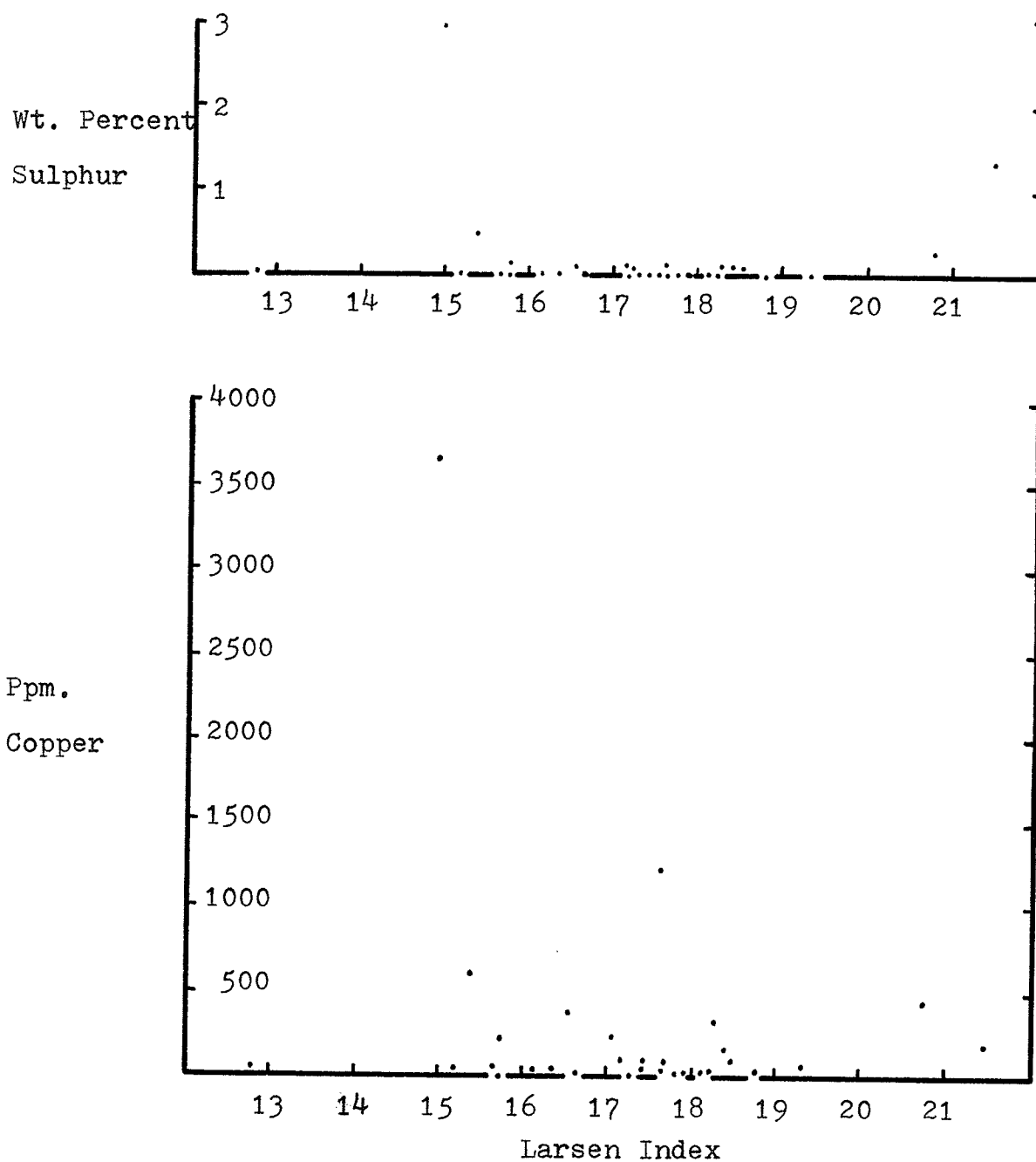


Figure 42a. Larsen variation diagrams for percent sulphur and ppm. copper. Larsen index number = $\frac{1}{3} \text{SiO}_2 + \text{K}_2\text{O} - \text{Total Iron} - \text{MgO} - \text{CaO}$.

break away from the overall trend. It is justifiable to disregard these two sulphur concentrations when examining the trend, because both these samples were taken adjacent to mineralized veins and do not represent a typical quartz diorite sample.

Figures 42a, 42b, and 42c show the trace elements plotted against their Larsen index numbers. The trend line for rubidium increases moderately toward the final stages of crystallization. Copper shows a major increase in concentration with decreasing temperature near the end of magmatic activity. The plots for nickel and zinc display minor decreases in concentration as the crystallization process was continued. Finally, cobalt and lead are noticeably steady in their concentrations throughout crystallization of the Canoe Lake quartz diorite.

Conclusions

The crystallization process within the Canoe Lake stock can be deduced from a study of the contoured chemical analyses with modal contour plots for the primary and alteration minerals. Although the solidification pattern appears complex and irregular, a poorly developed trend from the outer margins to the central portions of the quartz diorite intrusion is discernible.

SiO_2 and Al_2O_3 show high concentrations between

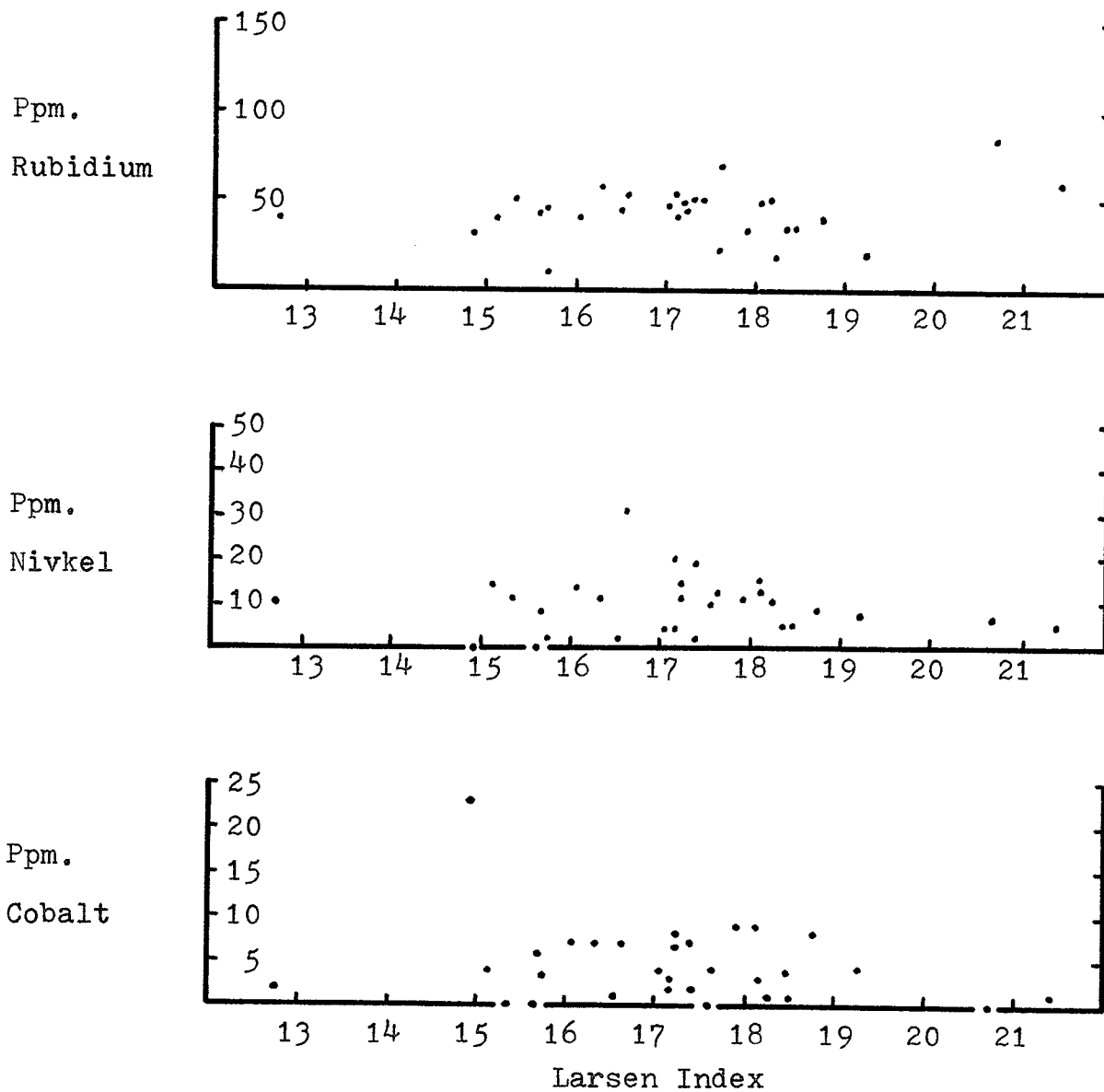


Figure 42b. Larsen variation diagrams for ppm. rubidium, nickel, and cobalt. Larsen index number = $\frac{1}{3} \text{SiO}_2 + \text{K}_2\text{O} - \text{Total Iron} - \text{MgO} - \text{CaO}$.

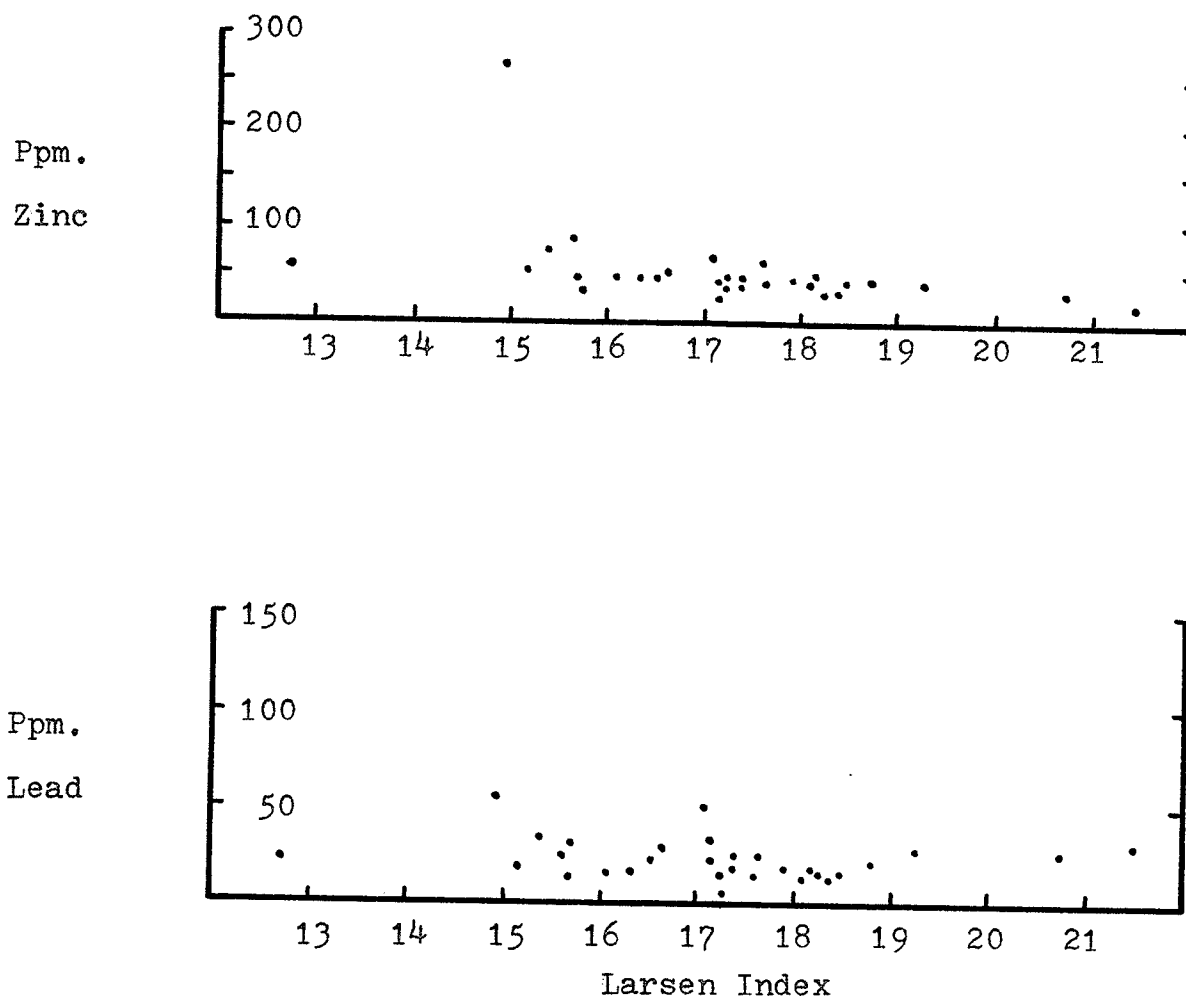


Figure 42c. Larsen variation diagrams for ppm. zinc and lead.
Larsen index number = $\frac{1}{3} \text{SiO}_2 + \text{K}_2\text{O} - \text{Total Iron} - \text{MgO} - \text{CaO}$.

Squaw Lake and Bag Bay, indicating later crystallization of the intrusive centre. The centrally low concentrations of Fe_2O_3 and MgO substantiate this conclusion, although low values of K_2O , H_2O , and CO_2 in the core of the pluton appear to contradict a late crystallization. The author suggests that these oxides may be centrally concentrated at greater depths than illustrated by the present level of erosion and due to irregular upward migration of the hydrothermal solutions they became offset from the exposed centre. The presently exposed internal high degree of alteration (Figure 19) is controlled by high sericite, chlorite, and clinozoisite, whereas carbonate is concentrated away from the centre.

The major area for metal-bearing hydrothermal activity was in the Squaw Lake - Potter Lake region, as depicted by high concentrations of sulphur, copper, cobalt, zinc, lead, and molybdenum.

The contoured chemical analyses and modal contour plots are in general agreement with the results of the Larsen variation diagrams.

STRUCTURAL FEATURES OF THE HOST INTRUSION

General Statement

The Canoe Lake stock is an oval-shaped igneous body, elongate in a northeast direction along the axial

trace of an anticlinal structure, which served as a favorable site for the intrusion. The adjacent mafic metavolcanic and minor metasedimentary rocks are foliated parallel to the contact and dip steeply away from the stock. Carbonatized shear zones are contained in the metavolcanic rocks near the intrusive boundary. Pillows are elongate parallel to the igneous margin and granitic dikes are buckled normal to the contact. Clifford (1972) describes a similar situation in the Lake St. Joseph area of northwestern Ontario, and attributes this flattening mode to diapiric intrusion of a granitic pluton.

The massive quartz diorite stock shows sharp contact features, intricate fracturing, shearing, minor occurrences of xenoliths, and numerous younger felsic intrusions.

Foliation and Contact Features

Flow Foliation

Flow foliation within the Canoe Lake stock is occasionally distinguishable on a microscopic scale by partial mineral alignment and interlocking grain boundaries, which suggest crystallization during sluggish flow of the magma. This foliation is parallel to the north and south contacts of the intrusion. Petrographic studies also indicate minor milling of grain contacts, yielding a protoclastic foliation. This foliation type suggests movement of the

granitic crystal mush during emplacement.

A megascopic flow pattern resembling a fold is present in the Canoe Lake area near the contact zone. This fold is unique, as other similar features were not identified in the field. It was probably caused by a swirling flow motion in the granitic magma during emplacement. Plagioclase and hornblende crystals show semi-parallel alignment due to flow movements. Strike and dip of the axial plane of this fold are $166^{\circ}/60^{\circ}\text{SW.}$ and the axis plunges $58^{\circ}/280^{\circ}$.

These foliation features could be syntectonic if the central portions of the stock are assumed to have been mobile during regional deformation.

Cataclastic Foliation

The Canoe Lake stock displays cataclastic foliation only within contact zones and along shear zones. Penetrative cataclastic foliation does not occur throughout the central parts of the intrusion, which suggests that the granitic body was not pretectonically emplaced. Dips of the foliation planes within the intrusive contact zone are everywhere steep and away from the centre of the stock. In the north and northeast the cataclastic foliation strikes approximately east-west and dips 75 to 85 degrees: in the south the east-west foliation dips less steeply from 55 to 65 degrees.

This cataclastic foliation is well developed in

hand specimens of the quartz diorite along the contacts and at shear zones. Figure 43 illustrates a photomicrograph of a foliated sample taken from the Squaw Lake contact zone. The deformational fabric is due to stringers of sericite and large flakes of chlorite being aligned in the rock. Broken crystals and sheared and granulated grain boundaries are numerous in thin sections from the contact areas. Involvement of the alteration minerals in this type of foliation suggests that the outer margins of the Canoe Lake stock were crystallized and altered at the time of regional deformation.

Brittle deformation along shear zones, which produced cataclasis in the quartz diorite, probably took place during a later period of deformation. This is suggested by the existence of these shear zones within the central portions of the Canoe Lake stock, which were still mobile when the cataclastic border foliation was produced.

Contact Features

The border of the Canoe Lake quartz diorite is sharp and Figure 44a illustrates the distinct break between the intrusion and the adjacent rocks. In other exposed areas of the contact minor brecciation and hybridization of the two rock types has taken place. This is evident in Figure 44b.

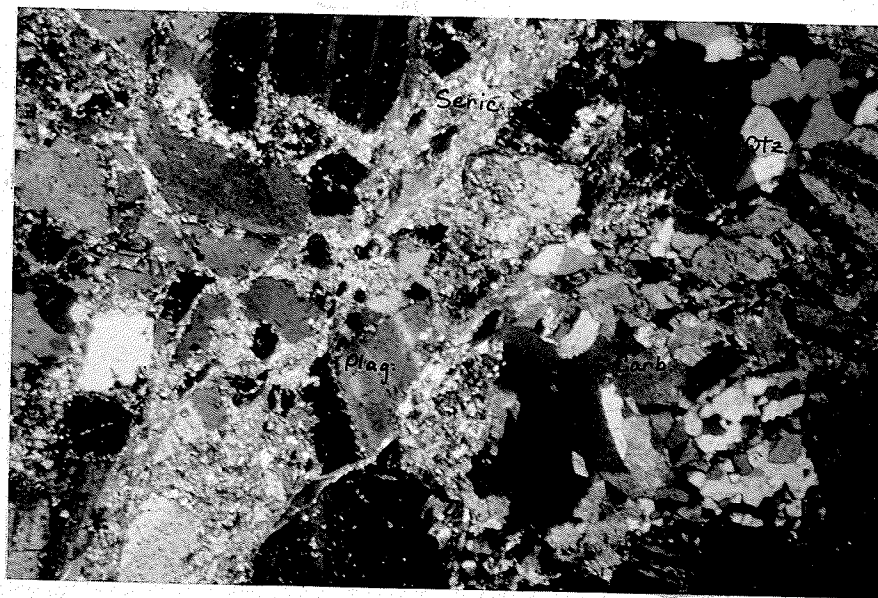


Figure 43. Photomicrograph of foliated quartz diorite from the Squaw Lake area.

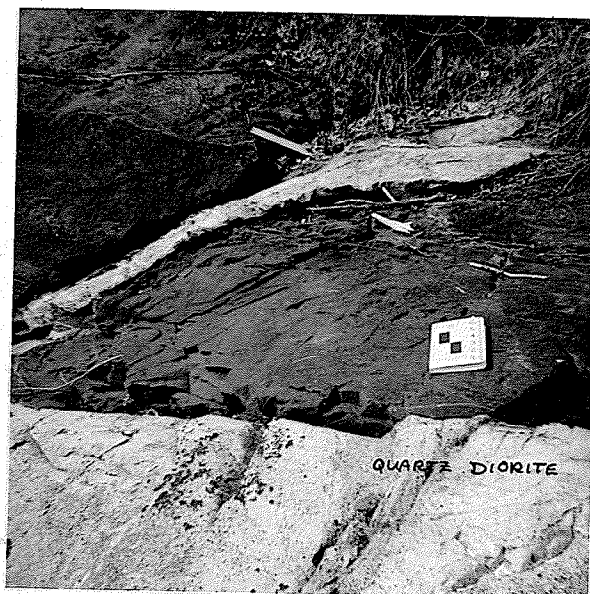


Figure 44a. Distinct contact between the quartz diorite stock and the mafic metavolcanic rocks in the Bag Bay area.

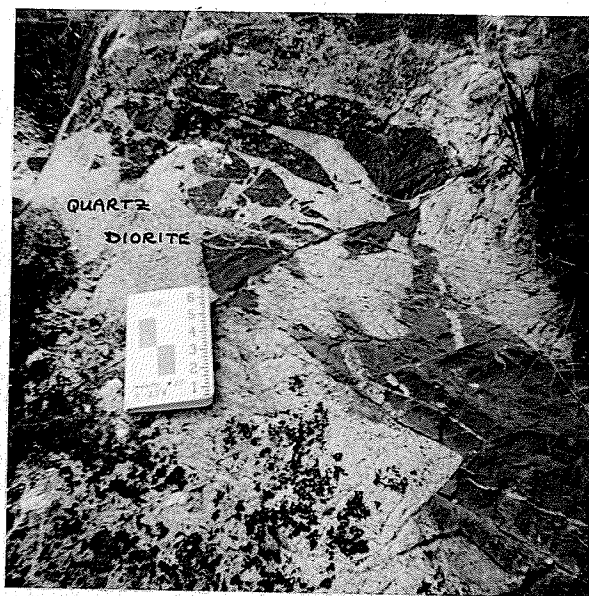


Figure 44b. A less distinct contact, resulting from brecciation and hybridization of the quartz diorite intrusion and the mafic metavolcanic rocks in the Bag Bay area.

The intrusive contact between Bag Bay and Helldiver Bay is believed to be fracture-controlled (Davies, 1972), since the edge is delineated by a series of perpendicular straight lines. Foliation in the stock at this boundary strikes parallel to these lines and is vertical. The structural aspect of the mafic metavolcanic rocks and mafic to ultramafic intrusions is another notable feature of the western contact. These units have been subjected to regional east-west faulting. According to Davies (1972) the movement appears to have been right lateral and to have post-dated the igneous activity. Thus, the massive metavolcanic rocks and mafic intrusions remained resistant during the granitic intrusion and were forced to fracture to allow for emplacement of the stock. Later shearing effects offset the fracture-controlled boundary, resulting in the observed perpendicular lines. A major concentration of xenoliths is found in the Bag Bay - Helldiver Bay portion of the Canoe Lake stock.

A number of pegmatitic offshoots are present in the adjacent rocks near the contacts. Three small, elongate offshoots of the granitic pluton penetrate the metavolcanic and mafic intrusive rocks south of the Bag Bay area. These offshoots are curved to folded, do not exceed a half mile in length, and trend east-west to northwest. Figure 45 illustrates a folded and fractured quartz-feldspar vein running into fine-grained gabbro. The photograph was taken near the southeast

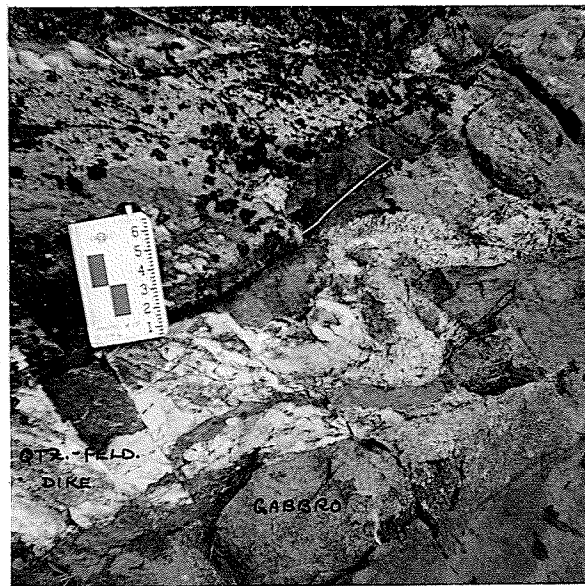


Figure 45. A folded and fractured quartz-feldspar dike dissecting fine-grained gabbro on the north shore of Shoal Lake Narrows.

contact of the stock at Labyrinth Bay.

Fracturing and Air Photo Lineaments

Fracturing and Shearing

The Canoe Lake stock is riddled with fractures ranging in size from microscopic to tens of feet in length. Some of the air photo lineaments represent large fractures extending up to a mile and a half in length. The intricate fracturing of the Canoe Lake quartz diorite is typical of porphyry copper mineralized granitic intrusions.

Over 1100 fracture directions were measured in the field. The fractures are vertical in most cases. Fracture traces vary from straight to curved and in many places radiate in straight lines through small angles or form horse-tailing aggregates of curved lines (see Figure 46). Spacing measurements were difficult due to the intricacy of fracturing, although from available data the average spacing ranges from 8 inches to 1 foot. Figure 47 illustrates the fracture spacing in a less complexly fractured outcrop.

A non-statistical rose diagram of strike directions for all measured fractures is given in Figure 48. Although more fracture readings were taken in the well exposed south and southwest portions of the intrusion, the plot is essentially unbiased because the various fracture directions are

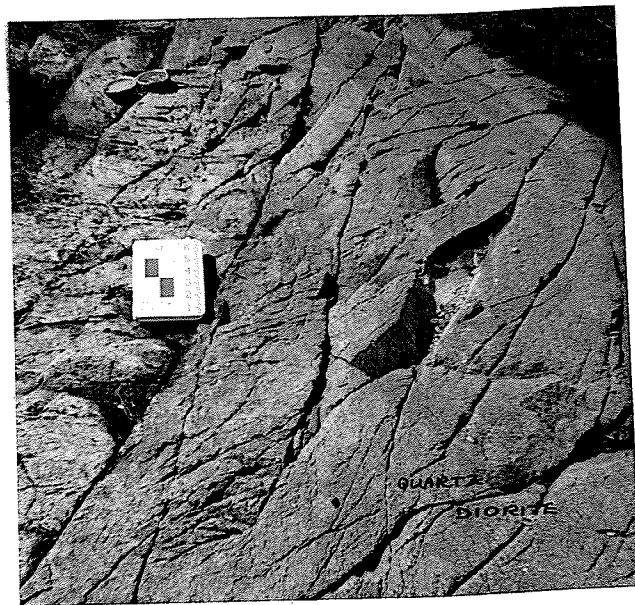


Figure 46. Horsetailing aggregates of curved fractures in the Canoe Lake quartz diorite near Squaw Lake.

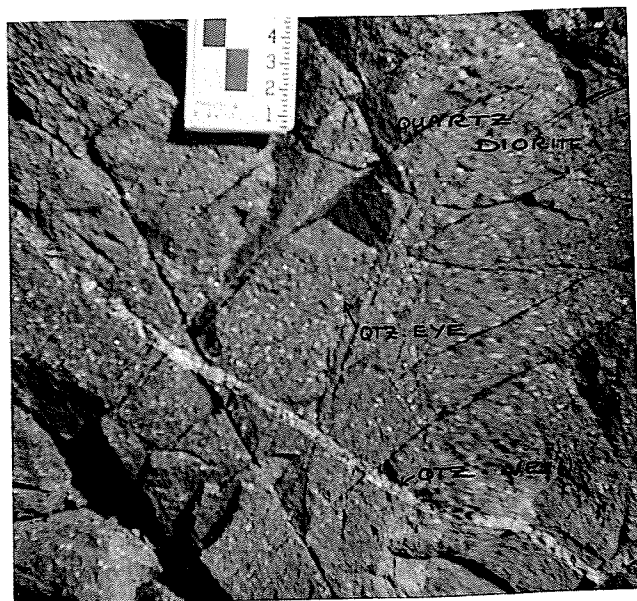


Figure 47. Typical fracture spacing in a less complexly fractured outcrop on the north shore of Squaw Lake.

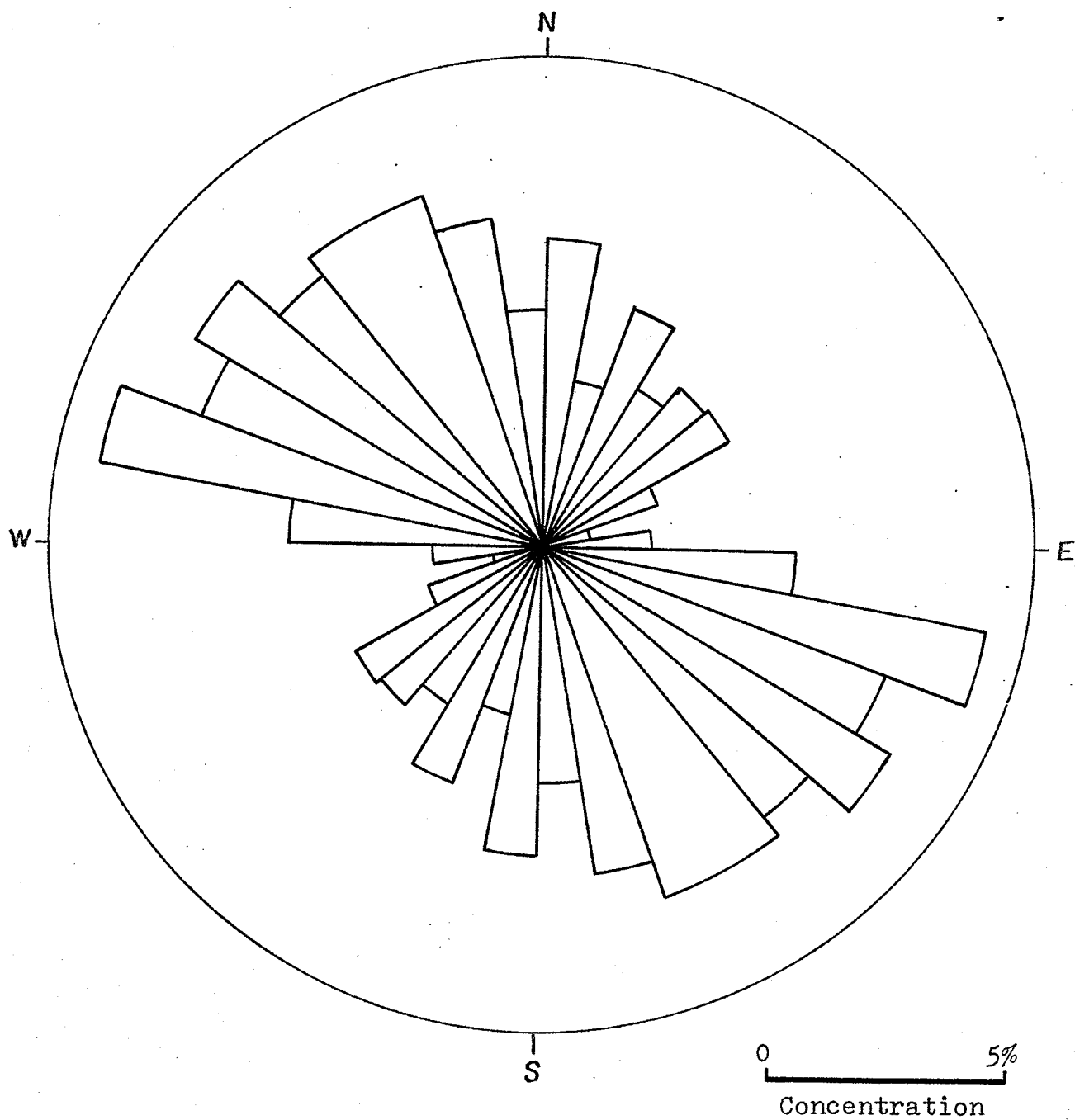


Figure 48. A rose diagram of all measured fracture strike directions in the Canoe Lake stock. (1170 strike directions were plotted; sampling is non-statistical).

uniform across the stock. A concentration of fractures lies within the 100° to 170° range. The largest concentration exists within the 100° to 109° interval. This northwest fracture trend is approximately perpendicular to the elongation of the Canoe Lake stock.

More than one period of fracturing has taken place in the quartz diorite pluton, resulting in the pattern portrayed by Figure 49. The fractures have been dated as pre- and post-hydrothermal alteration in age. The age relationships were significantly documented in a number of outcrops. The major strike directions of 240 pre-hydrothermal fractures were plotted in a rose diagram shown in Figure 50. This diagram depicts a main concentration along 135° and a nearly perpendicular, less distinct concentration along 035° . These two sets of fractures correspond to the cross joints and longitudinal joints of elongate igneous intrusions described by Balk (1937). The northwest and northeast pre-hydrothermal fracture directions are coincident with the two contour trends in the percent total alteration plot (see Figure 19). As mentioned earlier, Figure 19 shows a main contour trend in a northwest direction, paralleling the main fracture trend, and a subordinate trend in a northeast direction, paralleling the less distinct pre-hydrothermal fracture trend. Therefore, Figure 19 may possibly depict variations in the concentration of these two sets of pre-hydrothermal fractures. A statistical measure of the variation in fracture spacing

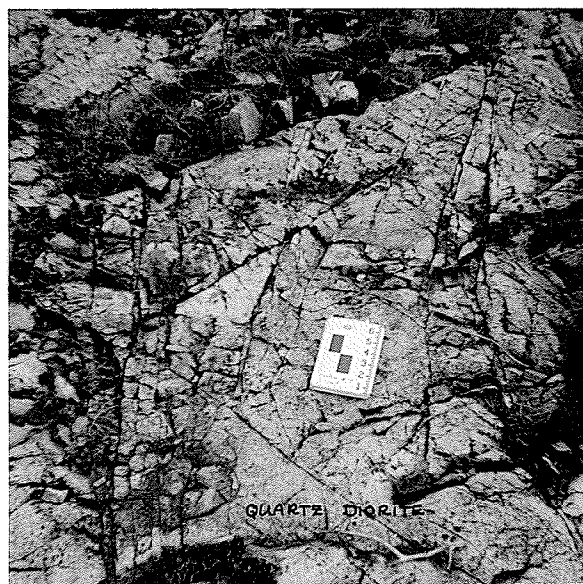


Figure 49. Intricate fracture pattern in the Canoe Lake stock, resulting from the formation of cross and longitudinal fractures with superimposed post-hydrothermal fractures.

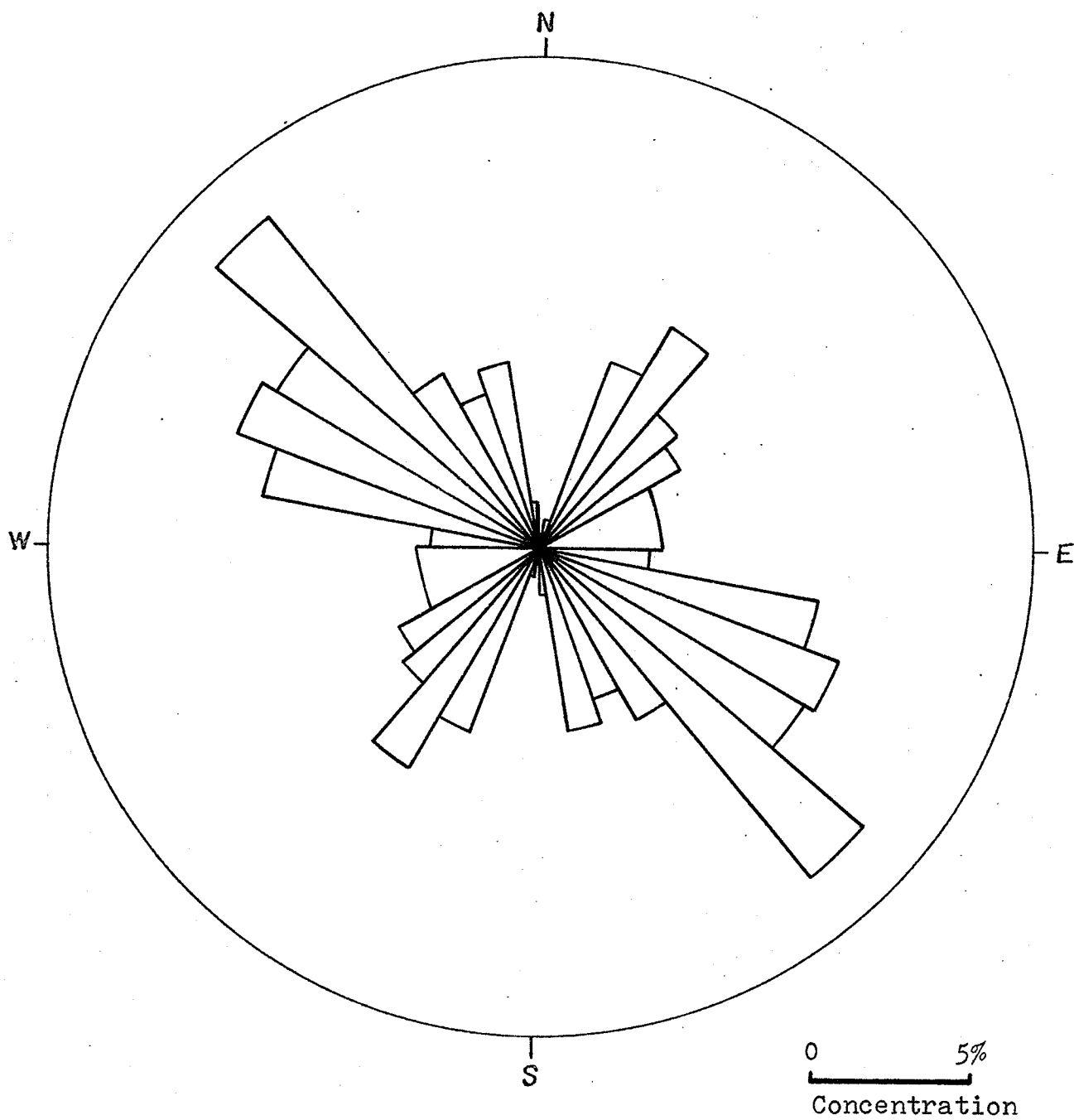


Figure 50. A non-statistical rose diagram of strike directions for pre-hydrothermal fractures in the Canoe Lake stock. (240 strike directions were plotted).

was not attempted, but the pattern of degree of alteration may reflect it, such that the closer the spacing, the higher the degree of alteration in the intrusion. The abundance of quartz-chlorite and quartz-carbonate veins along these two pre-hydrothermal fracture directions substantiates the view that these fractures acted as channelways for the hydrothermal solutions causing alteration.

Fracture-filled veins have been subjected to shearing effects in some places and the development of slickensides is prominent. Twenty-five sheared hydrothermal veins have been plotted on the rose diagram in Figure 51. An outstanding concentration lies within the 100° to 109° interval, while a much less prominent concentration exists at right angles. Other fractures, parallel to the two pre-hydrothermal fracture trends but devoid of hydrothermal vein material, are also sheared as recognized by the slickensided fracture walls. A sheared quartz-chlorite vein in the Squaw Lake area is shown in Figure 52.

Air Photo Lineaments

All air photo lineaments within the intrusion are plotted on the accompanying geologic map, as well as the major pre-hydrothermal fracture directions. These air photo lineaments are straight to curved and range in length from about $1/4$ mile to more than 1 and $1/2$ miles. Measurements of

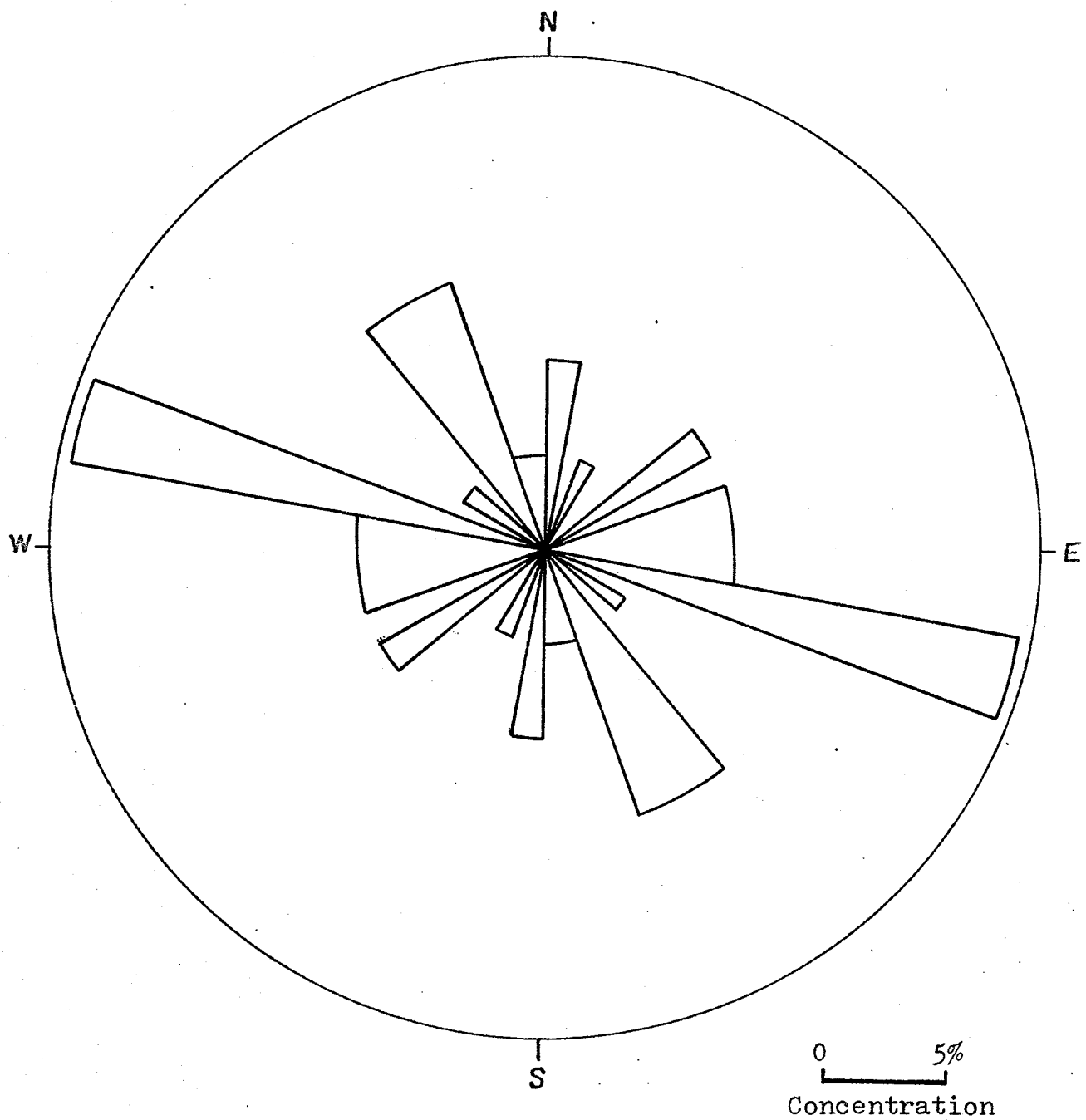


Figure 51. A rose diagram of 25 strike directions of sheared hydrothermal vein-filled fractures. (Sampling is non-statistical).

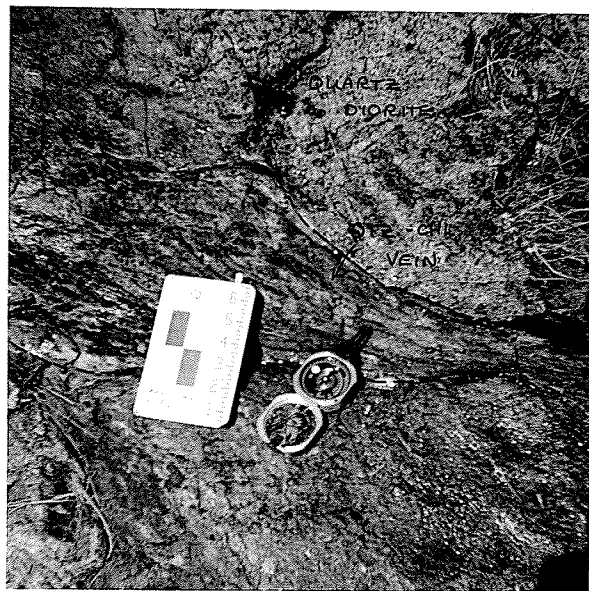


Figure 52. A sheared quartz-chlorite vein in the Squaw Lake area. Note the irregular shape of this foliated hydrothermal fracture-filling.

trend were taken on all of these lineaments and two strike directions were recorded where lineaments had a significant curve. The dip of the lineament planes is assumed to be vertical or nearly vertical. The resulting rose diagram is shown in Figure 53. A major trend is developed parallel to 45° , which is approximately coincident to the second most prominent pre-hydrothermal fracture direction. Very few air photo lineaments exist with strikes parallel to the main northwest-trending pre-hydrothermal fractures. Some of the lineaments are thought to represent large scale fractures: others appear to be major shear zones. The latter interpretation is substantiated by local cataclastic foliation parallel to the lineament.

Distribution of Xenoliths

Inclusions in the Canoe Lake stock are infrequent. Near the contacts there are small xenoliths, about 1 to 2 feet across, which are rounded to elongate in a northeast direction. Foliation is absent in the inclusions; they are massive and usually fine-grained. Their boundaries are distinct, as shown in Figure 54, although blurred reaction rims may be present (see Figure 55). Only one large xenolith occurs in the quartz diorite stock; it measures 400 feet in width and 1700 feet in length. This fine-grained, massive basalt inclusion is southwest of Love Lake and trends north-

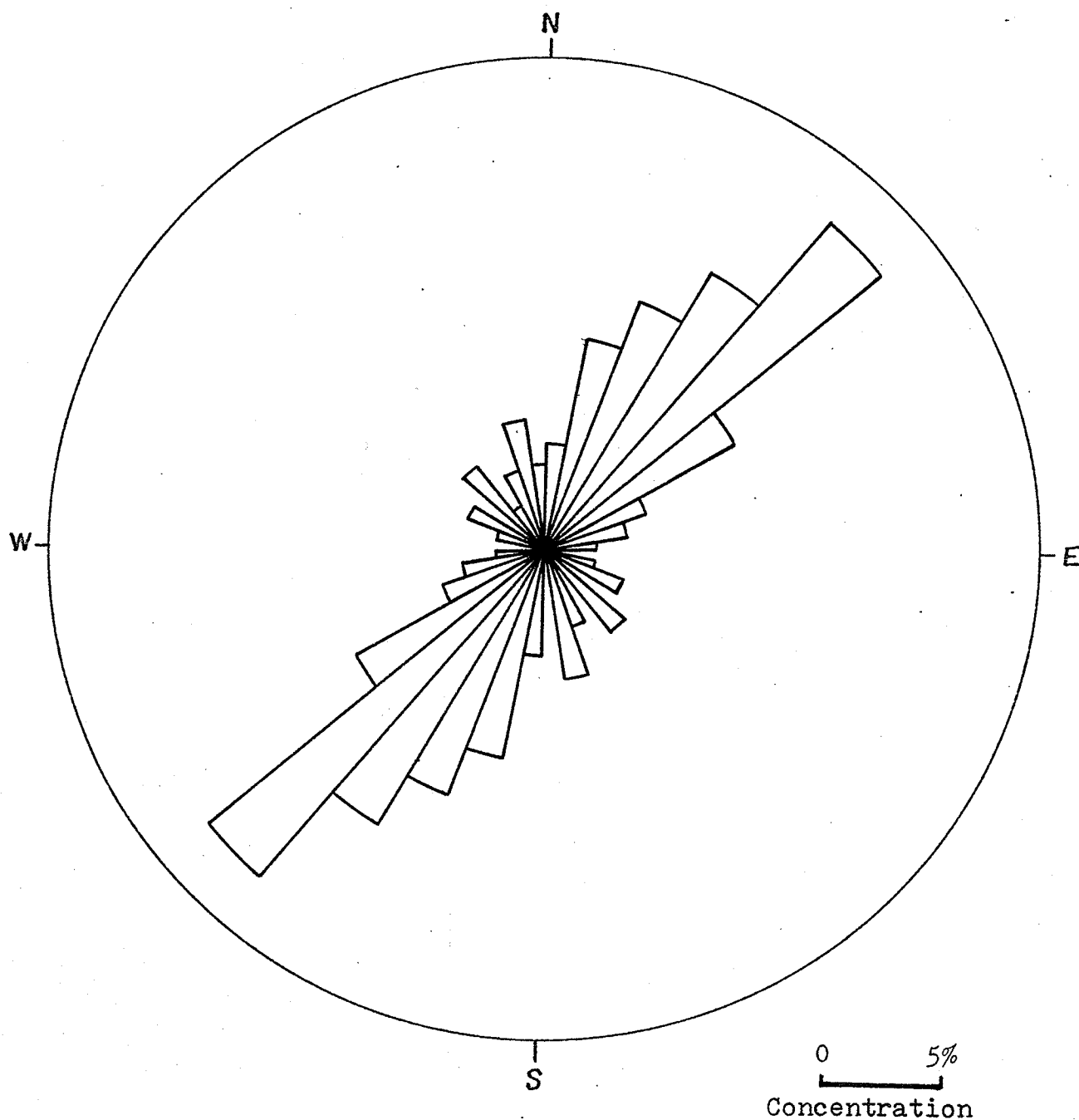


Figure 53. A rose diagram of all air photo lineament strike directions in the Canoe Lake stock. (90 strike directions were measured from the air photos; sampling is non-statistical).



Figure 54. Xenoliths in the quartz diorite showing distinct boundaries. The outcrop is in the Bag Bay area.

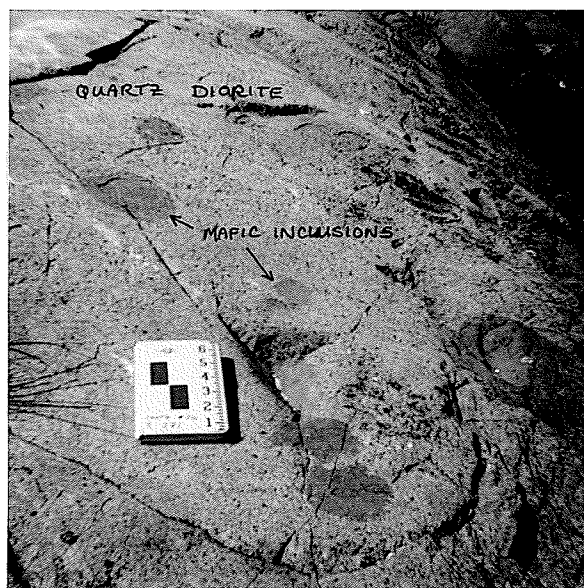


Figure 55. Minor blurred reaction rims around small massive xenoliths in the quartz diorite stock near Bag Bay.

east. Xenoliths appear to be most abundant in the Bag Bay - Helldiver Bay area.

Figure 56 is a rose diagram showing the orientation of the long horizontal dimension of nine inclusions. The prominent trend is sub-parallel to the two-dimensional long axis of the stock.

Younger Felsic Intrusions

Pegmatite Dikes and Quartz Veins

Pegmatitic phase intrusions are minor within the Canoe Lake stock. They tend to be restricted to a few potassium feldspar-quartz dikes. These dikes may or may not occur parallel to fractures, but are not fracture-controlled. They commonly crosscut the pre-hydrothermal fracture pattern. The granitic offshoots from the Canoe Lake intrusion are predominantly pegmatitic.

Quartz veins are common in the stock. Blocky white quartz is abundant along major pre-hydrothermal fracture directions and sheared fracture directions (see Figure 57). Small quartz veins occasionally crosscut pre-hydrothermal fracture trends, but are offset by post-hydrothermal fractures, as illustrated in Figure 47. The quartz veins are commonly associated with chlorite $\pm$ carbonate and display sulphide staining.

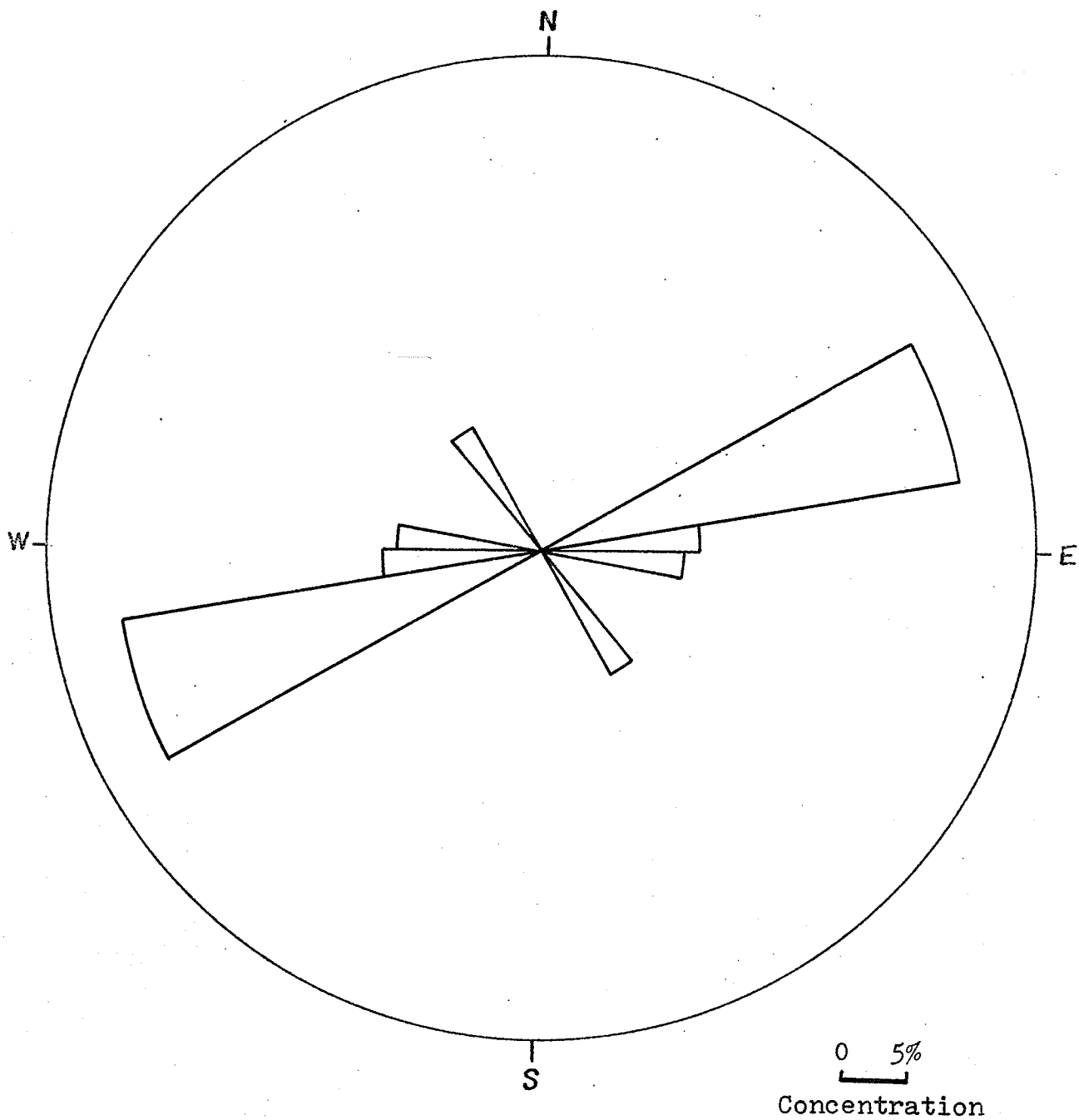


Figure 56. A non-statistical rose diagram of the two-dimensional elongation trend of nine inclusions.

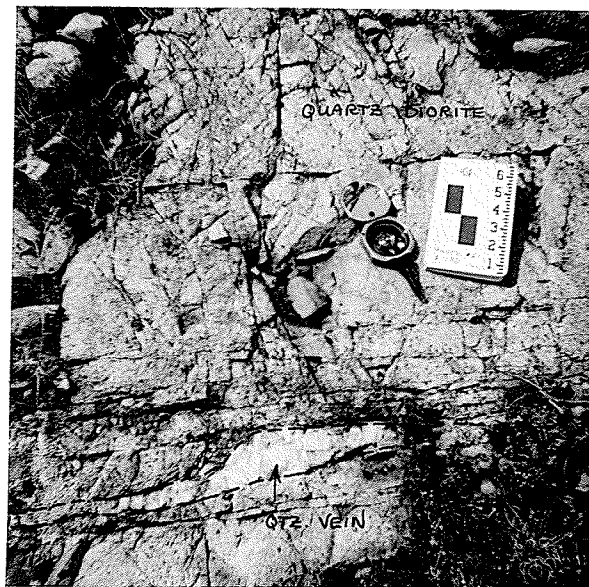


Figure 57. A sheared quartz-filled fracture in a small set of parallel fractures in the Canoe Lake quartz diorite.

Felsic Dikes and Irregular Intrusions

Quartz porphyry, quartz-feldspar porphyry, feldspar porphyry, and fine-grained granodiorite intrusions pervade the Canoe Lake stock. Their concentration is decreased in the adjacent rocks. These felsic rocks occur as dikes and irregularly shaped intrusive bodies, which may extend beyond the limit of the outcrop. The contact zones of the stock appear to favor these dikes, although they are distributed throughout the entire granitic mass. The weathered surface of the felsic intrusions is similar in color to that of the quartz diorite. Where this latter rock contains abundant quartz eyes the two granitic units are texturally similar and not easily distinguished.

Contacts between the stock and the felsic dikes are distinct, as shown in Figure 58, although some break-up and mixing of the quartz diorite has occurred in places (see Figure 59). Figure 59 shows the flow line pattern developed in a moderately wide quartz-feldspar porphyry dike. These flow lines are parallel to the contacts of the dike.

Figure 60 is a rose diagram of 25 felsic dike strike directions. A main concentration trends northwest and a subordinate, nearly perpendicular, direction trends northeast. These strike directions are parallel to the two pre-hydrothermal fracture trends. Post-hydrothermal fractures were observed to cut the dikes in some places. The

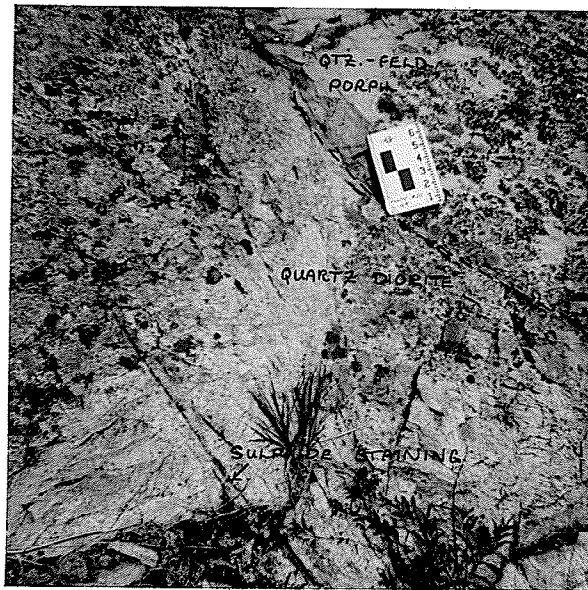


Figure 58. Distinct contact between a younger felsic dike intrusion and the quartz diorite pluton.

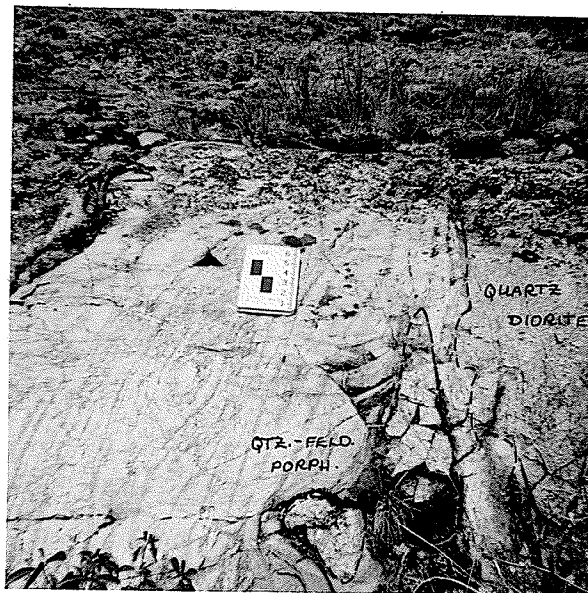


Figure 59. Minor break-up and mixing of the quartz diorite in a younger quartz-feldspar porphyry dike. Note the well developed flow line pattern in the dike.

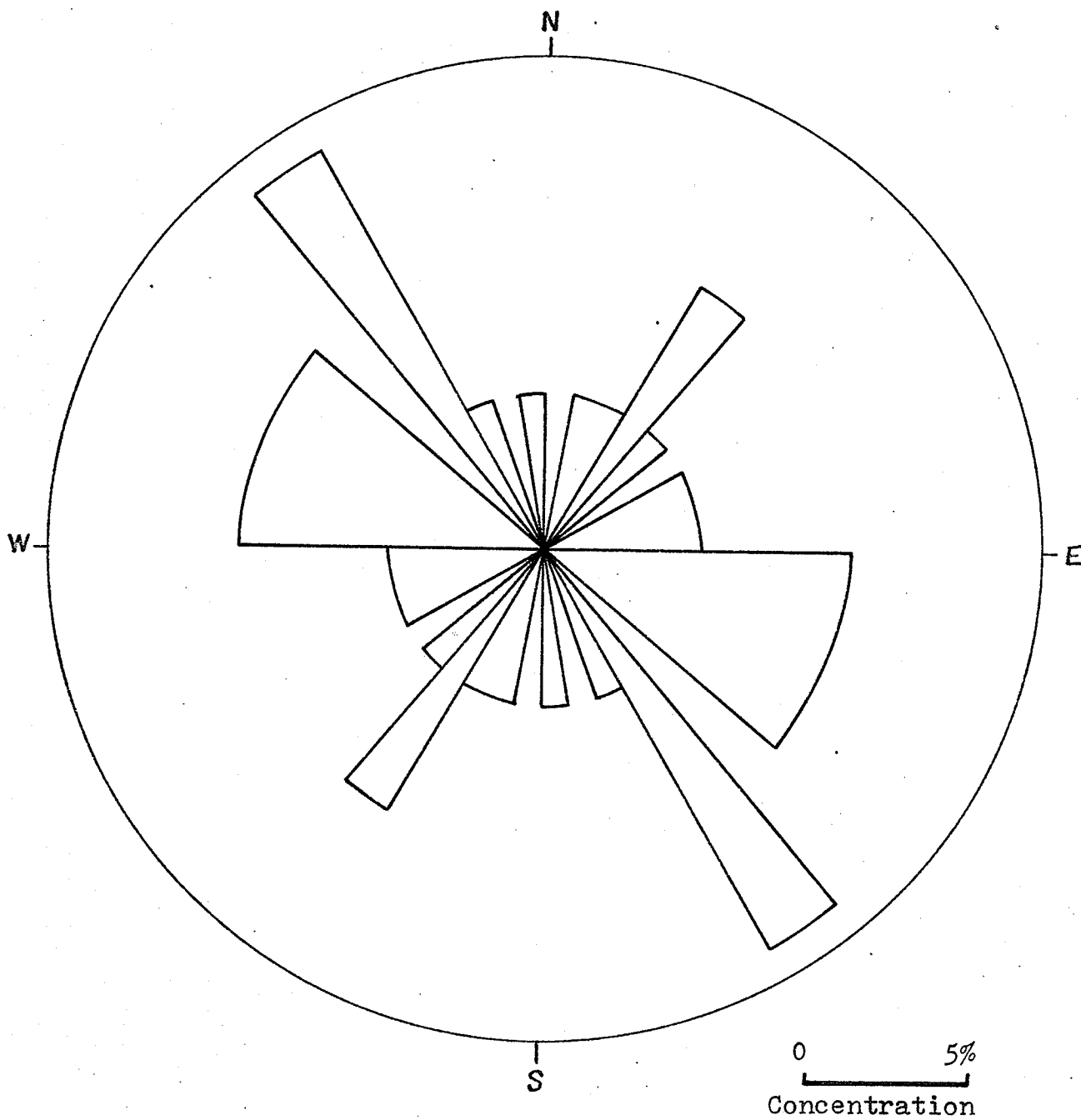


Figure 60. A non-statistical rose diagram of the strike directions of 21 younger felsic dike intrusions.

younger felsic intrusions are believed to be genetically related to the quartz diorite stock and probably represent an early hydrothermal phase prior to the alteration and mineralization stages.

Synopsis of Structural Processes

Imposed on the Canoe Lake Stock

The structural features of the stock represent more than one stage in a continuous deformational process, which acted on the syntectonic mineralized intrusion. The initial feature, related to the cooling and solidification of the quartz diorite pluton, is depicted by two pre-hydrothermal fracture sets striking 035° and 135° and dipping vertically. Other vertical pre-hydrothermal fractures, which resulted from cooling of the granitic magma, are abundant parallel to 105° and 165° .

Following emplacement and the numerous stages of hydrothermal alteration and mineralization, late brittle deformation resulted in shearing of the pre-hydrothermal fractures with preferential trends of 105° and 150° . Fracture wall slickensides are horizontal, however no relative sense of displacement could be determined. A possible interpretation to account for this movement is portrayed in Figure 61. The interpreted maximum principal stress direction is perpendicular to the long dimension of the intrusion, sug-

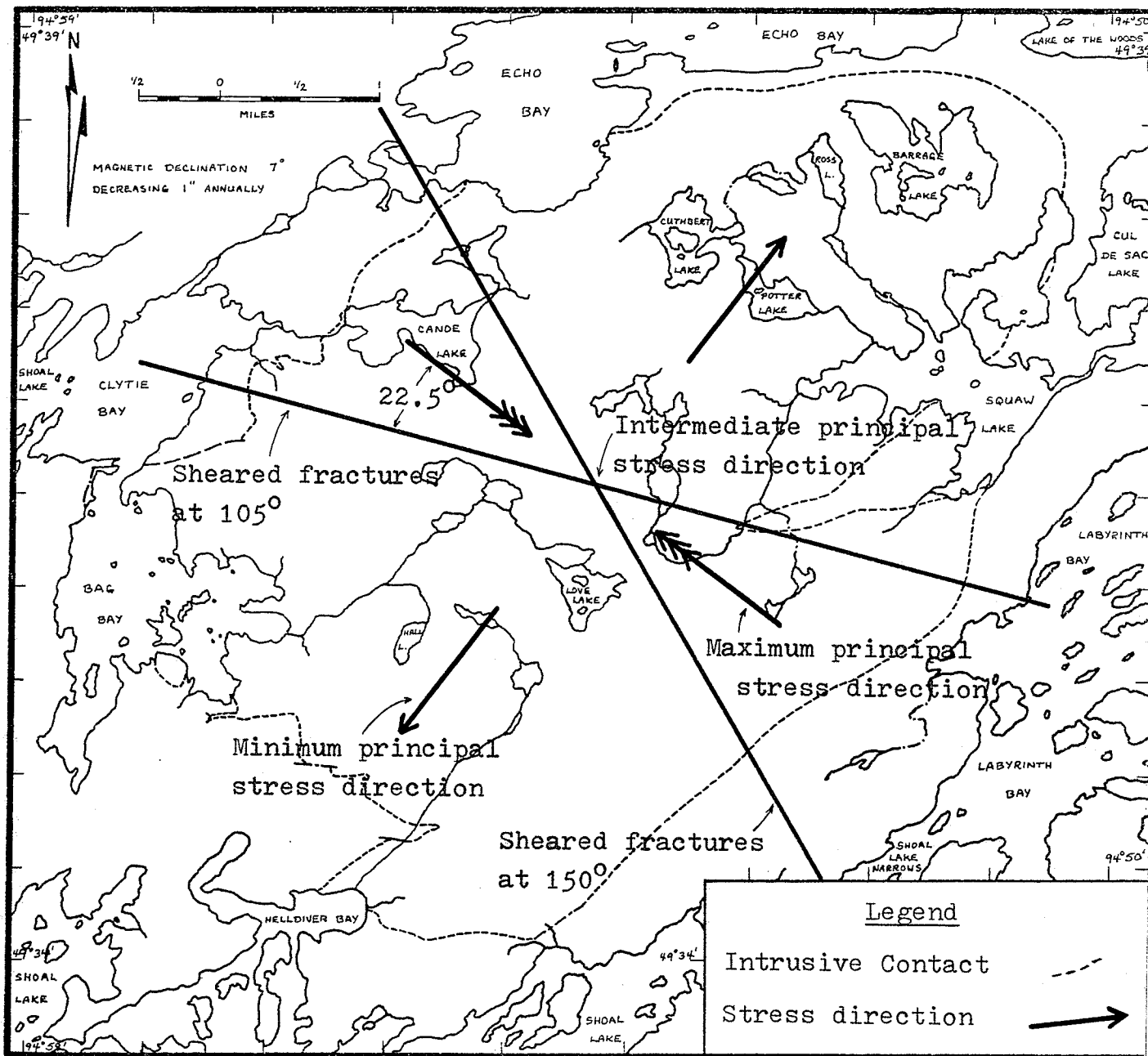


Figure 61. Diagrammatic interpretation of the stress directions imposed on the Canoe Lake stock and surrounding rocks. The measurement of more sheared fracture directions may possibly have resulted in an angle of shear rupture closer to the theoretical 30° value (Spencer, 1969).

gesting that this brittle deformation was a late stage of one continuous deformational process.

Davies (1969) interpreted the faults and shears, trending 105° in the adjacent rocks of the Bag Bay - Hell-diver Bay area, as right lateral shear zones. These linear features may have been produced by the same stress conditions which acted on the stock after emplacement and solidification. Thus, the shears within the intrusion would also be right lateral.

In summary, it should be mentioned that the abundance of porphyritic felsic dikes, lack of pegmatite veins, lack of a penetrative foliation or lineation, sharp contacts, and intense fracturing are indicative of epizonal emplacement of the Canoe Lake stock (Buddington, 1959).

MINERALIZATION PATTERN IN THE HOST INTRUSION

General Statement

The Canoe Lake stock is an epizonal quartz diorite intrusion, which has been highly fractured, altered, and mineralized. The sulphide minerals are ubiquitous pyrite, chalcopyrite, pyrrhotite, sphalerite, and molybdenite. Gold mineralization is also associated with the stock.

The sulphide minerals are concentrated near Squaw Lake and Potter Lake and a band, containing a relatively

high percent total sulphides (more than 0.2 percent), extends across the stock to Bag Bay. The hydrothermal alteration-mineralization pattern is zoned in the Squaw Lake area.

The copper-molybdenum-zinc mineralization in the Canoe Lake stock can be classified as porphyry copper type. Although the mineralization is not of ore grade and such a possibility is rather remote, the type of sampling undertaken in the area of highest copper-molybdenum-zinc mineralization and the extent of overburden and water in the area of most concentrated mineral occurrences does not preclude the possibility of the presence of a significant porphyry copper deposit (L. King, personal communication).

Description of Sulphide Mineralogy and Sulphide Distribution

Copper, Molybdenum, and Zinc Sulphides

The sulphide minerals in the Canoe Lake stock are, in order of abundance, pyrite, chalcopyrite, pyrrhotite, sphalerite, and molybdenite. Pyrite and chalcopyrite exist as crystals and irregularly shaped grains; pyrrhotite and sphalerite occur as grains; and molybdenite appears as fine wisps and flakes in thin section. Figure 62 is a photomicrograph of disseminated pyrite and chalcopyrite, and Figure 63 illustrates molybdenite and pyrite.

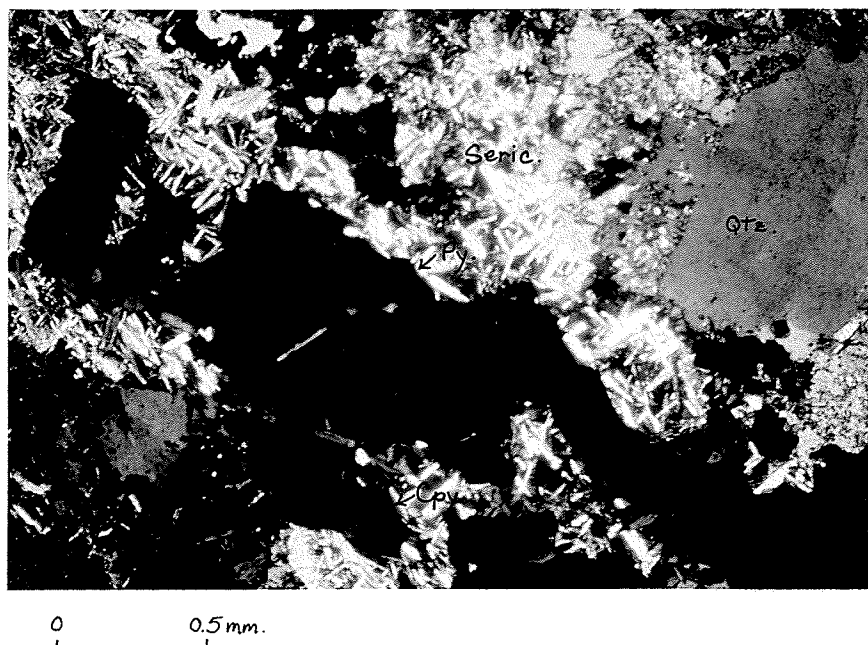


Figure 62. Photomicrograph of disseminated pyrite and chalcopyrite in quartz diorite.

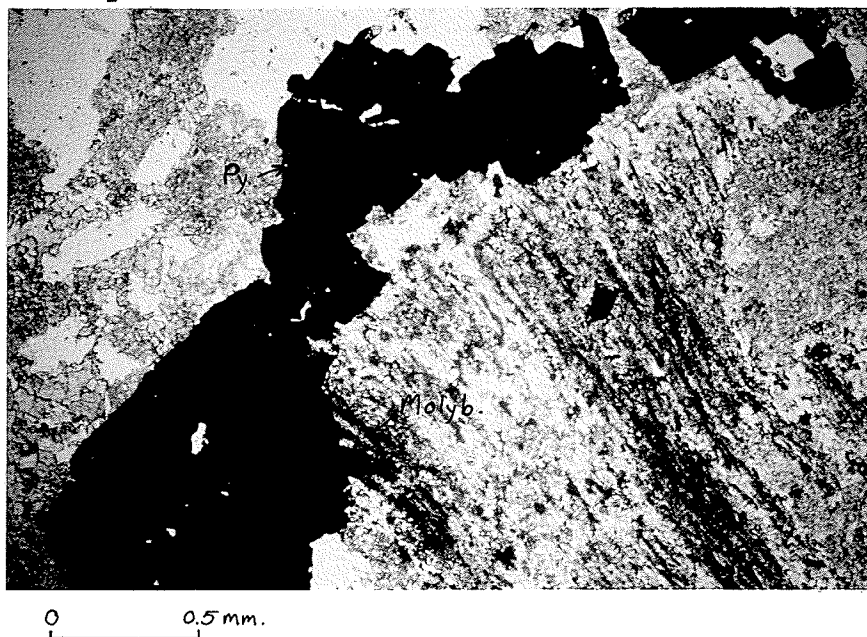


Figure 63. Photomicrograph of pyrite and associated molybdenite in quartz diorite. The sample location is immediately south of Potter Lake.

The sulphide minerals occur in two major modes.

1. Disseminated crystals and irregular grains are present in the Canoe Lake stock. Textural evidence suggests their late magmatic crystallization.

2. The sulphide minerals occupy microscopic stringers and veinlets running through the quartz diorite and megascopic quartz-chlorite and quartz-chlorite-carbonate veins of magmatic association. These veins fill fractures and small shear zones. Sulphide staining is present in quartz veins or in unfilled fractures as a wall coating. Figure 64 illustrates a sheared quartz-chlorite fracture filling, which contains pyrite, chalcopyrite, and minor amounts of sphalerite. Sulphide staining along an unfilled fracture is shown in Figure 65. This reddish-brown staining has resulted from the oxidation of pyrite. Molybdenite occurs as a fine coating on small microfractures, which is termed molybdenite 'paint' by Clark (1972) in his paper on molybdenite stockwork deposits.

Microscopic veinlets and aggregates of sulphides are numerous in the quartz diorite stock. These stringers usually contain one or more of quartz, chlorite, and carbonate, associated with the sulphide minerals. Simple, pure sulphide microveinlets are also present; these are composed of predominantly pyrite and subordinate chalcopyrite (see Figure 66).

Copper, molybdenum, and zinc mineralization has

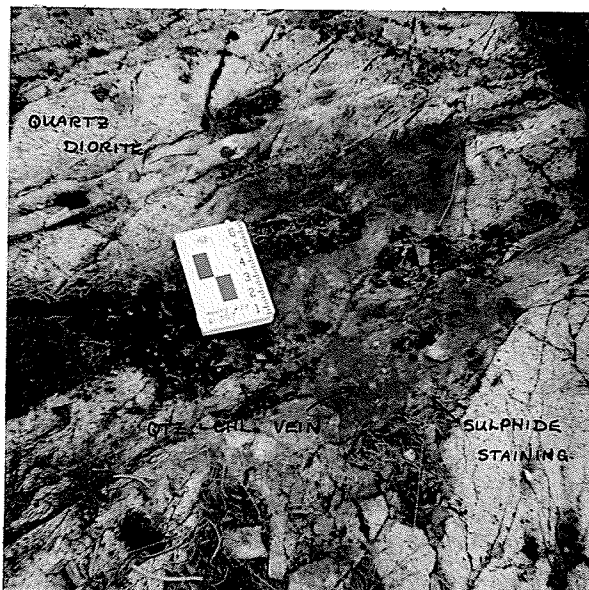


Figure 64. A sheared quartz-chlorite fracture filling containing pyrite, chalcopyrite, and minor amounts of molybdenite.

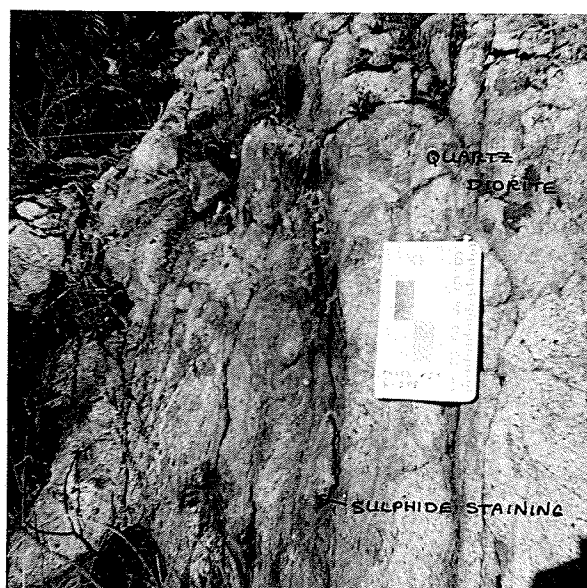


Figure 65. Sulphide staining along the walls of an unfilled pre-hydrothermal fracture.

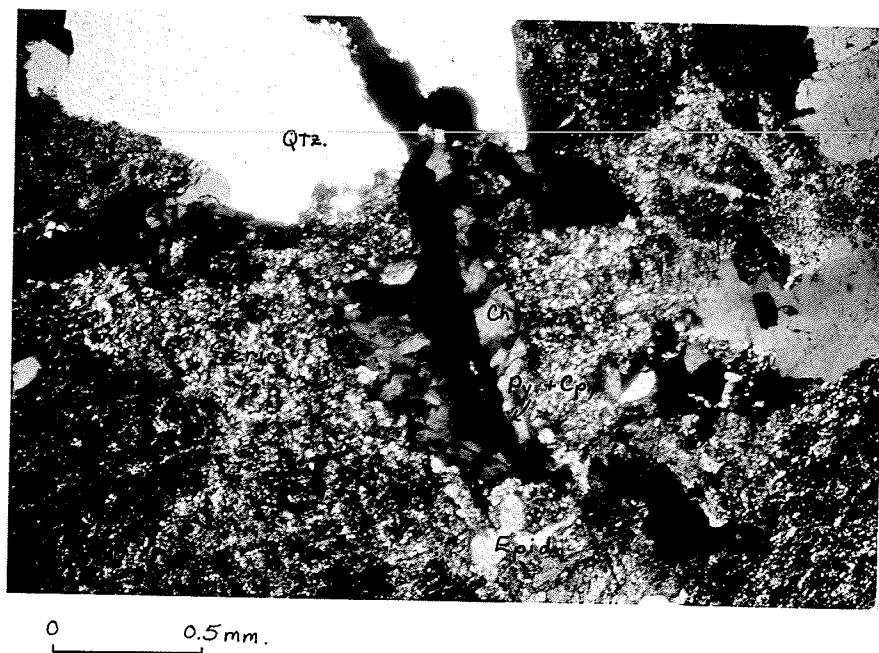


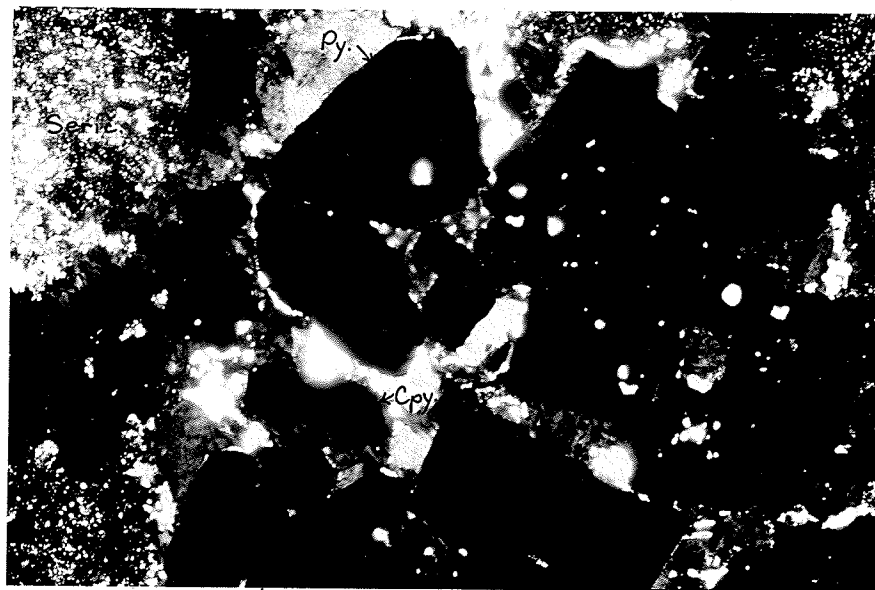
Figure 66. Photomicrograph of a pure sulphide microveinlet in quartz diorite. The sulphide minerals are pyrite and chalcopyrite.

pervaded the younger felsic dikes and irregularly shaped intrusions as well as the quartz diorite. These porphyry intrusions are especially abundant in the Squaw Lake - Potter Lake area. Figure 67 is a photomicrograph of quartz-feldspar porphyry with contained pyrite and chalcopyrite.

The distribution of the various metals in the Canoe Lake stock was presented earlier in a description of the chemical trends in the host intrusion. Sulphur, total iron, copper, and cobalt show concentrations in the Squaw Lake - Potter Lake area, while lead and zinc are scattered over a wider portion of the stock. Nickel shows a small concentration southeast of Love Lake. From these areal concentrations it is concluded that iron, copper, molybdenum, and zinc are predominantly in the sulphide minerals. Cobalt and lead are probably minor substitutes for copper or iron in chalcopyrite, while cobalt may substitute for zinc in sphalerite and for iron in pyrrhotite. The nickel content is not high in areas of high sulphur concentration and therefore, it is assumed to be present in the silicate minerals.

Figure 68 is a triangular diagram for copper-zinc-lead and shows an approximate straight line trend from the copper apex toward the zinc end of the zinc-lead tie line. This diagram illustrates a moderately constant lead:zinc ratio for the copper-zinc-lead system in the mineralized Canoe Lake stock.

Two copper oxide minerals are present in the minera-



0 0.5 mm.

Figure 67. Photomicrograph of pyrite and chalcopyrite contained in a quartz-feldspar porphyry intrusive rock.

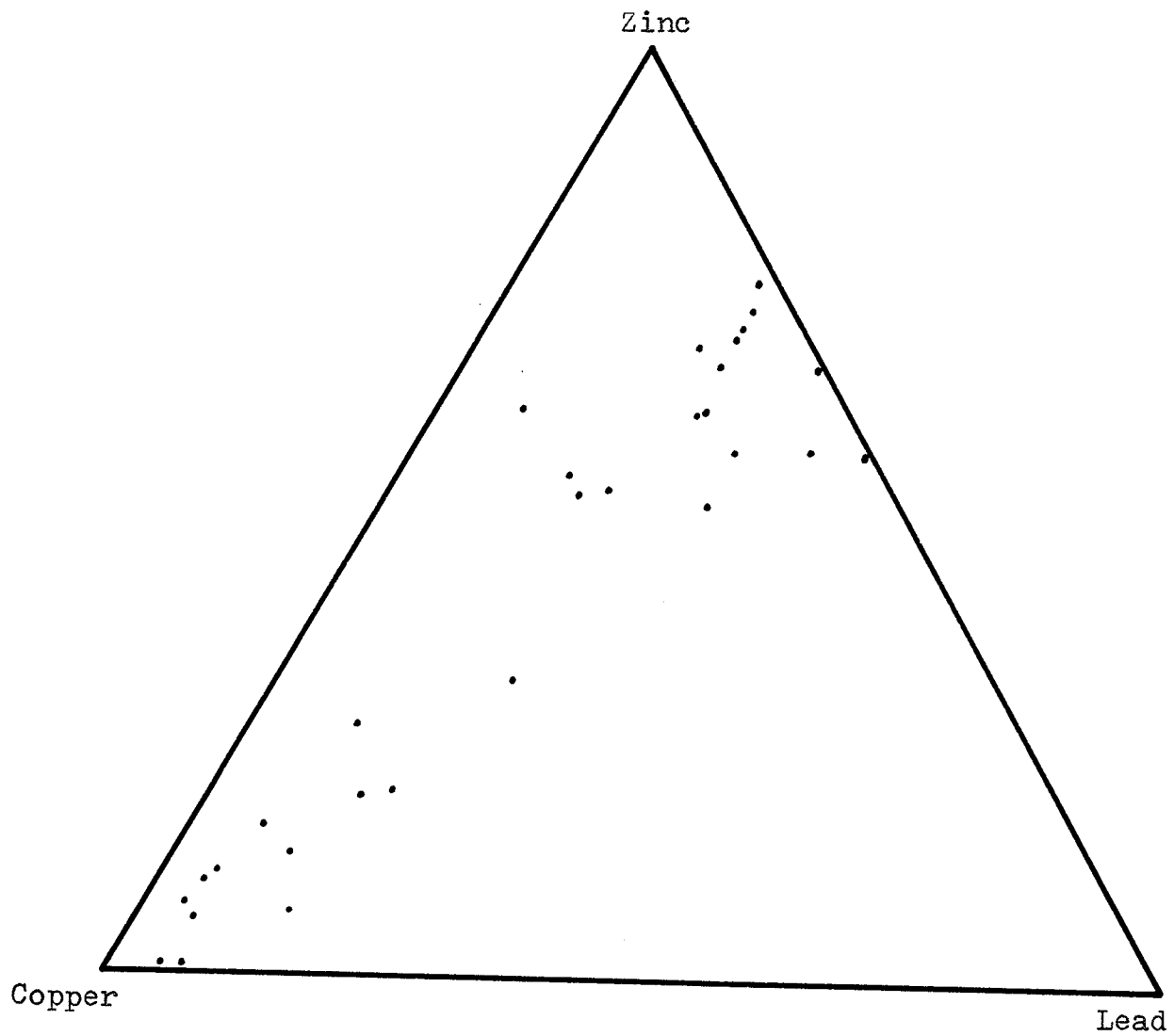


Figure 68. Copper-zinc-lead triangular diagram for the mineralized Canoe Lake stock. (30 points plotted from chemical analyses).

lized intrusion. The more prominent mineral is malachite; the less abundant one is azurite. Both occur as amorphous coatings on fracture walls and on oxidized quartz-chlorite-sulphide veins.

Extent of Total Sulphide Mineralization

A contour plot of percent total sulphide minerals is shown in Figure 69. The data for this plot came from the 150 modal analyses. The general sulphide distribution occurs as a wide, irregular band, trending parallel to the length of the Canoe Lake stock and stretching from Squaw Lake in the northeast to Bag Bay and Helldiver Bay in the southwest. This band of mineralization consists of four anomalous areas: near Bag Bay, east of Helldiver Bay, southwest of Love Lake, and between Squaw Lake and Potter Lake. The intensity of mineralization agrees with the degree of total hydrothermal alteration. This correlation is consistent with Putman's (1972) statement that the intensity of alteration corresponds with increased total sulphide minerals. He mentions that they both increase toward the centre of the host stock. A more complex picture than this is shown in the Canoe Lake quartz diorite, where the centre is not the only area of intense alteration and mineralization.

Figure 69 depicts a modal percent total sulphides range of 0.1 to more than 2.0 percent. More realistic con-

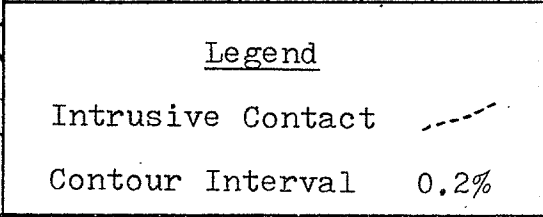


Figure 69. A contour plot of modal percent total sulphide minerals in the Canoe Lake quartz diorite intrusion.

centrations of sulphide minerals are observed from a study of sulphur and the analyzed trace elements. The sulphur content ranges from 0.00 to 2.92 percent. Copper shows a maximum value of 3660 ppm. in a highly fractured and mineralized sample from Squaw Lake. The next most highly concentrated trace metal is zinc with a maximum value of 265 ppm.. Lead and cobalt reach maximum concentrations of 55 and 23 ppm., respectively. A molybdenum value of 950 ppm. was obtained in a sample of quartz diorite taken along one side of a hydrothermally-filled fracture. A typical quartz diorite rock gave analytical results of less than 10 ppm. molybdenum.

The contour lines in the plot of percent total sulphides show two major trend directions: one is to the northwest and the other is to the northeast. This feature is in agreement with the two pre-hydrothermal fracture trend directions and with the contour trends for total alteration. Therefore, the relationship between the fractures, total hydrothermal alteration, and mineralization processes is emphasized.

Hydrothermal Alteration and Mineralization Pattern in the Canoe Lake Stock

Introduction

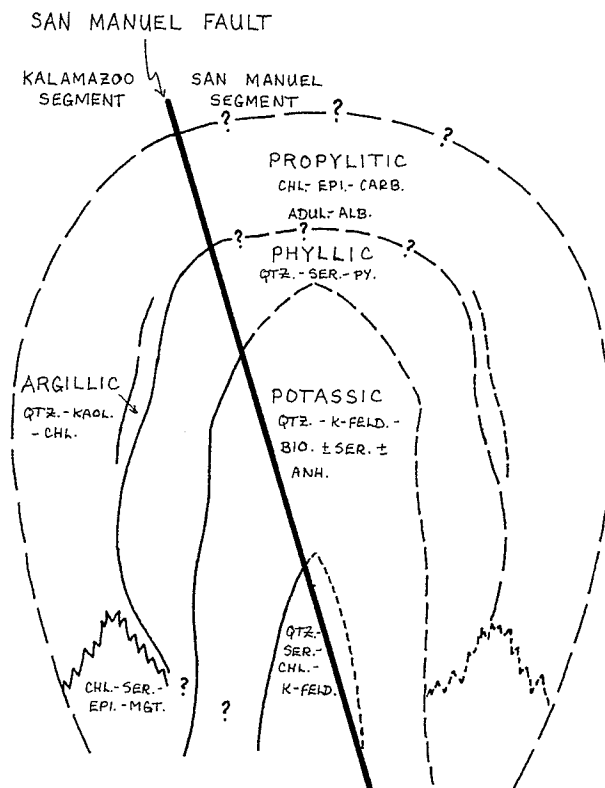
Numerous reports have been written on the important

hydrothermal alteration and mineralization patterns in porphyry copper deposits. Meyer and Hemley (1967) state that the study of the mineralogical and chemical variations in wall rock alteration leads to the interpretation of the assemblages of alteration minerals and to the distribution patterns of the alteration products and sulphides. The hydrothermal alteration and mineralization in the Canoe Lake stock shows a zonal pattern in the Squaw Lake - Potter Lake area, which is not consistent across the rest of the intrusion.

Types of Hydrothermal Alteration and Associated Sulphides in Porphyry Copper Deposits

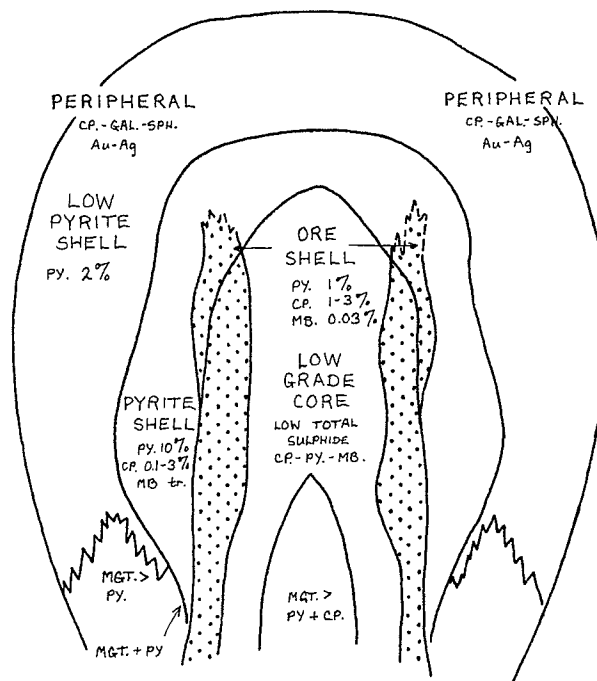
"Most of the porphyry copper deposits are characterized by a similar pattern of lateral zoning involving sulphides and silicate alteration assemblages."¹ Four major types of alteration have been documented by such authors as Creasey (1959, 1966), Meyer and Hemley (1967), Rose (1970), and Lowell and Guilbert (1970). These alteration types are named potassic, phyllic, argillic, and propylitic, in order from the core to the outermost zone. Lowell and Guilbert (1970) mention that mineralization zones are essentially coaxial with these alteration halos. Figures 70a, 70b, and 70c illustrate alteration, mineralization zoning, and a schematic

¹ Rose (1970), p. 920.



Adul.-Adularia	Chl. -Chlorite	Mgt.-Magnetite
Alb. -Albite	Epi. -Epidote	Py. -Pyrite
Anh. -Anhydrite	Kaol. -Kaolinite	Qtz.-Quartz
Bio. -Biotite	K-feld.-K-feldspar	Ser.-Sericite
Carb.-Carbonate		

Figure 70a. Schematic drawing of the alteration zones in the San Manuel - Kalamazoo deposit - a typical porphyry copper. (After Lowell and Guilbert (1970)).



Au - Gold	Gal.- Galena	Py. - Pyrite
Ag - Silver	Mgt.- Magnetite	Sph.- Sphalerite
Cp.- Calcopryrite	Mb. - Molybdenite	

Figure 70b. Schematic drawing of the mineralization zoning in the San Manuel - Kalamazoo deposit - a typical porphyry copper. (After Lowell and Guilbert (1970)).

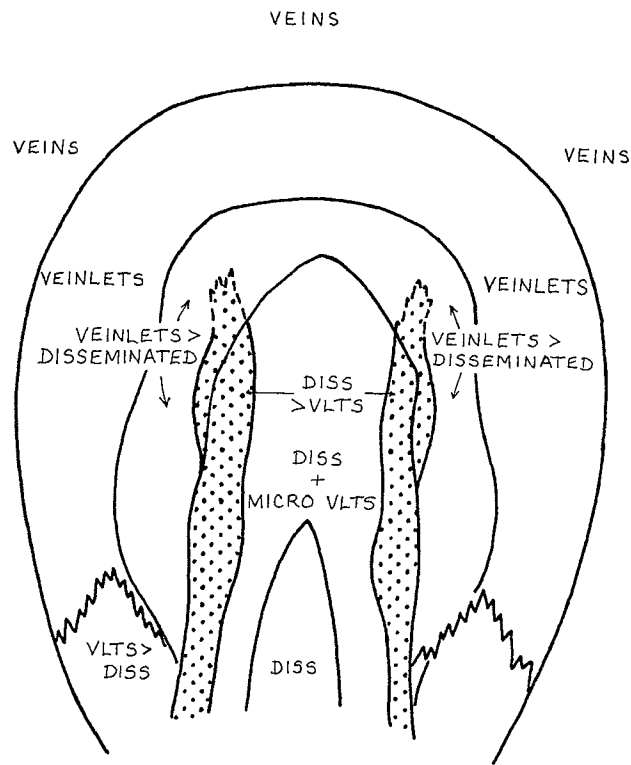


Figure 70c. Schematic diagram of the occurrences of sulphides in the San Manuel - Kalamazoo deposit - a typical porphyry copper. (After Lowell and Guilbert (1970)).

diagram of the occurrence of sulphide minerals for a typical porphyry copper deposit.

Hydrothermal alteration in the potassic core of the deposit consists of quartz with any two or all of biotite, potassium feldspar, and minor sericite. The clay minerals are not stable in this core. Lowell and Guilbert (1970) state that the alteration is pervasive and veinlet in character. These authors also mention that albitization was not recognized in their study of the San Manuel - Kalamazoo deposit, but that the potassium feldspar shows a greater soda content than the original orthoclase. Hydrothermal processes within the potassic core have resulted in a loss in Al_2O_3 , total iron, MgO , CaO , and Na_2O , and a gain in K_2O , H_2O , and sulphur. Sulphide minerals associated with the potassic core are, in order of abundance, pyrite, chalcopyrite, and molybdenite. These minerals occur as disseminated grains and in stock-work microveinlets. The chalcopyrite content is high and the pyrite:chalcopyrite ratio is 1:2. The distinctive sulphide assemblage is chalcopyrite and molybdenite, with a notable absence of sphalerite. Spatially, the potassic type alteration may be the most closely related to the sulphides (Meyer and Hemley, 1967).

Surrounding the potassic core is the phyllic zone of alteration. Creasey (1966) mentions that this zone grades into the argillic zone if clay minerals are added or into the potassic core if potassium feldspar is added. Quartz,

sericite, minor chlorite, and minor rutile are the major hydrothermal minerals. It is common to find plagioclase completely sericitized. Sulphide veinlets are more abundant than disseminated sulphides in this halo, which includes all of the marginally mineralized and pyritic zones of the deposit. The sulphide minerals are pyrite > chalcopyrite > molybdenite. The ore zone overlaps the phyllic zone and has a cutoff of 0.42 percent copper. Pyrite and chalcopyrite exist in veinlets with a pyrite:chalcopyrite ratio of 10:1 in both the phyllic and the outward argillic zone.

The argillic halo is peripheral to the phyllic zone and "is the least well developed and the most likely to be absent in any given penetration of the ore deposit symmetry."¹ The inner portion of the argillic zone contains hydrothermal kaolinite; the outer portion consists of montmorillonite. The overall mineral assemblage is quartz, sericite, kaolinite, and montmorillonite. Creasey (1966) states that this halo is characterized by strong leaching of lime and an absence of epidote and calcite. The sulphides occur in veinlets and the pyrite content is much greater than that of chalcopyrite.

The outermost or propylitic zone consists of a wide distribution of alteration assemblages, which are less distinctive than those of the inner zones. The main minerals present in this hydrothermal alteration halo are chlorite,

¹ Lowell and Guilbert (1970), p. 383.

carbonate, epidote, clinozoisite, and sericite. Pyrite and sphalerite are the dominant sulphide minerals and chalcopyrite is rare. This zone may contain minor copper veins, but this feature is not critical to the definition of the propylitic halo. The sulphide mineralization is confined to veinlets and pervasive pyrite veins. Small, low to high grade silver and gold deposits are found beyond the outer border.

Delineation of Alteration - Mineralization

Zones in the Canoe Lake Stock

Three hydrothermal alteration zones have been determined in the Canoe Lake stock. The alteration pattern is shown in Figure 71. The zones are poorly developed, irregular, and contain insufficient copper mineralization to reach ore grade. The alteration-mineralization pattern is complex and offset from the central part of the granitic intrusion.

The irregular alteration-mineralization pattern, extending across a major part of the stock, is a result of a deep level of erosion. Lowell and Guilbert (1970) mention that both the alteration and mineralization characteristics appear to change vertically in the San Manuel - Kalamazoo deposit. The mineralization also changes at depth. Percent total sulphides becomes less in the phyllic zone at deeper levels (Lowell and Guilbert, 1970). The Canoe Lake stock

shows the same at depth changes in the characteristic assemblages. Alteration biotite has been replaced by chlorite in the potassic and propylitic zones and the phyllic halo lacks a discernible mineral assemblage.

Three alteration zones outlined in the Canoe Lake stock are the potassic, phyllic, and propylitic. The argillic halo is absent. Boundaries between these zones are gradational and the mineral assemblages are not distinct. Certain criteria were used to draw actual boundary lines between the zones. These three alteration halos are shown in Figure 71.

The innermost zone or potassic core, offset from the centre of the Canoe Lake stock, is located immediately south of Potter Lake. It measures approximately 925 feet in diameter. This hydrothermal centre was distinguished by a FeO content of less than 0.50 percent and a MgO content of less than 0.95 percent (with two exceptions). Generally the potassic core shows considerable loss in CaO and a gain in K₂O. Albitization of primary andesine was most intense in this area of the stock. The mineralization within the potassic core is characterized by pyrite > chalcopyrite > molybdenite, and an absence of sphalerite. The sulphides occur as disseminated grains and stockwork microveinlets. The metal content is 175 to 435 ppm. copper, 16 to 30 ppm. zinc, and 10 to 950 ppm. molybdenite.

The irregular phyllic zone is the next outward alteration zone in the Canoe Lake stock. Abundant sericite and

small amounts of carbonate, epidote, and clinozoisite are characteristic of this halo. The main sulphide minerals are pyrite > chalcopyrite, occurring more commonly as veinlets than as disseminations. Minor sphalerite and molybdenite are found in the phyllic zone. The outer boundary for this halo was drawn at a copper:zinc ratio greater than or equal to one. The metal content in this alteration zone is variable.

The outermost or propylitic zone extends across the greatest surface area of the Canoe Lake stock, as compared to the areal extent of the other two halos. Chlorite, epidote, and clinozoisite are the most abundant alteration products within this halo. The sericite content is generally lower than in the phyllic zone, but this is not an absolute rule for distinction. The sulphide minerals in this outermost zone are predominantly pyrite and sphalerite. They commonly occur in veins and veinlets. Minor chalcopyrite is present in the propylitic zone and the areal definition of the zone is largely based on the existence of a copper:zinc ratio of less than one.

An attempt was made to outline a pyritic halo in the Canoe Lake porphyry copper mineralization pattern. Modal percent values for pyrite from counted thin sections of quartz diorite were contoured, but a continuous halo could not be delineated. Figure 71 contains these contoured pyrite percentages and shows that this irregular pyrite zone is usually contained within the phyllic zone or along the boun-

dary between the phyllic and propylitic halos. The author suggests that a more continuous pyrite halo could be delineated as a result of more detailed sampling in the area.

Genesis of the Canoe Lake Stock
Porphyry Copper Mineralization

Numerous hypotheses for hydrothermal alteration and mineralization processes in porphyry copper deposits have been outlined by such authors as Stringham (1953, 1966), Schwartz (1966), Bray (1969), and many others.

Holland (1972) presents numerous observations and laboratory data which support the hypothesis for the derivation of hydrothermal ore deposits of magmatic association. This hypothesis consists of three assumptions.

1. Granitic magmas possess a moderately high water content, which is released as hydrothermal fluids during progressive crystallization.
2. The concentration of base metals in these fluids is adequate to result in metal deposition.
3. The deposition of the sulphide minerals is caused by decreasing temperature and pressure and the reactions of fluids with the wall rocks.

The preparation of the host rock for the migration of hydrothermal solutions was essential to the deposition of the metals (Schwartz, 1966) and the channelways were pro-

vided by intense fracturing. Meyer and Hemley (1967) suggest that the hydrothermal mineralizing fluids evolved in their chemical characteristics as they migrated outward. This resulted in the zonal pattern of mineral assemblages.

Moore et al. (1968) and Moore and Lanphere (1971) conclude from isotopic age dating at Bingham, Utah that a brief (less than one million years), but measureable period of time separated the processes of magmatic crystallization and subsequent hydrothermal alteration and mineralization.

James (1971) has derived a hypothetical model for the shape of porphyry copper deposits. He concludes that the body of primary hypogene concentrations of sulphide minerals is probably an inverted cup-shape form, as depicted in Figures 70b and 70c.

Field and laboratory studies, together with a survey of the various hypotheses concerning the formation of porphyry copper deposits leads to postulation of the following sequence of events for the mineralization in the Canoe Lake stock.

1. The intruding granitic magma is assumed to have been moderately rich in water with adequate base metal concentrations.
2. The magma partially crystallized upon cooling, forming a solid outer shell. As crystallization progressed, fracturing and shattering of this shell took place.
3. Continued crystallization and decreasing temperature

concentrated the water-rich fluids and their contained metals. The sulphides are concentrated in one of the late crystallizing portions of the stock, near Squaw Lake and Potter Lake, as delineated by the high H_2O and SiO_2 contents.

4. These assumed magmatic hydrothermal solutions affected the partially crystallized magma and were also channelled upwards along the fractures.

5. Intense hydrothermal alteration of the stock included at least four stages and during this process the potassic, phyllic, and propylitic zones of alteration were created and the sulphide minerals - pyrite, chalcopyrite, pyrrhotite, sphalerite, and molybdenite, were deposited.

6. The alteration products and associated sulphide minerals are present in two modes in the Canoe Lake stock. Hydrothermal activity caused one or more of sericite, chlorite, carbonate, epidote, clinozoisite, and quartz, and any of the sulphides to replace the wall rock. The second mode of occurrence of the alteration products is as fracture fillings, involving quartz, chlorite and/or carbonate, and sulphide mineral concentrations.

7. The quartz-feldspar porphyry dikes and irregularly shaped intrusions are assumed to be very closely related to the mineralization process. They were emplaced prior to the commencement of hydrothermal alteration and display the same effects as the altered quartz diorite. Many of these felsic intrusions are mineralized, especially in the Squaw Lake -

Potter Lake area.

8. The processes of granitic emplacement, fracturing, felsic dike intrusions, magmatic hydrothermal alteration, and copper-molybdenum-zinc mineralization appear to have taken place within a short period of geologic time and each successive stage appears to have overlapped to some extent.

The poorly defined alteration-mineralization pattern within the quartz diorite, the low concentrations of copper, molybdenum, and zinc (relative to a typical porphyry copper deposit), and the irregularity of the total hydrothermal alteration pattern across the intrusion suggest that the Canoe Lake stock has been subjected to a deep level of erosion. The patchy distribution of the phyllic alteration zone is presumed to be due to an upwelling of fluids from more than one centre of hydrothermal activity, located at depth in the pluton. Erosion has now exposed the locations of these hydrothermal 'pockets'.

SUMMATION OF EVIDENCE FOR A PORPHYRY COPPER TYPE
CLASSIFICATION OF THE CANOE LAKE STOCK MINERALIZATION

General Statement

Titley (1966) mentions that the original meaning of the term porphyry copper was used in a genetic sense and applied to disseminated mineralization in porphyritic acidic

to intermediate igneous intrusive rocks. A more recent application of the term is to "large, low-grade, epigenetic, hypogene copper deposits mined by mass-mining methods."¹

Lowell and Guilbert (1970) provide a very complete definition of a porphyry copper deposit.

"... a copper and/or molybdenum sulphide deposit consisting of disseminated and stockwork veinlet sulphide mineralization emplaced in various host rocks that have been altered by hydrothermal solutions into roughly concentric zonal patterns... The relatively homogeneous and commonly roughly equidimensional deposit is associated with a complex, passively emplaced stock of intermediate composition including porphyry units. It contains significant amounts of pyrite, chalcopyrite, molybdenite, quartz, and sericite associated with other alteration, gangue, and ore minerals and metals including minor lead, zinc, gold, and silver. Mineralization and alteration suggest a late magmatic - mesothermal temperature range."²

The author classifies the Canoe Lake stock mineralization as porphyry copper type in view of the above definition. The mineralization within the restricted Squaw Lake area (more than 100 ppm. copper) may be classified as a porphyry copper deposit, although the deposit is not of ore grade.

1 Titley (1966), p. ix.

2 Lowell and Guilbert (1970), p. 375.

Significant Features of the Mineralized Stock

Most of the characteristics of the mineralized quartz diorite agree with the description of typical porphyry copper type mineralization. These features are summarized below.

1. The composition of the intrusion is quartz diorite with closely associated (both in time and space) subsequent felsic intrusions.
2. The intrusion is an irregularly shaped stock with a partially fracture-controlled boundary.
3. Intense fracturing is the main structural feature of the Canoe Lake stock.
4. The rock types that have been mineralized are the quartz diorite, the felsic intrusions, and to an insignificant extent the adjacent metavolcanic and mafic to ultramafic rocks.
5. The magmatic hydrothermal alteration is intense and typical of porphyry copper deposits. Three alteration zones are present: potassic, phyllic, and propylitic.
6. The zonal mineralization pattern within the stock includes pyrite, chalcopyrite, pyrrhotite, sphalerite, and molybdenite. Their sequence from the core to the outermost halo is: pyrite-chalcopyrite-molybdenite to pyrite-chalcopyrite to pyrite-sphalerite. Peripheral gold occurrences are present in the Bag Bay - Helldiver Bay area.

7. The sulphide minerals exist in two different modes: as veins, veinlets, and microveinlets which fill various sized fractures, and as disseminated grains.

A few typical porphyry copper features are missing in the Canoe Lake stock. First, the intrusion does not show supergene enrichment due to the lack of weathering. Also the grade of the mineralization is not of ore grade. The age of the Canoe Lake stock - Archean, makes it a much older intrusion than the typical porphyry copper igneous host rock.

Table 5 lists the features of a typical porphyry copper deposit, as compiled from Lowell and Guilbert (1970) and De Geoffroy and Wignall (1972). The characteristics of the Canoe Lake stock and its associated mineralization are also listed in this table.

Discussion

Classification by Type of Porphyry Copper Deposit

Numerous classifications for the type of porphyry copper deposit have been suggested and these appear to be moderately similar in construction. Titley (1966) lists three classes for these deposits.

1. Simple deposits with the mineralization entirely within the porphyritic host rock.

Table 5. Features of the Canoe Lake stock mineralization compared to a typical porphyry copper deposit.

Features	Typical Porphyry Copper	Canoe Lake Stock
<u>Pre-ore host rock:</u>	Precambrian to late Cretaceous seds.	Archean metavolcanics
<u>Igneous host rock:</u>		
Name	Quartz monzonite	Quartz diorite
Age	65 m.y.	Archean
Controlling structures	NE and NW faults	Anticline with axis parallel to NE
Characteristic internal structure	Intense fracturing	Intense fracturing
Shape	Elongate, irregular	Elongate, irregular
Size	4000 ft. x 6000 ft.	3 ⁺ mi. x 6 mi.
Emplacement depth	Moderate to shallow	Shallow
Type of intrusion	Stock with associated dikes	Stock with associated dikes
Sequence of intrusion	Dior. or granodior. to Quartz monzonite to Quartz monz. porph.	Quartz diorite to Quartz, feldspar, & qtz.-feld. porph. & fine-gr. granodior.
Rock types mineralized	All + sediments	Quartz diorite + felsic dikes
<u>Ore body:</u>		<u>Mineralized area:</u>
Outward shape	Oval, pipelike	Irregular
Boundaries	Original & post-ore faults	Original & possible faults
Percent in igneous host	70 percent	100 percent
Dimensions	3500 ft. x 6000 ft.	Max. 2 mi. x 2.5 mi.

Table 5 (cont.) Features of the Canoe Lake stock mineralization compared to a typical porphyry copper deposit.

Features	Typical Porphyry Copper	Canoe Lake Stock
<u>Hypogene alteration:</u>		
Known extent beyond ore	2500 ft.	Max. 3 mi.
Peripheral zone	Chlorite, epidote, kaolinite (skarn)	Chlorite, epidote, clinozoisite, carbonate
Outer zone	Chlorite, epidote, calcite	Chlorite, epidote, clinozoisite, carbonate
Intermediate zone	Quartz, kaolinite, sericite, montmorillonite	Quartz, sericite, minor carbonate
Inner zone	Quartz, sericite, pyrite	Quartz, sericite, pyrite
Innermost zone	Quartz, K-feldspar, biotite, sericite	Quartz, albitized plagioclase, sericite
Zoning from centre	Potassic-Phyllic-Argillic-Propylitic	Potassic-Phyllic-Propylitic
Exposure level	Inner or innermost zone	Innermost zone
<u>Hypogene mineralization:</u>		
Peripheral alteration zone	Galena, sphalerite, silver, gold	Pyrite, sphalerite, gold, arsenopyrite
Outer alteration zone	Pyrite, galena, sphalerite	Pyrite, sphalerite, minor chalcopyrite

Table 5 (cont.) Features of the Canoe Lake stock mineralization compared to a typical porphyry copper deposit.

Features	Typical Porphyry Copper	Canoe Lake Stock
<u>Hypogene mineralization</u> (cont.):		
Intermediate alteration zone	Pyrite » chalcopyrite > bornite Py:cpy = 23:1 Moderate total sulphides	Pyrite » chalcopyrite Copper:zinc > 1
Inner alteration zone	Pyrite > chalcopyrite > molybdenite > bornite Py:cpy = 13:1 High total sulphides	Pyrite > chalcopyrite (minor sphalerite)
Innermost alteration zone	Pyrite > chalcopyrite > molybdenite > bornite Py:cpy = 3:1 Low total sulphides	Pyrite > chalcopyrite > molybdenite
Zoning sequence from centre	Chalcopy., molyb. to Pyrite to Galena, sphalerite, silver, gold	Chalcopy., molyb. to Pyrite, chalcopyrite to Pyrite, sphalerite to
Overall abundance of major minerals	Pyrite > chalcopyrite > molybdenite > bornite	Pyrite, gold, arsenopy. Pyrite > chalcopyrite > molybdenite

Table 5 (cont.) Features of the Canoe Lake stock mineralization compared to a typical porphyry copper deposit.

Features	Typical Porphyry Copper	Canoe Lake Stock
<u>Occurrences of sulphides:</u>		
Peripheral alteration zone	Veins	Veins
Outer alteration zone	Veins + veinlets	Veins > veinlets
Intermediate alteration zone	Veinlets	Veinlets » disseminations
Inner alteration zone	Veinlets > disseminations	Veinlets > disseminations
Innermost alteration zone	Disseminations > microveinlets	Disseminations + microveinlets

Compiled and adapted from Lowell and Guilbert (1970) and De Geoffroy and Wignall (1972).

2. Simple with the mineralization entirely in the adjacent rocks.

3. Complex deposits with the mineralization occurring both in the igneous and adjacent rocks.

Brown (1969) suggests that porphyry copper deposits may be subdivided into four distinct groups according to their depth of intrusion and complexity.

1. Simple - annular stockwork mineralization around a small, cylindrical intrusive stock.

2. Elaborate - similar in structure to 1, except more developed as a result of either increased depth or more complex intrusive activity.

3. Complex - the same as 2, except that the deposit has undergone faulting.

4. Plutonic - this type occurs in rocks having an essentially granitoid texture, and which are closely associated with porphyritic intrusives. Both these rock types have the same type of mineralization and alteration. The sulphide deposit is related to a parallel or conjugate system of veins.

The Squaw Lake porphyry copper deposit is best described by type 1 of Titley (1966) and by type 4 of Brown (1969).

Porphyry Copper Mineralization in Northwestern Ontario

It is of interest to note that although porphyry

copper mineralization is considered to be essentially absent in the Precambrian Shield of Canada, the Squaw Lake deposit is not unique in northwestern Ontario.

"During the past few years copper and molybdenum mineralization has been recognized in several porphyritic, epizonal, felsic plutons in Early Precambrian rocks of Northwestern Ontario. The plutons vary from quartz-feldspar porphyries typical of many metavolcanic areas to equigranular to porphyritic medium-grained stocks ranging in composition from trondhjemite to quartz monzonite. Where mineralized they are highly fractured and altered. They are commonly found in or bordering meta-volcanic-metasedimentary belts..."¹

GOLD MINERALIZATION IN THE INTRUSION AND ADJACENT ROCKS

INTRODUCTION

General Statement

Occurrences of gold in quartz-chlorite-carbonate veins are present at the southwest contact of the Canoe Lake stock. Mining operations were in progress irregularly until the late 1930's. Accounts of the gold mining in Shoal Lake were written by Parsons (1911), Greer (1931), and Thomson (1936, 1937).

1 Riley et al. (1971), p. 30.

Brief History of Gold Mining in the Bag Bay Area

The history of gold mining in Shoal Lake began in 1893 when an Indian took a number of gold-bearing samples from Bag Bay to the manager of Hudson's Bay Company store in Kenora, Ontario. The promising nature of the specimens led the manager, Mr. C. Bunn, and Dr. S.S. Scovil to take up the property and commence mining operations. This created the Mikado mine, which is located on the south shore of Bag Bay near the quartz diorite contact. It was later sold to Col. Engledue of London, England, and his associates and mining continued until 1903, when the property was shut down indefinitely. Mr. H.A.C. Machin had the mine pumped out to the fourth level in 1910 and had assays made on the ore from the dumps and tailing piles. The result of these endeavors was the formation of the Kenora Prospectors and Miners, Limited, which took over the property. The Mikado operated periodically from 1895 to 1931 before abandonment. Table 6 shows the production history of the Mikado mine, which was one of four principal producing mines of the Lake of the Woods region in the late 1890's (Parsons, 1911).

The Cedar Island or old Cornucopia mine also went into production a few years after the first gold discovery. This mine is located about 1 mile west of the Mikado on Cedar Island in Bag Bay. The Kenora Prospectors and Miners, Limited owned this property as well as the Mikado and other

Table 6. Gold production in the
Bag Bay - Helldiver Bay area.

Producing Mines	Years	Tons	Value	Years Prod ⁿ . ex- ceeded \$50,000
Cedar Island (Cornucopia)	1896	17,050	\$174,146	1936
	1932			
	1935			
	1936			
Mikado	1896-1902	57,813	\$421,070	1898-1900
	1910			
	1911			
	1931			
Olympia	1906	1,598	\$ 4,782	—
	1911			
	1912			
	1915			

Compiled from data in old issues of the Ont. Dept. Mines
reports.

claims in the vicinity. Thomson (1936) mentions that gold recovered from the Cedar Island mine in the early days amounted to \$1560. Production from Cedar Island is summarized in Table 6. Underground development of this property continued in 1935 and 1936 and a 40-ton mill was installed toward the end of 1935. Thomson (1937) states that in 1936 up to the end of March production totalled 2202.63 ounces of gold and 0.15 ounces of silver per ton of ore.

There were a number of other properties in the Bag Bay - Helldiver Bay area during the gold mining period. The Tycoon location is on a small island in Bag Bay. A shaft was sunk at this site in the hope of intersecting the gold-bearing Mikado vein, which would have come close to the island if it had been continuous. Failure to discover the vein resulted in removal of equipment and abandonment of the mine. The Bullion mine is located east of the Mikado with its shaft at the contact of quartz diorite and massive basalt. A test pit was constructed, but was not developed any further and the shaft was soon abandoned. The Sirdar mine is located north of the Bullion mine. The shaft was sunk 125 feet in quartz diorite and quartz-feldspar porphyry, but was abandoned because of the lack of vein material. The Olympia mine is situated on the northwest arm of Helldiver Bay. It was developed in the early 1900's and four years of production occurred during the period 1906 to 1915. Greer (1931) mentions that a few thousand dollars worth of gold was recovered during opera-

tions in 1912 and 1915. A small stamp mill on the property handled treatment of the ore. The production history of this property is summarized in Table 6. A final location which deserves mention is the Yum Yum property, situated on the shore of Shoal Lake about 1.5 miles west of the Olympia. A shaft was sunk to a maximum of about 200 feet, but discovery of the pinching out of vein material 15 feet below the surface resulted in termination of the work.

DISTRIBUTION OF GOLD MINERALIZATION

General Statement

Gold occurrences within the study area are located near the Bag Bay and Helldiver Bay portion of the granitic contact zone. More than a dozen properties are concentrated in this area. Most of the shafts were constructed in the adjacent basalts and mafic to ultramafic intrusive rocks, but the Tycoon location, Sirdar mine, and Crown Point mine were developed in the quartz diorite stock.

The gold deposits occur in quartz, quartz-carbonate, quartz-chlorite, and quartz-carbonate-chlorite veins with associated pyrite. These fracture fillings trend north to northwest.

It is possible that these gold-bearing veins are genetically related to the hydrothermal activity within the

quartz diorite stock.

Local Setting and Distinct
Features of the Mineralization

Occurrences of gold are numerous between Bag Bay and Helldiver Bay. The accompanying geologic map indicates the locations of the old properties and past-producing mines.

The author visited many of the old mining properties, but investigations were limited to the dumps and tailing piles. Unfortunately these piles have been thoroughly picked over since the early 1900's and well mineralized vein samples were not available. Descriptions of the mineralization are briefly included in reports by Parsons (1911), Greer (1931), and Thomson (1936, 1937).

Most of the mines are located in the adjacent rocks near the intrusive contact. The Cedar Island mine is situated on an island in the southwest part of Bag Bay. The exposed rock is fine- to medium-grained basalt and amphibolite. Numerous dikes of quartz porphyry, quartz-feldspar porphyry, granite, pegmatite, aplite, and lamprophyre crosscut the mine workings (Thomson, 1936). Calcite, feldspar, and quartz veinlets are associated with the dikes. The mineralized vein material, striking 135° and dipping 69° SW., typically follows the aplite dikes along their contacts with the greenstones, but in some places angles away from the dikes and is trans-

formed into a stockwork of quartz veinlets in basalt. Gold values in these stockworks generally decrease from those in the vein material (Thomson, 1937). Aplite dikes grade into quartz vein material in other places, producing lenticular and deformed bodies of quartz.

The main gold-bearing vein at the north end of Cedar Island is set in a schistose zone of basalt and amphibolite. The vein consists of quartz, chlorite, and carbonate. Thomson (1936) mentions that there are two generations of vein quartz. Fine-grained, sugary quartz forms the earlier material, which usually contains chlorite stringers. The vein is fractured and fine-grained sulphides line the fracture walls. Pyrrhotite, arsenopyrite, galena, sphalerite, chalcopyrite, native gold, and two generations of pyrite are associated with the silicic vein material. Thomson (1936) states that distinct crystals of pyrite are first generation, followed by fine-grained pyrite, which surrounds the earlier formed crystals. Native gold is closely associated with the fine-grained pyrite and occurs as tiny veinlets in quartz. A later generation of white quartz crosscuts the first generation quartz and sulphides. When Thomson (1936) investigated this vein material at the 144-foot level he discovered that the vein measured 180 feet in length and averaged 1.476 ounces of gold per ton across a distance of 46 inches.

The Mikado mine is one of the more geologically interesting locations. It is situated on a coarse-grained

pegmatitic offshoot of the Canoe Lake stock, the contact of which lies less than 400 feet to the east. This offshoot strikes east-west and divides into two tongues about 350 feet west of the mine. The major mineralized vein intersects this dike and strikes 150° with a northeast dip of 85° . This lenticular-shaped vein crosscuts other smaller granitic dikes at depth. The main ore shoot was located at the intersection of the vein with the pegmatitic dike (Greer, 1931). The wall-rock of the pegmatite vein is massive fine- to medium-grained basalt.

At the Mikado mine the mineralized material consists of quartz, partly divided into bands by stringers of chlorite, sericite, and talc. Pyrite, chalcopryrite, bismuthinite, molybdenite, and malachite were identified by Parsons (1911). Free gold was noted and some specimens were of high grade. Three veins were mined at the Mikado. The first vein had a width of 4 to 5 feet and consisted of white to bluish-white quartz with associated narrow bands of darker quartz, chlorite, and sericite. Most of the gold recovered at the Mikado came from this vein. Average assay values for a part of the No. 3 vein were \$4.00 per ton (Parsons, 1911).

The Tycoon and Sirdar mines are located within the quartz diorite stock. Little vein material was found at either of these locations, although pyrite and siderite altering to hematite at the Tycoon and pyrite and chalcopryrite at the Sirdar were noted by Parsons (1911). Numerous tailing samples

of sheared quartz diorite showing slickensides and sulphide-staining were observed in the field.

The ore was reported to contain molybdenite at the Bullion mine as well as other sulphides occurring at the Mikado. The dump material does not contain highly mineralized samples, but a test pit in a nearby vein shows molybdenite and small amounts of free gold.

The Yum Yum property is located in massive gabbro with minor vein material, which pinches out at a shallow depth. Again the vein contacts are distinct and foliated.

The vein material is predominantly quartz with abundant calcite at the Olympia mine. The vein contacts are sharp and schistose, but the foliation quickly disappears, leaving massive gabbro and amphibolite.

Genesis of the Gold Mineralization

Riley et al. (1971) mention that 30 percent of the gold deposits in northwestern Ontario occur in epizonal felsic intrusions. Thirteen percent of these intrusions are fine-grained quartz and quartz-feldspar porphyry dikes and 17 percent are fine- to medium-grained trondhjemite to quartz diorite.

"Yet these intrusions, occurring within or along the margins of the metavolcanic-metasedimentary belts, form only 8 percent of the belts and suggest a genetic rela-

tionship between gold deposits and felsic intrusions."¹

The proximity of gold occurrences to the Canoe Lake stock at its western margins suggests that the mineralization is genetically related to the granitic magma.

RELATION BETWEEN THE GOLD AND COPPER MINERALIZATION

General Statement

The Canoe Lake stock contains both copper mineralization and gold. The porphyry copper mineralization predominates and extends across a major portion of the intrusion. The occurrences of gold are confined to the west contact and are more abundant in the adjacent rocks than in the quartz diorite.

The question arises as to whether or not the gold and copper mineralization are related to the same sequence of hydrothermal activity.

Extent of Both Types of Mineralization

Copper mineralization of more than 50 ppm. extends across most of the Canoe Lake stock. Figures 37 and 39 show the contoured chemical analyses for ppm. copper and zinc, ~~the~~

¹ Riley et al. (1971), p. 38.

respectively. Both these metals are present in sulphides disseminated in the quartz diorite mass or in hydrothermal veins filling fractures. The mineralization is concentrated in the Squaw Lake - Potter Lake area. Molybdenum is found near the south shore of Potter Lake, marking the central zone of the deposit. Figure 69, a contour plot of percent total sulphides, shows that the mineralization is concentrated near Squaw Lake and decreases across the intrusion, forming a moderately continuous band from Squaw Lake to Bag Bay. The porphyry copper mineralization is essentially restricted to the quartz diorite intrusion.

Bag Bay is the major area of gold mineralization. The gold-bearing quartz veins are restricted to contact regions between the quartz diorite stock and the adjacent rocks and many of the old mining properties are in the metavolcanic and mafic to ultramafic intrusive rocks. Gold occurrences extend as far south as Helldiver Bay and Yum Yum Point. Gold-bearing veins are not found in any other portions of the Canoe Lake stock.

Discussion on Genesis of the Gold and Copper Mineralization

The author was unable to establish the existence or nonexistence of a genetic relationship between the copper-molybdenum-zinc deposit near Squaw Lake and the gold

mineralization in Bag Bay.

A genetic association with the porphyry copper mineralization is favored for the following reasons.

1. Porphyry copper-molybdenum deposits typically contain associated gold mineralization at their outer edges.

2. The hydrothermal gold-bearing veins are mineralogically, texturally, and structurally similar to those containing copper-molybdenum-zinc mineralization. Both types of veins consist of one or more of quartz, chlorite, and carbonate; show medium- to coarse-grained textures and schistose margins; and strike east-west to slightly north-west with steep to vertical dips. Many of the gold-bearing veins show slickensides similar to the shearing features of the copper-bearing veins.

3. The association of chalcopyrite, pyrrhotite, sphalerite, molybdenite, and pyrite with gold-bearing veins suggests their possible genetic relationship to the porphyry copper mineralization.

The occurrence of most of the gold-bearing veins in the basalts and mafic to ultramafic intrusions adjacent to the Canoe Lake stock suggests that the gold mineralization may not be a part of the porphyry copper hydrothermal activity, which is essentially contained within the granitic intrusion. In any case, the gold-bearing hydrothermal solutions must have been active prior to shearing, but post-dating pre-hydrothermal fracturing.

GEOPHYSICAL AND GEOCHEMICAL DATA FOR
THE CANOE LAKE STOCK

GEOPHYSICAL RESULTS

General Statement

Geophysical data obtained during this study include specific gravity measurements and magnetic susceptibility determinations. More than 30 samples were used for this collection of data. A contour plot of aeromagnetic values across the Canoe Lake stock is also included.

Specific Gravity Results

Laboratory Techniques

Density determinations were carried out using an Ohaus Triple Beam Balance with a weight capacity of 2610 grams. Copper wire was attached to the balance and a small platform for the rock samples was suspended from it. Each rock was weighed once in air and once in water. A test was made to determine whether or not fractures in a rock affected its weight measurements and therefore, its specific gravity. This was done by taking five samples and drying them thoroughly in a Precision Scientific Heated Vacuum Dessicator

at 100°C., using a vacuum pump. The dried samples were then weighed in air and in water and returned to the dessicator. The dessicator was completely filled with water and covered and the temperature lowered to about 80°C.. The flooded samples were removed from the dessicator after approximately 24 hours and weighed in water. They were subsequently dried and weighed in air.

Discussion

Table 7 records the 30 samples with their weights in air and in water and their resulting specific gravity values. The formula for density is shown below.

$$\text{Density} = \frac{\text{Weight in Air}}{\text{Weight in Air} - \text{Weight in Water}}$$

The results of the two runs for the five test samples are shown in Table 8. It is evident that the fractures have a relatively minor effect on the resulting density values.

Figure 72 is a contour plot of the 35 density measurements. The overall range in specific gravity across the stock is considerable: from 2.63(7) to 2.74(1) g./cc.. Dobrin (1960) mentions that the density range for granite is 2.668 to 2.785 g./cc.. Therefore, the density values for the Canoe Lake stock are not unique.

The contour map illustrates a continuous high (more than 2.70(0) g./cc.) in specific gravity around the outer

Table 7. Specific gravity determinations
for the Canoe Lake quartz diorite stock.

Sample No.	Weight in Air (g.)	Weight in Water (g.)	Density (g./ cc.)
10-1	466.72	292.46	2.67(8)
25-1	753.81	472.78	2.68(2)
36-1	810.47	512.28	2.71(7)
38-1	690.36	436.19	2.71(6)
47-1	717.29	453.81	2.72(2)
67-1	858.10	535.52	2.66(0)
93-3	992.30	625.09	2.70(2)
112-1	322.14	202.52	2.69(3)
122-1	647.81	407.34	2.69(3)
128-1	666.08	418.54	2.69(0)
139-1	1017.86	640.02	2.69(3)
144-1	901.53	572.66	2.74(1)
150-1	845.35	528.45	2.66(7)
152-1	516.02	324.39	2.69(2)
171-1	493.79	310.21	2.68(9)
194-1	498.98	309.82	2.63(7)
199-1	710.65	445.17	2.67(6)
206-1	393.66	246.14	2.66(8)
236-1	605.46	379.31	2.67(7)
239-1	619.39	389.98	2.69(9)
242-1	694.33	435.52	2.68(2)
252-1	814.44	512.32	2.69(5)
267-1	754.38	478.07	2.73(0)
283-1	803.97	505.94	2.69(7)
294-1	384.13	240.90	2.68(1)
296-1	492.55	309.47	2.69(0)
299-1	858.16	537.33	2.67(4)
307-1	993.87	623.42	2.68(2)
312-1	473.65	299.50	2.71(9)
326-1	585.39	368.11	2.69(4)

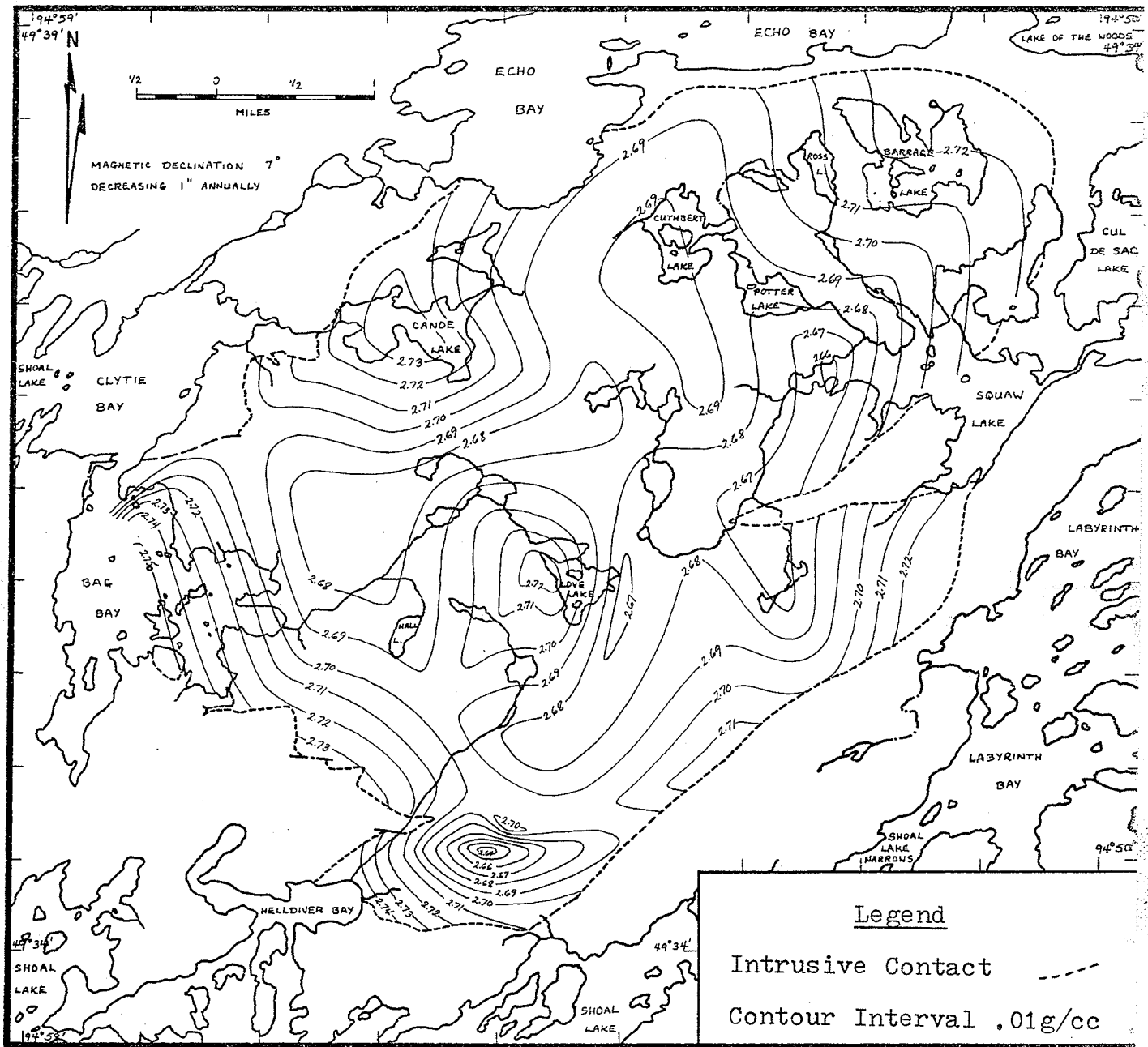
Table 8. Specific gravity test results.

Run Number 1

Sample No.	Weight in Air (g.)	Weight in Wa- ter (g.)	Density (g./ cc.)
163-1 (dry)	816.14	513.52	2.69(5)
(wet)	816.53	514.36	2.70(0)
193-1 (dry)	674.28	424.95	2.70(2)
(wet)	675.44	426.58	2.71(1)
213-1 (dry)	709.99	447.79	2.70(5)
(wet)	703.87	449.03	2.75(9)
282-1 (dry)	963.15	610.81	2.73(2)
(wet)	962.68	610.99	2.73(5)
314-1 (dry)	790.13	500.11	2.72(2)
(wet)	792.49	502.49	2.73(0)

Run Number 2

Sample No.	Weight in Air (g.)	Weight in Wa- ter (g.)	Density (g./ cc.)
163-1 (dry)	816.58	513.89	2.69(5)
(wet)	816.21	514.34	2.70(2)
193-1 (dry)	674.71	425.72	2.70(7)
(wet)	675.79	427.22	2.71(6)
213-1 (dry)	703.25	448.17	2.75(4)
(wet)	704.36	450.17	2.76(8)
282-1 (dry)	963.16	611.32	2.73(6)
(wet)	962.95	611.69	2.73(9)
314-1 (dry)	790.65	500.84	2.72(6)
(wet)	793.44	503.93	2.73(8)



margins of the quartz diorite intrusion. One additional high density area exists at the east shore of Love Lake. The reason for this isolated high is not known. The high density contact portions generally grade inwards to lower values at the centre of the stock. Two contour lows (less than 2.68(0) g./cc.) trend essentially parallel to the elongation of the granitic body. Because the specific gravity determinations were performed on quartz diorite samples, there would be no effect on the data from the adjacent rocks unless hybridization had occurred. Care was taken to select samples which represent the quartz diorite composition and which are located away from the contact zone.

Cain (1964) mentions that because rock density is dependent on mineral composition, the type and intensity of alteration, nature of the mafic minerals, plagioclase composition, and other factors would influence the density values. He also mentions that if the composition of biotite is variable across the intrusion, the specific gravity would be expected to vary. The author believes that a similar situation is present in the Canoe Lake stock, where a range in density for chlorite is to be expected. Low density values (less than 2.68(0) g./cc.) in the quartz diorite intrusion show a poor correlation with low quartz content. High specific gravity values (more than 2.70(0) g./cc.) show moderately good correlation with high plagioclase and chlorite contents and a poor correspondence to high hornblende, biotite, cli-

nozoisite, and epidote contents and to high alteration.

Cain (1964) offers another alternative on which density is dependent:

"... as specific gravity (and other variates) will presumably show vertical variability within the mass, the areal distribution pattern could be merely the result of erosion to different levels."¹

Magnetic Susceptibility Data

Laboratory Techniques

Thirty magnetic susceptibility determinations were made on crushed samples using a Halliburton MS-3 Magnetic Susceptibility Bridge. Seven additional samples of the Canoe Lake stock were measured to investigate the significance of two anomalous values.

Discussion

Table 9 contains the magnetic susceptibility data for the 37 samples. The change in resistance (ΔR) was less than 500 ohms in all cases so that the following equation was applicable to the 37 measurements.

¹ Cain (1964), p. 538.

Table 9. Magnetic susceptibility measurements for the Canoe Lake stock.

Sample No.	R _{Air}	R _{Sample}	ΔR	V(ml.)	ΔV(ml.)	Mag. Suscep. Kx10 ⁻⁶ c.g.s.
10-1	10905	10900	5	27.85	22.15	47.05
25-1	10910	10904	6	25.98	24.02	52.07
36-1	10910	10906	4	26.40	23.60	35.33
38-1	10909	10896	13	26.68	23.32	116.2
47-1	10910	10905	5	28.68	21.32	48.89
67-1	10909	10903	6	27.06	22.94	54.52
73-1	10880	10796	84	28.40	21.60	903.2
93-3	10911	10895	16	27.24	22.76	146.5
97-1	10880	10875	5	28.40	21.60	48.28
108-2A	10880	10876	4	27.82	22.18	37.59
112-1	10910	10906	4	26.20	23.80	35.03
122-1	10911	10714	197	27.10	22.90	1793
124-1	10879	10691	188	30.38	19.62	1988
128-1	10910	10906	4	27.88	22.12	37.69
139-1	10910	10895	15	26.58	23.42	133.5
144-1	10911	10904	7	26.92	23.08	63.22
150-1	10910	10905	5	26.86	23.14	45.04
152-1	10911	10905	6	27.00	23.00	54.38
168-1	10880	10829	51	27.80	22.20	479.3

Table 9 (cont.) Magnetic susceptibility measurements for the Canoe Lake stock.

Sample No.	R _{Air}	R _{Sample}	ΔR	V(ml.)	ΔV(ml.)	Mag. Suscep. Kx10 ⁻⁶ c.g.s.
171-1	10911	10904	7	26.62	23.38	62.41
183-1	10880	10864	16	28.38	21.62	154.3
194-1	10909	10854	55	27.86	22.14	517.8
199-1	10910	10905	5	27.80	22.20	46.95
206-1	10910	10905	5	25.80	24.20	43.07
216-1	10877	10869	8	25.90	24.10	69.17
236-1	10909	10892	17	28.48	21.52	164.7
239-1	10909	10901	8	28.82	21.18	78.73
242-1	10911	10906	5	26.66	23.34	44.66
252-1	10910	10903	7	26.76	23.24	62.79
267-1	10909	10905	4	26.40	23.60	35.33
283-1	10910	10897	13	28.38	21.62	125.3
294-1	10909	10902	7	29.40	20.60	70.83
296-1	10910	10901	9	29.58	20.42	91.87
299-1	10910	10902	8	25.84	24.16	69.02
307-1	10909	10903	6	27.04	22.96	54.47
312-1	10909	10904	5	27.26	22.74	45.83
326-1	10910	10905	5	27.38	22.62	46.08

$$\text{True Mag. Susc.} = R \times 3.57 \times 10^{-6} \times \left| \frac{1.413}{d^2} \right| \left| \frac{50}{50 - V} \right|$$

where: R = change in resistance (ohms)

3.57×10^{-6} = constant

1.413 = diameter of the sample holder (cm.)

d = inside diameter of the sample test tube (cm.)

50 = volume of water held in test tube (ml.)

50 - V = volume of water displaced by the sample

Figure 73 is a contour plot of the data, which ranges from 30×10^{-6} to nearly 2000×10^{-6} c.g.s. units. Dobrin (1960) states that granitic rocks have a range of magnetic susceptibilities from 28×10^{-6} to 2700×10^{-6} c.g.s. units. It is interesting to note that the Canoe Lake stock has values which extend across most of the given range for granites. The contoured data show two significant susceptibility highs (more than 200×10^{-6} c.g.s. units); one between Barrage Lake and Squaw Lake, and the other northeast of Helldiver Bay. The former contour high is the more dominant. The magnetic susceptibility of the quartz diorite is higher at the intrusive boundaries than at the centre, except for the contact zone southeast of Bag Bay. The Barrage Lake - Squaw Lake susceptibility high is offset to the northeast of the zone of highest copper mineralization. The two magnetic susceptibility highs are approximately coincident with high magnetite and high sulphide content (see Figures 24a and 24b, and 69, respectively).

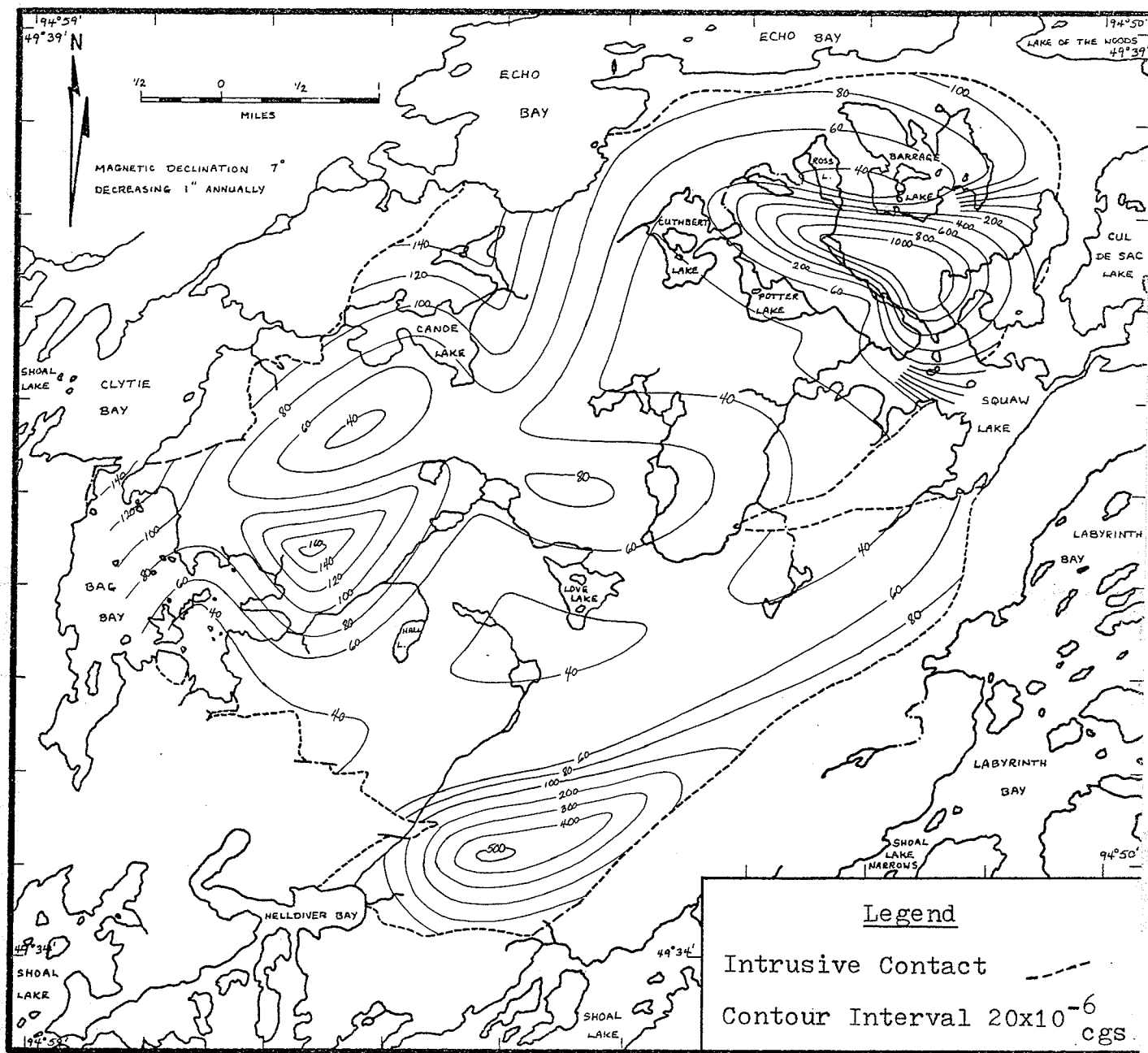


Figure 73. Contour plot of 37 magnetic susceptibility measurements across the Canoe Lake stock.

Brant (1966) states that porphyry copper deposits in the southwestern United States have magnetic susceptibility values ranging from less than 100×10^{-6} to 4000×10^{-6} c.g.s. units. He mentions that Jurassic, Laramide, and Tertiary intrusions in Nevada and Utah have average values of about 1500×10^{-6} c.g.s. units. Intrusions in Arizona are weakly magnetic, having values of 500×10^{-6} or less and averaging 100×10^{-6} c.g.s. units.

Aeromagnetic Data

Figure 74 shows the contoured aeromagnetic measurements across the Canoe Lake stock. The diagram was taken from a part of the Clearwater Bay, Kenora District, Ontario Map No. 1186G, published in 1962 by the Department of Mines and Technical Surveys of the Geological Survey of Canada. There is a continuous aeromagnetic low (less than 60,400 gammas) which is very similar to the intrusion in outline. The boundary of this low follows the southeast and southwest contacts almost exactly, but falls to the south and west of the north and east borders. The high magnetic contour values (more than 60,600 gammas) around the intrusion are expressions of the mafic and ultramafic rocks.

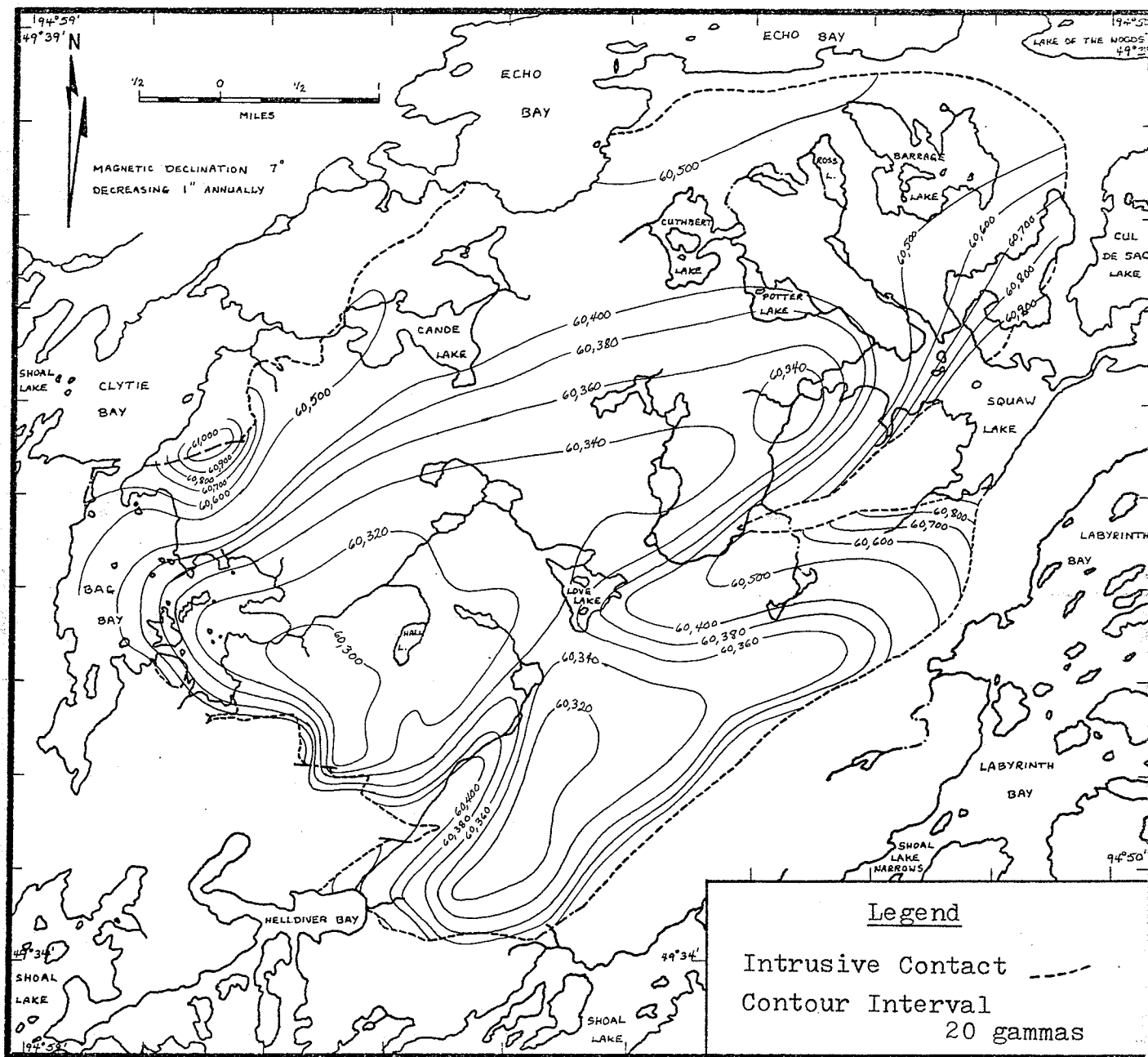


Figure 74. Contoured aeromagnetic data across the Canoe Lake stock. (Taken from a part of the Clearwater Bay, Kenora District, Ontario Map No. 1186G, published in 1962.)

GEOCHEMICAL RESULTS

General Statement

Samples from the Canoe Lake stock were used for sulphur isotope determinations. The results of the sulphur isotope work indicate an igneous origin for the sulphide minerals.

Sulphur Isotope Data

Laboratory Techniques

Twelve whole rock samples were crushed, pulverized, and sieved to obtain the -70 to +150 mesh portion. This fraction was washed, dried, and mixed in a separatory funnel with bromoform to separate the sulphides from most of the silicates. After drying the separated samples were returned to the separatory funnels and mixed with methylene iodide to remove the remaining silicates. The resulting samples ranged from 80 to 100 percent pure sulphide grains. The sulphide minerals present were pyrite, chalcopyrite, pyrrhotite, sphalerite, and rarely molybdenite. Each sample contained at least 80 percent pyrite and in subsequent steps of the laboratory procedure the samples were considered to be 100 percent pyrite. These mixed sulphide samples were necessary

because of the relatively small total sulphide fractions in the quartz diorite hand specimens.

The sulphide specimens were then subjected to conversion to SO_2 according to the procedure outlined in Secombe (1973). Briefly, from 65 to 90 mgm. of sample, depending on the purity, was mixed with about twice as much CuO in a combustion boat and burnt for 10 minutes at 1200°C . and 10 mm. of Hg. in an evacuated combustion tube. Progressive removal of water and CO_2 (combustion contaminants) was accomplished by freezing mixtures of dry ice - chloroform - carbon tetrachloride (-80°C .) and melting n-pentane (-130°C .). Collection of purified SO_2 was made in a sample bulb and the isotope ratios determined on a 180° dual collector Varian MAT GD 150 spectrometer operated by the Department of Chemistry, University of Manitoba. A sample of SO_2 of known ratio ($\delta\text{S}\%$ equal to +2.5) was prepared for the 12 runs and a ratio comparison made for each sample.

Discussion

Table 10 shows the results of the sulphur isotope determinations. It should be noted that percent yield from the SO_2 preparation step was included with each sample. Poor and impossible yields can be attributed to the fact that the samples were treated as pure pyrite, when in fact there was as much as 20 percent other sulphides in some of the samples.

Table 10. Sulphur isotope determinations.

Sample No.	Sample Wt. (mg.)	$\delta S^{34}\%$	Yield (cc.)	% Yield
59-1B	66	+3.09	19.0	91
61-4	69	+3.14	25.5	100
61-4 (W)*	68	+2.96	26.0	103
62-1	78	+3.39	24.0	90
67-1	26	+2.70	4.4	50
93-3	79	+1.73	13.1	52
108-1B	81	+1.65	21.4	82
108-2A	71	+1.53	26.4	100
110-1	90	+2.50	10.8	42
111-2	79	+2.88	11.2	44
112-1	52	+2.34	7.4	47
294-1	69	+2.93	12.9	55
Py. Std.	69	+7.61	27.8	106
Std. F	112	-0.28	22.4	150

* W = weathered sample, used as comparison to fresh sample results.

The percent yield was determined by the following formula:

$$\frac{65 \text{ mgm. Pyrite}}{X \text{ mgm. Sample}} + \frac{X \text{ cc. Yield}}{24.25 \text{ cc. Pyrite}} + \frac{100\%}{\text{Purity}}$$

The enrichment or depletion of the S^{34} isotope relative to the S^{32} isotope in the unknown samples was compared to standard meteoric troilite sulphur (accepted S^{32}/S^{34} ratio is 22.220 or δS enrichment is 0 permil) according to the following formula:

$$\delta S^{34} = 1100.95 \times \frac{R_x' - 1}{R_{SO_2}'} + 2.5$$

where: R_x' = the apparent S^{34}/S^{32} ratio of the sample

R_{SO_2}' = the apparent S^{34}/S^{32} ratio of the substandard SO_2

Figure 75 shows the spatial distribution of the 12 sulphur isotope determinations in the Canoe Lake stock. The values range from +1.53 to +3.39 permil.

Jensen (1967) states that hypogene sulphides within a magmatic hydrothermal deposit have values of δS^{34} which rarely vary more than ± 5 permil and usually vary less than this range.

"Such deposits have generally formed at higher temperatures where the kinetic isotope effects and exchange reactions result in much less fractionation... Almost all Cordilleran hydrothermal ore bodies of magmatic association exhibit δS^{34} values near zero permil.

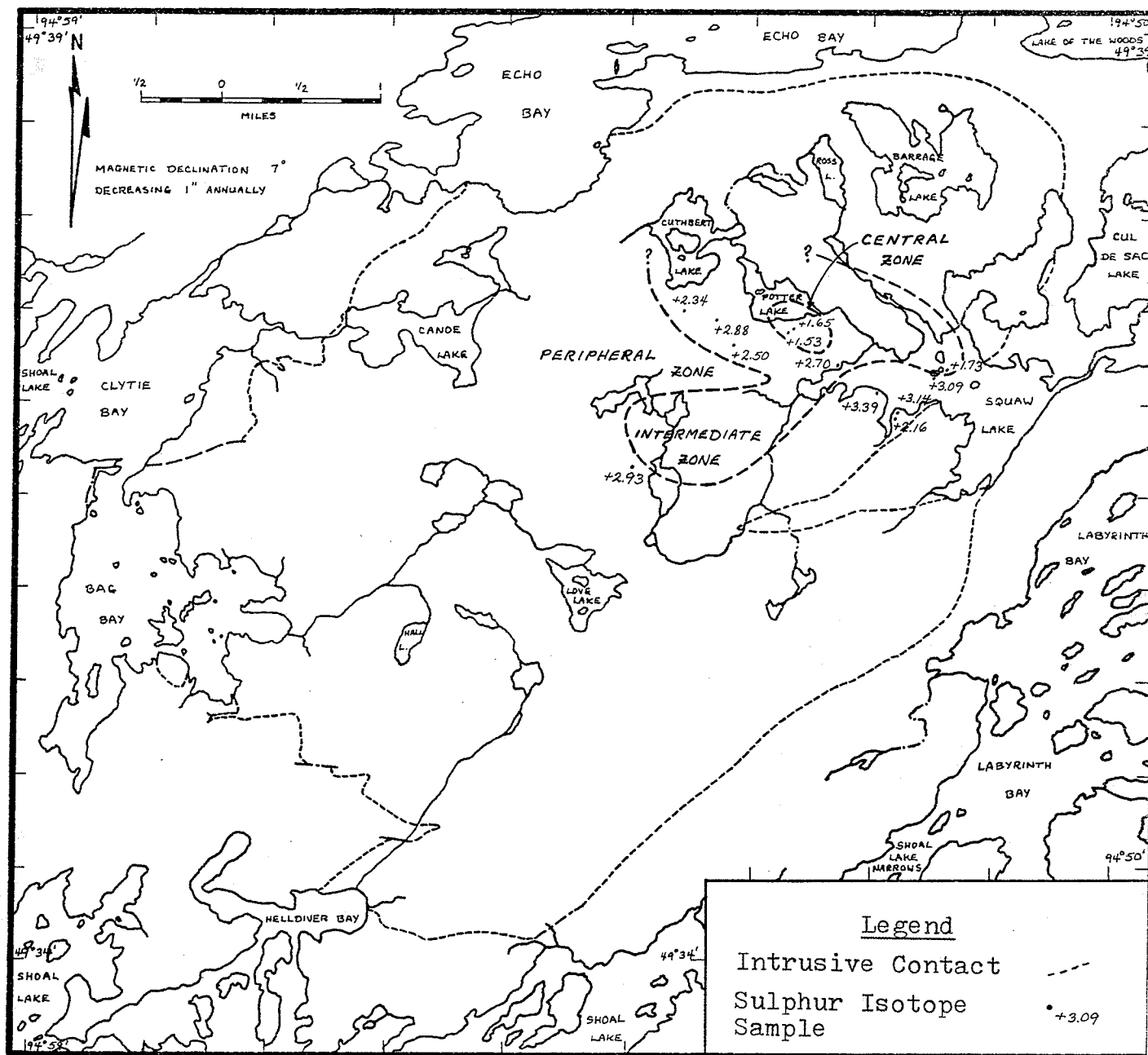


Figure 75. Spatial distribution of the 12 sulphur isotope determinations in the Canoe Lake stock. The central, intermediate, and peripheral zones have been added.

Examples are the porphyry coppers..."¹

Jensen (1967) mentions that the small degree of fractionation is due to a homogenizing effect, which the well mixed magma has on any previously existing isotopic variations.

Shima et al. (1963) state that granitic bodies usually have small positive values of δS^{34} , similar results were obtained in this study.

Recently, Lange and Cheney (1971) conducted a study of sulphur isotopes at Butte, Montana. They found a zonal variation in permil δS^{34} values of the various sulphides, such that the outer zones had larger positive values. For example, pyrite had a δS^{34} value of +0.7 permil in the central zone, grading outward to +1.3 permil in the intermediate zone, and to +3.6 permil in the peripheral zone. This range corresponds well with the δS^{34} results for the Canoe Lake stock. The central zone, immediately south of Potter Lake, has values of +1.53 and +1.65 permil; the outer zones range from +1.73 to +3.39 permil. However, in this study the zonal pattern near Squaw Lake and Potter Lake is not well developed. Lange and Cheney (1971) mention that this outward permil δS^{34} increase is due to an increase in the pH with or without a temperature decrease in the hydrothermal solutions as they migrated away from the central core. They also conclude that their sulphur isotopic data show that the por-

1 Jensen (1967), p. 151.

phyry copper deposit is genetically related to the Butte quartz monzonite intrusion.

From the foregoing the following conclusions apply to the porphyry copper mineralization in the Canoe Lake stock.

1. The small standard deviation of ± 0.63 permil and the range of values for the 12 samples analyzed indicates that the deposit at Squaw Lake was a result of magmatic hydrothermal activity. This reason is discussed in detail in Jensen (1959).

2. The standard deviation, mean value (+2.57 permil), and the range of δS^{34} values agrees with sulphur isotope data obtained for other deposits of magmatic genesis (for example, the porphyry copper deposits).

3. Because the sulphur isotope values are moderately close to 0.0 permil it is not possible to state whether the sulphur originated in the mantle or in the crust (Lange and Cheney, 1971). However, if the hydrothermal mineralized solutions were unrelated to the Canoe Lake stock, the sulphur isotope values would be expected to vary considerably in relation to values obtained from a magmatically homogenized crustal sulphide deposit.

4. There is a general trend toward higher sulphur isotope values away from the central core of the Squaw Lake deposit, although the trend is not as well developed as it is in much larger porphyry copper deposits such as Butte, Mon-

tana. Figure 75 shows the central, intermediate, and peripheral zones for the Squaw Lake porphyry copper deposit.

Figure 76 illustrates the sulphur isotopic compositions of sulphides in various hydrothermal deposits. Values for the porphyry copper mineralization in this study are also included in the diagram as a frequency plot.

SUMMARY OF RESULTS

INTERPRETATION OF THE GEOLOGIC HISTORY OF GRANITIC EMPLACEMENT AND SUBSEQUENT MINERALIZATION

The emplacement and subsequent mineralization of the Canoe Lake stock may be summarized in a number of steps. The author interprets all of these stages to be closely related in time. The geologic history is reviewed by the following sequence of events.

1. During the deformation of the metavolcanic and meta-sedimentary rocks and mafic to ultramafic intrusions, granitic magma was intruded along an anticlinal fold axis.

2. Intrusion of the Canoe Lake pluton caused foliation of the adjacent rocks except in the Bag Bay - Helldiver Bay area, where the rocks were more resistant and fractured.

3. Crystallization of the granitic magma formed an essentially solid outer shell which suffered cataclasis during the regional deformation.

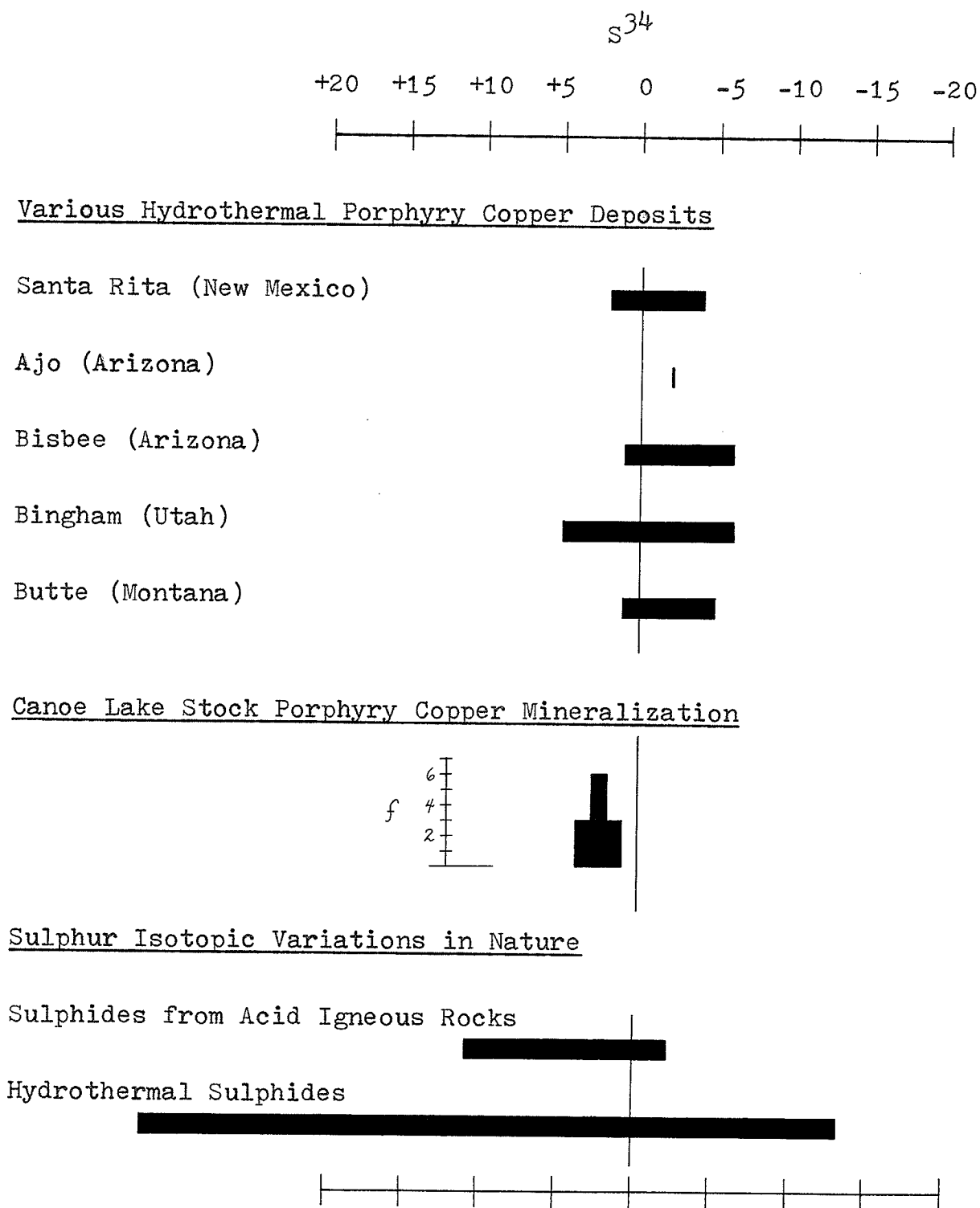


Figure 76. Sulphur isotopic compositions for sulphides in various hydrothermal deposits and in nature. Compiled from Jensen (1967, 1971).

4. Fracturing of this outer shell occurred during continued crystallization of the magma. The type of fractures produced were cross fractures at 135° and longitudinal fractures at 045° .

5. The first concentrated, more acidic solutions from the magma intruded into the partially solidified portions of the stock as dikes and irregularly shaped masses. The rock types formed were quartz porphyry, quartz-feldspar porphyry, feldspar porphyry, and fine-grained granodiorite. The felsic dikes generally trend parallel and perpendicular to the elongation of the pluton and have a well developed flow foliation.

6. Both the quartz diorite pluton and the associated felsic intrusions contained sufficient metal concentrations to cause precipitation of pyrite, chalcopyrite, pyrrhotite, sphalerite, and minor molybdenite as disseminated grains during the late magmatic stage.

7. Continued crystallization of the quartz diorite pluton led to sufficient concentration of the magmatic hydrothermal fluids, resulting in the first two stages of alteration.

8. With progression to the third stage of hydrothermal alteration the crystal mush continued to solidify and termination of this alteration stage was marked by nearly complete crystallization of the stock. The only remaining fluids at this point were the highly water-rich, metal-rich hydrother-

mal solutions.

9. Final solidification of the Canoe Lake stock and the younger felsic dikes was accompanied by the migration of the magmatic hydrothermal solutions from depth along channelways supplied by the two sets of pre-hydrothermal fractures.

10. The fourth stage of alteration was marked by the crystallization of hydrothermal fluids as microveinlets, veinlets, and veins along fractures. The mineral composition of these solutions was one or more of quartz, chlorite, sericite, carbonate, epidote, and various sulphides in the microveinlets and veinlets, and quartz $\pm$ chlorite $\pm$ carbonate $\pm$ copper, zinc, and/or molybdenum sulphides in the larger veins.

11. Minor late stage tectonic adjustment of the massive quartz diorite intrusion resulted in a scatter of multi-directional, irregular, curved fractures. Displacement was not observable on these poorly developed post-hydrothermal fractures.

12. The Canoe Lake stock and adjacent rocks in the Bag Bay - Helldiver Bay area were then subjected to late stage brittle deformation, involving the shearing of fractures parallel to 105° and 150° . The sense of displacement is believed to be right lateral.

13. Uplift of the region and intense erosion has resulted in the present depth level of exposure of the Canoe Lake stock, showing its complex alteration and mineraliza-

tion patterns. Minor oxidation of chalcopyrite to malachite and traces of azurite and of molybdenite to yellow and yellow-green molybdic oxide has occurred. Supergene enrichment of the porphyry copper mineralization was prevented by a lack of weathering.

BRIEF COMPARISON WITH OTHER GRANITIC INTRUSIONS IN THE AREA

General Statement

The Canoe Lake stock is one of the most distinct granitic plutons in the Falcon Lake - Lake of the Woods region. Vagt (1968) describes numerous intrusions in this area, emphasizing their tectonic significance. Ziehlke (1972) presents a description of the Aulneau Dome from preliminary studies.

The Canoe Lake intrusion is briefly compared, in the following discussion, to the Winnetka Lake stock, Granite Lake porphyry, High Lake granitic complex, Snowshoe Bay granodiorite, Indian Reserve granodiorite, Carl Bay granodiorite, and especially to the Aulneau Dome.

Discussion

Petrology

The Canoe Lake stock and other plutons in the area are predominantly medium-grained to pseudo-porphyritic and pink to grey. The Granite Lake, Snowshoe Bay, Indian Reserve, Carl Bay, and both of the High Lake intrusions have a uniform granodioritic composition. The Winnetka Lake stock and the Aulneau batholith display compositional zoning. The former is zoned outward from a granitic centre to a hornblende diorite peripheral zone; the latter is composed of trondhjemite, granodiorite, porphyritic granodiorite, and diorite (Ziehlke, 1972). The Canoe Lake stock is not unique in its uniform composition, but its quartz diorite classification is different.

The Canoe Lake intrusion and the Aulneau batholith are the only two plutons showing intense alteration. Alteration products in the quartz diorite stock are sericite, muscovite, chlorite, epidote, clinozoisite, carbonate, magnetite, and leucoxene, and from 20 to 60 percent by volume of the rock has been subjected to magmatic hydrothermal alteration. The Aulneau Dome has undergone alteration producing sericite, minor chlorite after biotite, epidote, clinozoisite, carbonate, and biotite after hornblende. The Canoe Lake pluton has encountered a greater degree of hydrothermal altera-

tion than has the Aulneau batholith.

Structure

All of the plutons in the Falcon Lake - Lake of the Woods region have sharp contacts, indicating an igneous origin as opposed to granitization. The Canoe Lake stock has a uniform, fracture-controlled contact in the Bag Bay - Helldiver Bay area. Fractures or joints in these intrusions have one or more of four major directions: northeast, northwest, east-west, and north-south. All fractures are vertical to nearly vertical. Fracturing is most intense in the Canoe Lake quartz diorite.

The Canoe Lake pluton is distinct in its numerous closely associated felsic intrusions, which are not as abundant in the other granitic masses.

The Winnetka Lake stock, Granite Lake porphyry, High Lake porphyritic granodiorite, Carl Bay granodiorite, and the Aulneau Dome have poorly to well developed east-west penetrative cataclastic foliation. The Snowshoe Bay granodiorite, Indian Reserve granodiorite, High Lake grey granodiorite, and the Canoe Lake stock lack a penetrative regional foliation. Therefore, the first group represents pre- to early syn-tectonic intrusion, whereas the second group represents syn- to post-tectonic emplacement (Vagt, 1968).

Most of the intrusions show large scale shear zones. Cataclastic deformation of the Winnetka Lake stock has produced fractured, crushed, and deformed grains and recrystallized quartz, such that the rock is pseudo-porphyrific in appearance. The Granite Lake porphyry and High Lake porphyritic granodiorite have also undergone cataclasis. The Canoe Lake stock shows cataclastic foliation only at its contacts and along shear zones; incipient mortar texture is rare and present in only a few slides.

Mineralization

Most of the intrusions in the Falcon Lake - Lake of the Woods area are not mineralized. Davies (1970) mentions that the Carl Bay granodiorite contains minor amounts of chalcopyrite and galena. The High Lake granodioritic complex and the Canoe Lake stock are similar in that they both contain embryonic porphyry copper deposits. The actual deposit in the Canoe Lake stock is centred near Squaw Lake, although copper mineralization pervades the rest of the intrusion. Peripheral gold mineralization is present in the Canoe Lake quartz diorite at its southwest contact.

Conclusions

The Canoe Lake stock is a distinctive granitic

pluton in the Falcon Lake - Lake of the Woods region. It differs from most or all of the other intrusions in the following features.

1. The stock has a quartz diorite composition.
2. Magmatic hydrothermal alteration in the Canoe Lake intrusion has been severe.
3. The pluton lacks a penetrative cataclastic foliation. Cataclasis has occurred only at the intrusive contacts and along shear zones.
4. Abundant pre- and post-hydrothermal fractures and sheared fractures are present in the Canoe Lake stock.
5. Porphyritic felsic dikes are numerous and closely associated, both genetically and spatially, with the quartz diorite pluton.
6. The fracture-controlled contact in the Bag Bay - Helldiver Bay area appears to be unique to the Canoe Lake stock.
7. The porphyry copper deposit near Squaw Lake and pervasive porphyry type copper mineralization are major features of the Canoe Lake quartz diorite intrusion. The sulphide minerals include pyrite, chalcopyrite, pyrrhotite, sphalerite, and molybdenite.
8. The Canoe Lake pluton has associated peripheral gold mineralization along its Bag Bay - Helldiver Bay contact zone.

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APPENDIX I

MODAL ANALYSES FOR THE
CANOE LAKE STOCK

Mineral	Slide Number (Values in Volume Percent)									
	3-1	7-1	10-1	20-1	23-1	24-1	25-1	31-1	32-1	34-1
<u>Primary</u>										
Plagioclase	56.4	51.4	57.0	56.8	58.8	47.1	53.2	50.6	50.6	58.2
Quartz	32.3	38.6	38.4	32.8	29.3	36.7	33.7	26.2	36.5	29.7
Hornblende	6.6	6.4	1.5	5.4	8.3	10.7	8.7	13.0	6.0	7.6
Biotite	3.7	3.6	3.1	5.0	3.6	5.5	4.2	10.2	6.8	4.2
Microcline		tr		tr					0.1	0.3
Apatite		tr			tr			tr	tr	tr
Rutile		tr		tr				tr		tr
<u>Total Sulphides</u>							0.2			
<u>Hydrothermal</u>										
Sericite (Stage 1)	6.5	6.6	12.0	7.4	10.8	10.1	9.2	11.3	14.4	18.2
Sericite (Stage 2)	14.6	5.4	9.8	3.5	11.6	7.7	16.1	7.6	5.6	5.0
Sericite (Stages 3&4)	6.2	8.2	5.0	0.7	1.0	0.3	4.1	7.8	2.0	2.4
Chlorite (Stages 1-3)		7.3	2.3	7.1	10.6	12.6	10.1	19.9	10.2	9.4
Chlorite (Stage 4)	0.8		1.4		0.1	0.3	0.1			
Epidote (Stages 1-3)		2.5	2.1	2.1	0.1	0.9	0.6	2.5	2.3	1.6
Epidote (stage 4)				8.2					0.7	
Clinozoisite (S.1-4)		11.0	1.0	16.8				1.9	8.3	1.3
Carbonate (S.1-3)	2.1	0.6	2.4	0.6	2.7	19.0	2.0	3.2	2.4	5.2
Carbonate (Stage 4)	4.1	2.0	2.2	2.1	0.1	0.5	0.5	7.6	1.1	3.2
Mgt./Ilm. (S.1-4)	0.5	0.3	0.3	0.1	0.3	1.3	0.3	1.0	0.5	tr
Leucoxene (S.1-4)	0.8	0.5	0.3		1.5	0.8	2.1			
Hematite	0.4	0.2		0.1		0.1		0.3	0.1	0.1
<u>Total Alteration</u>	36.0	44.6	38.8	48.7	38.8	53.1	45.1	63.1	47.6	46.4

Mineral	Slide Number (Values in Volume Percent)									
	35-1	36-1	37-1	38-1	39-1	41-1	47-1	48-1	59-2A	61-4
<u>Primary</u>										
Plagioclase	55.7	55.8	49.5	54.9	57.4	58.8	64.5	63.4	58.8	59.8
Quartz	34.4	33.0	36.2	34.9	29.6	32.6	28.4	28.1	27.4	34.8
Hornblende	6.0	4.8	8.9	3.3	7.3	3.8	1.6	3.6	7.4	0.8
Biotite	3.6	6.4	5.1	6.5	5.7	4.8	5.3	4.4	5.4	2.2
Microcline	0.3	tr	0.3				0.2	0.5		
Apatite	tr		tr		tr		tr			tr
Rutile			tr	0.4		tr				
<u>Total Sulphides</u>									1.0	2.4
<u>Hydrothermal</u>										
Sericite (Stage 1)	17.6	17.2	8.5	12.6	16.7	20.0	6.1	10.0	16.6	21.8
Sericite (Stage 2)	6.2	4.0	13.7	7.9	7.1	8.0	4.7	3.6	13.6	11.8
Sericite (Stages 3&4)	1.9	2.0	0.2	0.5	1.2	0.6		2.0	0.4	2.7
Chlorite (Stages 1-3)	9.6	8.6	12.6	9.1	6.1	5.6	2.4	5.0	6.0	4.8
Chlorite (Stage 4)			0.8		0.2	0.4			1.4	1.7
Epidote (Stages 1-3)	1.7	3.4	0.7	5.8	5.1	1.2	4.1	2.0	0.8	
Epidote (Stage 4)		0.2		0.3						
Clinozoisite (S.1-4)		15.6		1.4	2.1		13.0	1.6		
Carbonate (S.1-3)	3.6	1.8	9.8	0.7	11.6	0.3	0.5	2.0	8.4	1.3
Carbonate (Stage 4)	4.6	0.2	4.6		4.3	4.4			3.2	0.3
Mgt./Ilm. (S.1-4)			0.2	0.4	0.2	1.1	tr	0.4	0.3	
Leucoxene (S.1-4)			1.9	0.1	4.5	0.2	0.1	1.0	3.7	
Hematite	0.1					0.2		0.1	0.6	tr
<u>Total Alteration</u>	45.3	53.0	53.0	38.8	59.1	41.8	30.9	27.7	55.0	44.4

Mineral	Slide Number (Values in Volume Percent)									
	62-1	63-1	64-1	65-1	66-1	67-1	68-1	69-1A	70-1	73-1
Primary										
Plagioclase	55.3	52.2	53.8	56.4	58.2	53.8	62.5	49.9	55.0	47.6
Quartz	33.0	37.0	37.2	34.8	30.5	36.3	30.8	38.2	33.4	41.2
Hornblende	8.4	4.4	4.8	2.5	4.2	4.0	3.0	6.0	5.0	6.2
Biotite	2.9	6.2	3.9	6.0	7.0	5.4	2.4	5.8	6.4	4.7
Microcline										
Apatite	tr		tr		tr			tr	tr	tr
Rutile										
Total Sulphides	0.4	0.2	0.3	0.3	0.1	0.5	1.3	0.1		
Hydrothermal										
Sericite (Stage 1)	15.2	8.4	18.4	14.0	19.0	7.4	19.4	9.6	12.6	15.0
Sericite (Stage 2)	13.3	6.3	9.4	8.8	1.2	1.8	7.4	9.8	11.4	11.2
Sericite (Stges 3&4)	2.7	10.6		4.7		0.7	4.0	5.6	7.6	2.2
Chlorite (Stges 1-3)	8.5	7.2	6.2	6.6	7.4	5.0	3.8	7.0	8.4	6.4
Chlorite (Stage 4)	4.4	2.0		0.6	0.8					
Epidote (Stages 1-3)	1.7	3.6	1.6	0.1	2.6	4.0	1.4	4.5	2.2	1.2
Epidote (Stage 4)		2.8	0.2		3.0					
Clinozoisite (S.1-4)	tr	7.8		tr	0.7	0.5				
Carbonate (S.1-3)	3.7	1.6	5.4	2.1	7.6	3.0	10.6	1.4	4.6	4.6
Carbonate (Stage 4)	1.1	0.2		1.1	0.3	0.8	2.9	2.3	1.3	3.4
Mgt./Ilm. (S.1-4)	0.1			0.2	0.5	0.2	0.2	0.4	0.6	1.5
Leucoxene (S.1-4)	4.9		0.2	0.6	0.2		0.8	0.4		2.5
Hematite					tr	tr	0.4	0.3	0.1	0.1
Total Alteration	55.6	50.5	41.4	38.8	43.3	23.4	50.9	41.3	48.8	48.1

Mineral	Slide Number (Values in Volume Percent)									
	76-1	90-1	93-3	97-1	103-1	108-2A	110-1	111-2	112-1	115-1
Primary										
Plagioclase	56.0	54.2	59.5	64.6	49.6	57.0	55.6	59.0	47.4	53.1
Quartz	30.8	33.6	27.4	20.1	32.0	40.8	33.4	29.6	44.4	35.2
Hornblende	7.7	7.1	7.3	10.7	10.0	0.2	5.4	4.8	5.5	8.0
Biotite	5.5	5.1	5.5	4.6	8.2	0.3	5.6	6.2	2.4	3.7
Microcline	tr		tr		0.2	tr		0.1		
Apatite		tr		tr	tr			tr	tr	tr
Rutile		tr			tr					
Total Sulphides			0.3		tr	1.7	tr	0.3	0.3	
Hydrothermal										
Sericite (Stage 1)	9.7	13.0	10.8	10.4	14.0	13.2	8.1	15.2	4.9	5.3
Sericite (Stage 2)	3.9	15.4	13.8	8.2	12.8	8.4	0.4	12.8	10.7	5.4
Sericite (Stges 3&4)	5.9	1.3	4.4	0.5	4.4	0.4		2.8	2.0	3.3
Chlorite (Stges 1-3)	9.3	6.7	9.0	8.6	13.2	0.3	9.8	6.2	5.1	4.7
Chlorite (Stage 4)				0.7				1.1	0.2	
Epidote (Stages 1-3)	2.8	3.0	1.2	3.1	3.8	0.1	1.6	3.4	1.2	7.1
Epidote (Stage 4)				1.8						
Clinozoisite (S.1-4)		0.8	0.8	13.3		0.1		2.2	0.2	13.3
Carbonate (S.1-3)	1.1	3.4	4.8	2.6	3.6	5.0	0.8	2.6	1.4	3.0
Carbonate (Stage 4)	1.8	0.5	3.0	0.4	4.8	3.2		5.1	5.1	
Mgt./Ilm. (S.1-4)	1.3	3.1	0.4	tr	0.3	tr	0.1	0.6	0.2	0.3
Leucoxene (S.1-4)		0.5	0.6	0.7	1.3		0.3	tr	1.6	tr
Hematite	0.2	0.2	0.1	tr	0.1	0.1	0.1	0.2		
Total Alteration	36.0	47.9	48.9	50.3	58.3	30.8	21.2	52.2	32.6	42.4

Mineral	Slide Number (Values in Volume Percent)										
	116-1	117-2	119-2	120-1	121-1	122-1	123-1	124-1	128-1	130-1	
<u>Primary</u>											
Plagioclase	63.0	54.1	60.1	57.2	48.2	57.3	57.4	51.2	52.4	59.0	
Quartz	30.4	40.4	31.8	36.7	46.4	35.5	34.0	30.7	40.4	36.9	
Hornblende	2.8	1.0	3.4	4.1	2.7	2.1	1.4	9.0	1.0	0.4	
Biotite	3.8	4.3	4.4	2.0	2.5	4.7	6.4	9.1	5.0	3.3	
Microcline	tr			tr	tr	0.4	0.8	tr	1.2		
Apatite					tr	tr					
Rutile	tr						tr				
<u>Total Sulphides</u>		0.2	0.3		0.2				tr	0.4	
<u>Hydrothermal</u>											
Sericite (Stage 1)	8.2	11.4	8.7	12.2	8.7	5.5	6.4	9.0	7.0	7.5	
Sericite (Stage 2)	3.8	0.7	10.8	11.8	9.6	1.7	2.0	4.8	5.8	7.4	
Sericite (Stages 3&4)	0.7		0.9	3.4	0.7	0.8	1.2	0.4	0.6	4.1	
Chlorite (Stages 1-3)	4.4	5.2	5.8	5.1	4.7	4.9	1.6	13.8	4.6	3.9	
Chlorite (Stage 4)				1.2	0.2						
Epidote (Stages 1-3)	2.4	0.2	1.9	0.7	0.3	1.9	1.5	4.4	2.6		
Epidote (Stage 4)											
Clinozoisite (S.1-4)	17.0	13.7	0.6			16.9	11.4	8.8	18.8	5.6	
Carbonate (S.1-3)	2.3	0.2	2.2	2.6	2.1	0.6		1.0		3.5	
Carbonate (Stage 4)	1.5		3.6	7.6	3.4		0.3			0.4	
Mgt./Ilm. (S.1-4)	0.1	0.2	0.1	0.1	0.1	0.2	1.9	1.8	tr		
Leucoxene (S.1-4)		0.2		1.0							
Hematite	0.1	0.1	0.1	0.1	0.2		0.1		tr		
<u>Total Alteration</u>	40.5	31.9	34.7	45.8	30.0	32.5	26.4	44.0	39.4	32.4	

Mineral	Slide Number (Values in Volume Percent)										
	132-1	133-1	139-1	140-1	141-1	144-1	145-1	148-1	149-1	150-1	
Primary											
Plagioclase	65.5	59.6	56.0	57.6	49.4	57.6	57.4	52.6	62.8	57.2	
Quartz	26.8	30.6	30.6	28.3	39.4	30.4	34.2	41.0	31.6	35.0	
Hornblende	3.0	4.2	3.8	9.6	5.2	4.6	1.4	2.2	1.6	1.5	
Biotite	4.4	5.0	9.2	4.5	5.8	7.4	7.0	3.6	4.0	6.1	
Microcline		0.3			0.2	tr		0.6		tr	
Apatite	tr	tr	tr			tr			tr		
Rutile		tr	0.4	tr	tr	tr		tr	tr	0.2	
Total Sulphides	0.3	0.3									
Hydrothermal											
Sericite (Stage 1)	11.8	12.6	15.0	16.8	6.0	12.0	7.8	7.4	14.8	10.4	
Sericite (Stage 2)	3.4	8.8	8.5	10.1	5.2	4.5	5.0	10.1	10.4	11.7	
Sericite (Stges 3&4)	0.4	1.8	2.1	3.1	2.1	1.2	5.2	7.0	6.7	3.5	
Chlorite (Stges 1-3)	3.5	4.2	8.9	12.7	8.6	8.1	6.6	5.9	4.3	6.1	
Chlorite (Stage 4)											
Epidote (Stages 1-3)	3.8	4.5	1.5	1.0	2.0	1.2	1.9	0.5	1.1	0.7	
Epidote (Stage 4)		0.3			0.3	3.0					
Clinozoisite (S.1-4)	24.7	16.0	3.8	1.0	17.4	22.1	19.7	0.3	1.5	1.9	
Carbonate (S.1-3)	1.0	0.3	4.0	1.2	0.4	0.4	3.4	4.9	1.6	3.0	
Carbonate (Stage 4)	0.4	1.2		3.8	1.5	0.6	1.2	1.8	1.3	2.1	
Mgt./Ilm. (S.1-4)	0.2	0.2	0.7	0.3	tr	0.6	0.7	0.8	0.3	0.6	
Leucoxene (S.1-4)			0.4				0.4				
Hematite	0.2	0.2	tr	0.1	0.1					tr	
Total Alteration	49.4	50.1	44.9	50.1	43.6	53.7	51.9	38.7	42.0	40.0	

Mineral	Slide Number (Values in Volume Percent)											
	151-1	152-1	154-1	155-1	161-1	162-1	167-1	170-1	171-1	172-1		
<u>Primary</u>												
Plagioclase	56.6	66.4	63.2	65.2	56.6	65.1	61.1	58.9	63.2	58.7		
Quartz	32.7	29.4	26.4	25.6	37.0	27.1	28.5	29.8	30.6	32.5		
Hornblende	3.9	1.7	3.6	3.7	0.9	6.0	4.7	5.4	4.1	6.1		
Biotite	6.8	2.5	6.4	5.5	5.5	1.8	4.9	4.7	1.4	1.9		
Microcline			0.4	tr	tr	tr	0.8	0.8	0.5	0.8		
Apatite				tr	tr							
Rutile		tr	tr					0.4	0.2			
<u>Total Sulphides</u>												
<u>Hydrothermal</u>												
Sericite (Stage 1)	10.8	13.4	22.1	20.0	12.3	25.2	14.4	6.8	8.8	13.5		
Sericite (Stage 2)	7.9	13.1	3.6	3.8	5.2	4.6	2.7	6.4	7.6	10.0		
Sericite (Stages 3&4)	11.0	7.3	1.4	1.1	1.6		0.1	11.6	7.6	2.2		
Chlorite (Stages 1-3)	8.6	3.0	7.6	7.4	3.3	6.1	7.4	7.5	3.3	4.5		
Chlorite (Stage 4)						1.2	0.3					
Epidote (Stages 1-3)	2.1	1.1	0.7	1.1	1.3		0.6	1.2	0.5	2.8		
Epidote (Stage 4)			1.0	0.6	0.5							
Clinozoisite (S.1-4)	1.5	3.0	4.0		10.4		2.5	3.4	1.5	2.1		
Carbonate (S.1-3)	2.4	2.6	1.1	0.8		1.9	3.0	2.4	2.1	2.2		
Carbonate (Stage 4)	1.2	1.3	4.5	3.1	1.3	6.8	0.6		1.9	0.4		
Mgt./Ilm. (S.1-4)	0.7	0.9	0.5	0.9	0.1	0.4	0.9	1.2	0.9	0.7		
Leucoxene (S.1-4)			0.2				0.3	tr	0.3	0.2		
Hematite	tr	tr	0.1	0.2			0.4	tr	tr	tr		
<u>Total Alteration</u>	46.2	45.7	46.8	39.0	36.0	46.2	33.2	40.5	34.5	38.6		

Mineral	Slide Number (Values in Volume Percent)									
	178-1	180-1	183-1	189-1	190-1	194-1B	195-2	199-1	201-1	204-1
Primary										
Plagioclase	58.0	63.2	60.1	60.8	60.3	58.0	54.5	56.2	55.8	60.0
Quartz	36.2	32.0	29.7	31.9	28.5	32.2	35.5	33.4	33.8	23.6
Hornblende	1.9	1.8	6.6	2.4	3.9	3.4	5.5	6.4	2.8	8.2
Biotite	3.9	1.0	3.6	4.6	7.0	6.4	3.4	4.0	7.6	7.5
Microcline	tr	0.6		0.2	0.3	tr	0.5		tr	0.6
Apatite	tr		tr		tr			tr	tr	tr
Rutile		tr		0.1	tr		0.4	tr		0.1
Total Sulphides		1.4					0.2			
Hydrothermal										
Sericite (Stage 1)	14.2	22.0	10.0	5.6	5.0	4.9	6.0	8.0	15.2	7.6
Sericite (Stage 2)	7.0	11.8	7.9	3.9	3.5	7.1	9.4	9.4	2.6	10.4
Sericite (Stges 3&4)	4.0	3.4	2.7	1.6	0.3		9.2	8.0	0.6	4.7
Chlorite (Stges 1-3)	5.0	1.6	7.6	tr	1.3	0.4	6.8	8.1	6.0	13.0
Chlorite (Stage 4)		1.6							0.2	
Epidote (Stages 1-3)	0.3	0.2	2.4	0.7	1.6	1.8	1.5	1.4	0.8	1.3
Epidote (Stage 4)		0.2							2.3	
Clinozoisite (S.1-4)			13.4	11.8	13.3	11.7	5.5		13.8	4.7
Carbonate (S.1-3)	0.3	1.6	2.1	0.1	0.6	1.1	2.6	0.8		4.2
Carbonate (Stage 4)	3.8	2.4					0.6	3.9	1.8	0.3
Mgt./Ilm. (S.1-4)	0.9	1.0	0.3	0.8	0.7	0.7	0.4	1.2	0.4	0.5
Leucoxene (S.1-4)			0.1	0.4	tr	0.4	0.2	0.4		tr
Hematite		0.1						0.2		
Total Alteration	35.5	45.9	46.5	24.9	26.3	28.1	42.2	41.4	43.7	46.7

Mineral	Slide Number (Values in Volume Percent)											
	205-1	206-1	207-1	211-1	212-1	217-1	219-1	221-1	222-1	223-1		
<u>Primary</u>												
Plagioclase	63.5	54.2	61.1	58.9	56.6	58.0	56.6	53.6	59.6	51.2		
Quartz	23.3	29.6	30.2	32.8	31.2	33.8	32.1	30.1	24.8	36.9		
Hornblende	6.2	7.2	3.2	2.5	5.6	6.0	1.6	11.9	10.2	9.5		
Biotite	7.0	8.8	5.5	5.8	6.4	2.2	9.7	4.2	4.6	2.4		
Microcline		0.2	tr			tr	tr	tr	0.6			
Apatite								tr		tr		
Rutile		tr		tr	0.2			tr	0.2			
<u>Total Sulphides</u>								0.2				
<u>Hydrothermal</u>												
Sericite (Stage 1)	9.7	9.2	7.2	3.9	9.2	9.3	11.6	4.2	4.7	6.9		
Sericite (Stage 2)	14.2	10.9	9.8	11.5	9.7	18.4	10.4	8.9	13.1	5.3		
Sericite (Stages 3&4)	1.4	4.5		3.2	1.7	0.7	2.8	3.0	7.8	0.4		
Chlorite (Stages 1-3)	4.8	12.0	1.8	5.5	6.4	4.0	4.7	10.1	8.6	5.6		
Chlorite (Stage 4)						1.8				2.3		
Epidote (Stages 1-3)	2.6	3.3	2.4	1.1	3.0	0.6	1.2	3.7	3.2	5.7		
Epidote (Stage 4)										7.1		
Clinozoisite (S.1-4)	10.7	2.8	0.6	10.3	11.6	1.6	6.0	1.3	2.4	2.6		
Carbonate (S.1-3)	2.9	4.4	0.2	2.3	2.1	4.8	0.6	3.7	3.0	1.4		
Carbonate (Stage 4)		0.9		1.8	tr	1.3	3.1	1.2	1.9	6.7		
Mgt./Ilm. (S.1-4)	0.8	0.5	0.2	0.4	0.6	1.5	0.4	0.3	0.3	0.3		
Leucoxene (S.1-4)	0.6	0.4	tr		tr	tr	0.3	1.7	1.0	1.6		
Hematite		tr		tr	tr	tr		0.2				
<u>Total Sulphides</u>	47.7	48.9	22.2	40.0	44.3	44.0	41.1	38.3	46.0	45.9		

Mineral	Slide Number (Values in Volume Percent)										
	226-1	228-1	234-1	236-1	238-2	239-1	240-1	241-1	242-1	243-1	
<u>Primary</u>											
Plagioclase	58.1	51.6	55.2	50.2	50.9	57.2	49.4	50.3	55.6	54.1	
Quartz	32.8	42.2	40.4	40.8	28.8	28.7	33.0	36.0	32.4	34.1	
Hornblende	5.0	5.2	3.0	4.6	9.3	10.5	11.4	7.4	8.6	8.0	
Biotite	4.1	1.0	1.2	4.0	8.5	3.6	5.8	6.0	3.4	3.1	
Microcline			0.2	0.4	0.2		0.2	0.3	tr		
Apatite	tr	tr	tr		tr	tr					
Rutile			tr	tr	tr	tr	0.2		tr		
<u>Total Sulphides</u>					2.3					0.7	
<u>Hydrothermal</u>											
Sericite (Stage 1)	12.1	10.8	21.8	9.2	15.4	6.1	14.0	7.7	10.6	3.2	
Sericite (Stage 2)	9.8	9.2	2.0	5.6	14.6	12.3	6.0	3.8	10.0	9.0	
Sericite (Stages 3&4)	9.3	2.8	0.4	0.8	6.2	10.4	0.9	0.2	6.6	8.8	
Chlorite (Stages 1-3)	8.2	6.0	2.8	6.2	6.4	6.8	11.0	10.8	7.8	7.2	
Chlorite (Stage 4)							0.2				
Epidote (Stages 1-3)	0.6	0.3	1.0	1.4	4.2	6.0	2.3	2.9	3.9	3.8	
Epidote (Stage 4)				0.6							
Clinozoisite (S.1-4)				7.2		0.2	tr	5.7	2.0	1.8	
Carbonate (S.1-3)	1.0	0.6	1.3	0.4	1.4	4.6	5.0	3.0	3.2	2.7	
Carbonate (Stage 4)	3.3	4.8	4.1	1.0	3.4	5.7	0.2	0.8	5.0	3.2	
Mgt./Ilm. (S.1-4)	0.3	1.1	0.2	0.4	0.3	0.2	0.3	0.2	0.2	0.4	
Leucoxene (S.1-4)						2.3	0.8	0.5	1.1	0.2	
Hematite	0.1			0.1			0.2		tr	0.9	
<u>Total Alteration</u>	44.7	35.6	33.6	32.9	51.9	54.6	40.9	35.6	50.4	41.2	

Mineral	Slide Number (Values in Volume Percent)									
	244-1	247-1	248-1	249-1	251-1	252-1	253-1	254-1	256-1	263-1
Primary										
Plagioclase	54.4	49.0	58.6	48.3	48.7	57.9	51.8	57.1	62.0	61.3
Quartz	39.2	45.3	30.4	44.0	36.4	34.9	28.3	33.4	30.8	28.4
Hornblende	4.2	3.7	5.9	3.9	1.9	1.8	14.3	3.7	1.8	7.1
Biotite	1.8	2.0	4.7	3.8	12.5	5.4	5.4	5.5	5.4	3.2
Microcline			0.1		0.4					
Apatite	tr	tr	tr	tr	0.1	tr	tr	tr	tr	tr
Rutile						tr	tr		tr	tr
Total Sulphides	0.4		0.3	tr			0.2	0.3		
Hydrothermal										
Sericite (Stage 1)	6.7	9.7	8.2	8.7	11.4	6.7	8.6	10.6	20.8	6.6
Sericite (Stage 2)	8.3	3.4	5.1	7.7	0.5	7.3	7.3	9.1	3.0	8.0
Sericite (Stges 3&4)	6.8	0.9	11.0	5.5		0.9	0.8	1.2	0.8	16.8
Chlorite (Stges 1-3)	3.2	3.1	5.4	3.6	0.8	2.7	11.2	7.2	5.4	5.2
Chlorite (Stage 4)		0.3								
Epidote (Stages 1-3)	2.8	1.9	4.8	3.7	0.4	2.4	3.6	0.4	1.8	2.1
Epidote (Stage 4)		0.9		0.3	0.2					
Clinozoisite (S.1-4)	3.2	0.8	5.1	3.4	12.0	7.0	0.6	1.1	8.6	
Carbonate (S.1-3)	1.8	1.7	2.3	1.3		0.4	2.2	2.3	1.2	2.4
Carbonate (Stage 4)	4.6	1.4	1.1	2.1			0.8	1.0	0.8	1.9
Mgt./Ilm. (S.1-4)	0.1	0.2	tr	0.2	0.7	0.2	1.3	0.9	1.0	2.0
Leucoxene (S.1-4)	tr	0.9		0.1		0.2	0.7	0.6		2.0
Hematite	0.3		0.1	0.1	0.1	tr	0.3	0.8		1.3
Total Alteration	37.8	25.2	43.1	36.7	26.1	27.8	37.4	35.2	43.4	48.3

Mineral	Slide Number (Values in Volume Percent)										
	265-1	267-1	269-1	272-1	274-1	277-1	280-1	281-1	283-1	287-1	287-1
<u>Primary</u>											
Plagioclase	54.0	61.2	57.4	59.0	50.6	52.8	51.6	57.0	60.4	55.6	
Quartz	33.4	30.4	28.6	30.0	37.0	36.8	37.5	28.6	29.2	20.4	
Hornblende	2.6	1.5	8.6	2.4	6.2	6.0	6.5	9.0	5.2	4.8	
Biotite	10.0	6.9	4.7	8.6	6.2	4.4	4.4	5.2	5.0	19.2	
Microcline							tr		0.2		
Apatite	tr	tr					tr	0.2	tr		
Rutile	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	
<u>Total Sulphides</u>			0.7								
<u>Hydrothermal</u>											
Sericite (Stage 1)	2.4	2.2	20.6	16.0	10.4	8.8	4.3	3.6	5.2	3.0	
Sericite (Stage 2)	2.5	5.4	10.2	5.2	2.8	6.5	6.7	5.6	10.0	8.4	
Sericite (Stages 3&4)		1.2	0.4	0.2	0.2	2.6	4.2	1.6	7.4	0.6	
Chlorite (Stages 1-3)	3.0	3.8	7.2	2.6	9.2	9.1	7.5	7.4	9.1	9.0	
Chlorite (Stage 4)											
Epidote (Stages 1-3)	5.2	1.6	0.2	3.0	2.0	0.8	2.8	4.8	1.4	5.4	
Epidote (Stage 4)				0.4	0.2						
Clinozoisite (S.1-4)	13.1	7.4		3.8	5.6	6.0	9.4	21.6	2.8	22.8	
Carbonate (S.1-3)	0.5	0.8	3.8	2.2	1.1		1.3	1.2	2.4	1.1	
Carbonate (Stage 4)		0.6	4.0	1.1	1.6	3.0	0.3	1.1	1.5	0.4	
Mgt./Ilm. (S.1-4)	0.8	0.2	0.2	1.2	1.0	0.1	0.5	1.3	1.1	0.8	
Leucoxene (S.1-4)	0.3	tr	0.4				0.8	0.4	0.5	1.8	
Hematite	0.3	0.1	0.1		0.1	0.1	0.5	0.3	0.2	0.3	
<u>Total Alteration</u>	28.1	23.3	47.1	35.7	34.2	37.0	38.3	48.9	41.6	53.6	

Mineral	Slide Number (Values in Volume Percent)										
	288-1	289-1	291-1	292-1	293-1	294-1	295-1	296-1	297-1	298-1	
<u>Primary</u>											
Plagioclase	52.0	51.1	59.4	56.3	50.4	59.8	60.1	63.3	57.3	52.0	
Quartz	40.3	37.2	32.4	30.4	43.7	35.3	30.4	29.4	38.2	38.6	
Hornblende	2.8	4.0	3.1	3.8	2.2	1.6	4.2	1.8	2.2	5.0	
Biotite	4.2	7.6	5.1	9.5	3.4	3.0	5.0	5.4	2.0	4.0	
Microcline					0.3		0.2				
Apatite		tr	tr	tr	tr	tr	tr	tr			
Rutile	tr			tr	tr						
<u>Total Sulphides</u>	0.7	0.1				0.3	0.1	0.1	0.3	0.4	
<u>Hydrothermal</u>											
Sericite (Stage 1)	12.6	7.2	19.2	5.8	11.3	8.6	11.2	12.2	16.4	11.0	
Sericite (Stage 2)	19.8	8.0	4.4	10.5	7.4	3.8	8.0	11.0	8.7	8.0	
Sericite (Stages 3&4)	3.6	6.0	0.6	3.6	6.6	2.1	2.2	2.8	3.9	3.7	
Chlorite (Stages 1-3)	4.4	6.6	5.3	6.3	3.2	1.4	5.2	3.6	3.0	5.9	
Chlorite (Stage 4)			2.2								
Epidote (Stages 1-3)	1.6	3.8	2.8	6.8	1.2	2.4	3.8	3.3	1.3	3.4	
Epidote (Stage 4)			1.5							1.6	
Clinozoisite (S.1-4)		11.0	2.6	20.2	7.4	22.3	27.6	17.2	6.8	3.0	
Carbonate (S.1-3)	2.8	1.1	1.2	0.9	0.2	0.2	0.2		1.2	0.8	
Carbonate (Stage 4)	7.3	2.0	2.3	1.0	2.1	0.9	1.2	1.3	3.0	1.5	
Mgt./Ilm. (S.1-4)	0.1	0.6	0.3	tr	0.2	0.2	0.2	0.8	0.4	0.2	
Leucoxene (S.1-4)	0.2	2.0	0.4	0.7	0.8	0.4	0.2	0.4	tr	tr	
Hematite		0.2	0.3	tr	tr	0.3	0.1	0.6	0.3	0.4	
<u>Total Alteration</u>	52.4	48.5	43.1	55.8	40.4	42.6	59.9	53.2	45.0	39.5	

Mineral	Slide Number (Values in Volume Percent)										
	299-1	300-1	301-1	304-1	305-1	306-1	307-1	308-1	309-1	310-1	
<u>Primary</u>											
Plagioclase	48.7	47.8	64.5	50.7	58.0	62.3	63.0	63.3	60.3	58.2	
Quartz	41.6	35.4	27.3	33.4	34.5	33.9	24.2	29.6	29.2	33.2	
Hornblende	1.2	6.7	2.8	4.0	4.2	1.7	1.6	2.2	2.4	1.7	
Biotite	8.2	9.7	5.2	11.7	3.0	1.9	10.4	4.6	7.3	6.6	
Microcline	0.3	0.4	0.2	0.2	0.2	0.2	0.8	0.3	0.6	0.2	
Apatite	tr	tr	tr				tr	tr	tr		
Rutile	tr			tr			tr	tr	0.2	0.1	
<u>Total Sulphides</u>					0.1						
<u>Hydrothermal</u>											
Sericite (Stage 1)	8.4	4.2	6.8	9.3	19.0	15.6	8.6	10.6	19.0	14.6	
Sericite (Stage 2)	10.1	8.4	11.2	7.8	11.6	7.2	6.7	12.0	9.4	5.1	
Sericite (Stages 3&4)	7.6	11.8	3.0	2.6	8.6	11.0	3.6	1.2	6.6	0.8	
Chlorite (Stages 1-3)	6.0	10.2	7.1	7.9	3.8	2.0	5.6	3.8	6.5	5.0	
Chlorite (Stage 4)										0.6	
Epidote (Stages 1-3)	2.9	5.8	2.9	5.3	1.4	1.2	6.4	2.6	4.1	3.2	
Epidote (Stage 4)						0.2				1.2	
Clinozoisite (S.1-4)	9.2	8.2	22.2	12.1	0.4	1.2	15.9	16.8	9.1	23.2	
Carbonate (S.1-3)	1.0	1.6	1.0	1.9	3.8	4.6	0.2	0.2	1.8	0.8	
Carbonate (Stage 4)	0.6	3.5	1.2	tr	3.4	2.0		1.0	2.0	1.2	
Mgt./Ilm. (S.1-4)	0.4	0.2	0.5	0.5	0.6	0.6	0.2	0.1	0.2	0.1	
Leucoxene (S.1-4)	0.8	1.2	tr	0.2	1.0	0.3	tr		0.2	0.1	
Hematite	tr	tr	0.1	0.1	0.1	tr	tr		0.2	0.2	
<u>Total Alteration</u>	47.0	55.1	56.0	47.7	53.7	45.9	47.2	48.3	59.1	56.1	

Mineral	Slide Number (Values in Volume Percent)									
	311-1	312-1	313-1	314-1	315-1	316-1A	320-1	324-1	325-1	326-1
<u>Primary</u>										
Plagioclase	59.4	49.1	65.4	57.4	61.6	63.6	58.0	49.1	52.4	56.0
Quartz	29.9	38.8	27.3	31.6	25.4	29.4	33.0	34.8	36.0	34.0
Hornblende	1.4	2.7	1.5	1.6	3.4	2.1	1.4	2.1	3.2	1.3
Biotite	9.3	9.2	5.4	7.8	8.0	4.5	7.2	13.9	8.3	8.1
Microcline		0.2	0.2			0.2	0.2	0.1	0.1	0.1
Apatite					tr	tr				
Rutile	tr	tr	tr	tr	tr			tr	tr	tr
<u>Total Sulphides</u>	tr	tr	0.2	1.6	1.6	0.2	0.2	tr		0.5
<u>Hydrothermal</u>										
Sericite (Stage 1)	7.2	9.0	17.4	13.2	28.4	16.0	10.2	2.8	6.4	4.8
Sericite (Stage 2)	10.0	5.2	8.4	9.8	2.8	13.8	7.8	6.5	7.8	12.0
Sericite (Stges 3&4)	2.0	1.2	0.6	0.3	1.4	4.2	0.6	2.0	0.6	2.5
Chlorite (Stges 1-3)	7.0	6.0	4.1	6.8	6.7	4.8	5.6	9.3	7.3	3.0
Chlorite (Stage 4)					0.3	0.4		0.2		
Epidote (Stages 1-3)	4.1	5.1	2.9	3.1	4.7	2.8	4.0	6.6	4.0	3.4
Epidote (Stage 4)	1.8	0.5	0.3	2.0	1.4			0.3	0.2	
Clinozoisite (S.1-4)	18.6	18.0	21.1	25.6	15.8		16.2	14.8	20.2	2.4
Carbonate (S.1-3)	0.3	0.2	1.8		0.3	3.0	1.4	0.3	0.6	0.4
Carbonate (Stage 4)	1.1		0.2	0.2	2.3	2.6	1.0	1.0	0.3	1.0
Mgt./Ilm. (S.1-4)	0.1	0.1	0.1	0.4	0.2	0.2	0.1	0.1	0.3	0.3
Leucoxene (S.1-4)			0.1							
Hematite	0.1	tr	0.1	1.2	0.1	0.5	0.1	0.1		0.2
<u>Total Alteration</u>	52.3	45.3	57.1	62.6	64.4	48.3	47.0	44.0	47.7	30.0

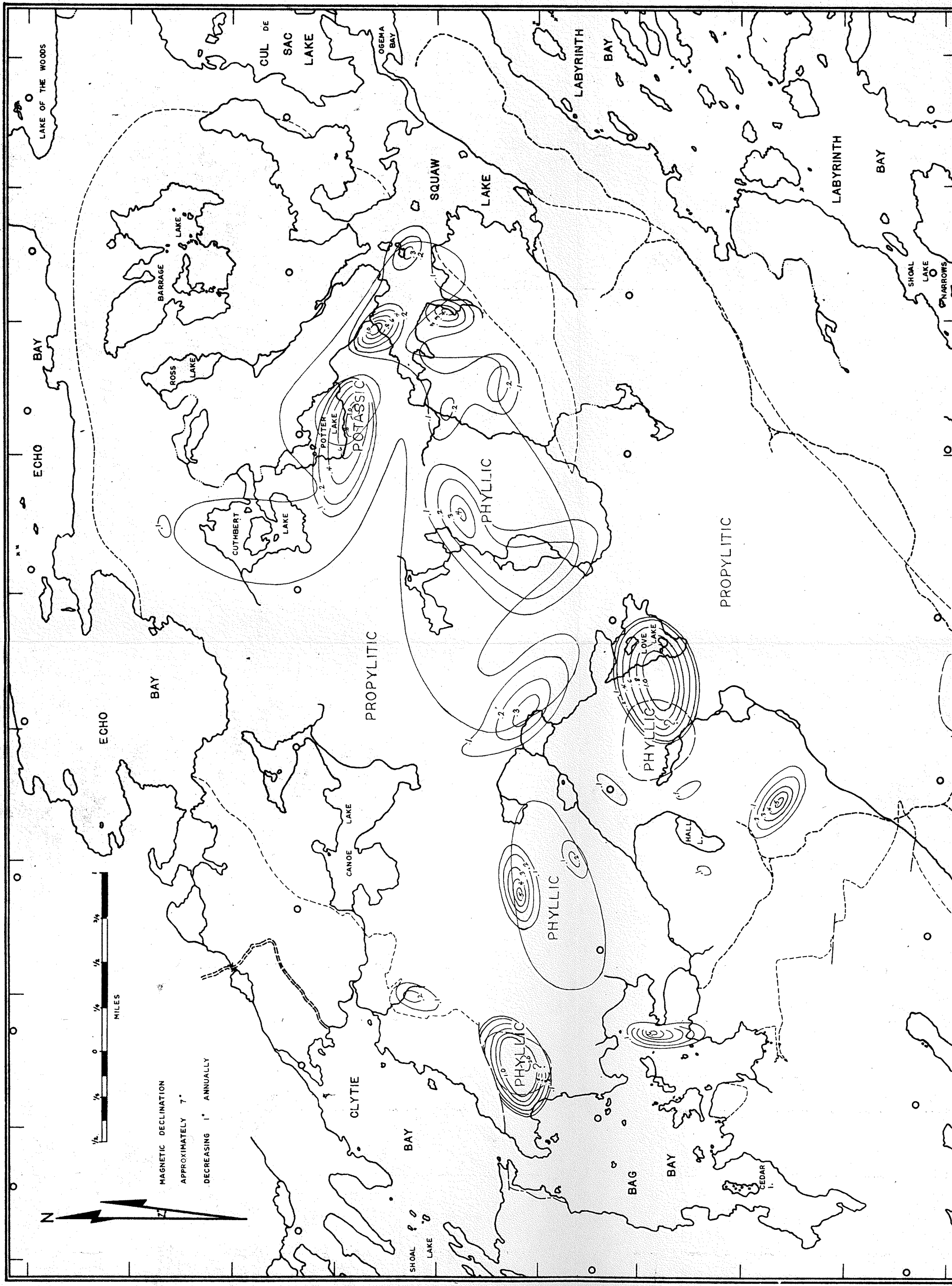
APPENDIX II

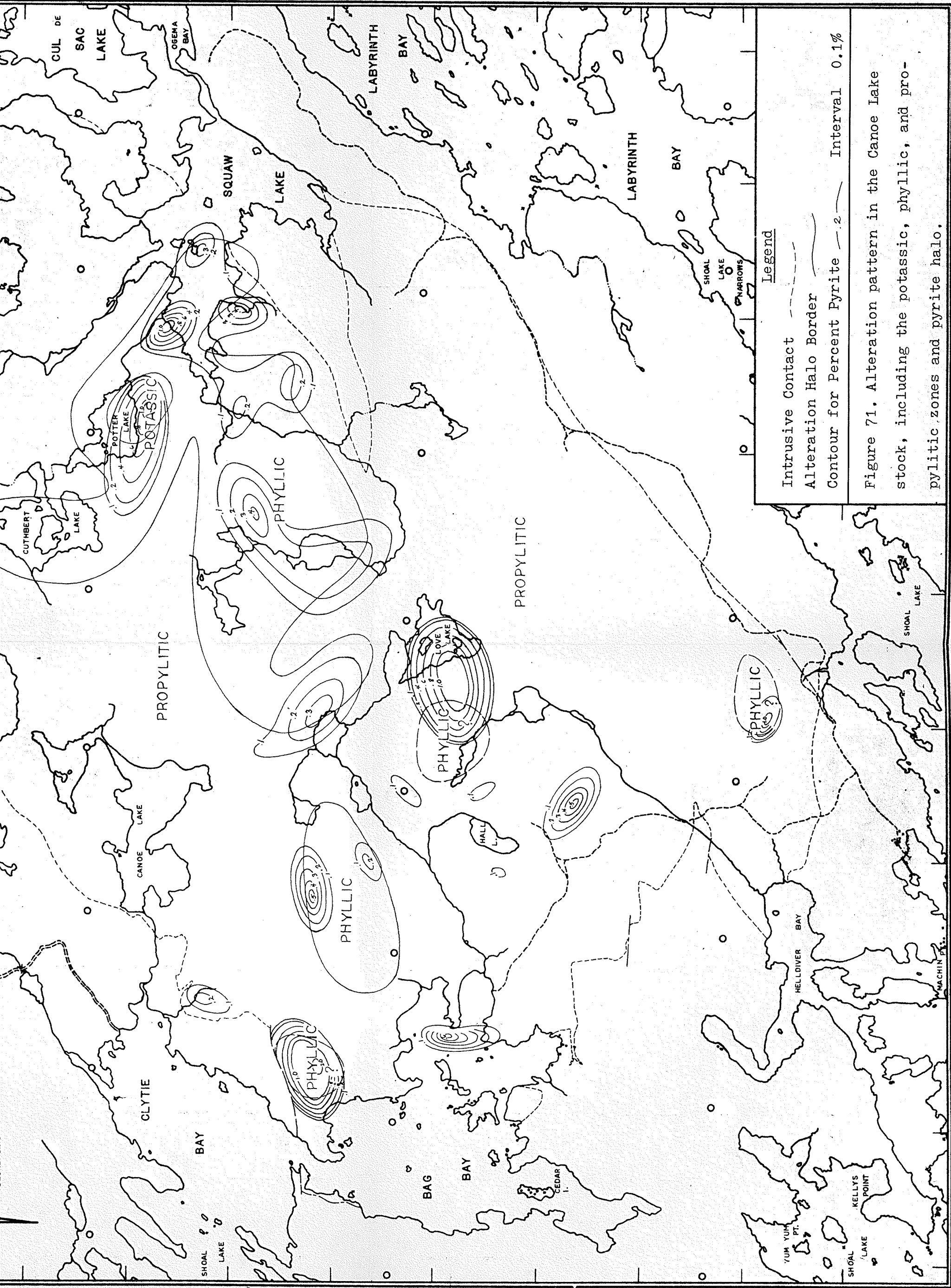
RESULTS OF THE
NIGGLI NORM PROGRAM

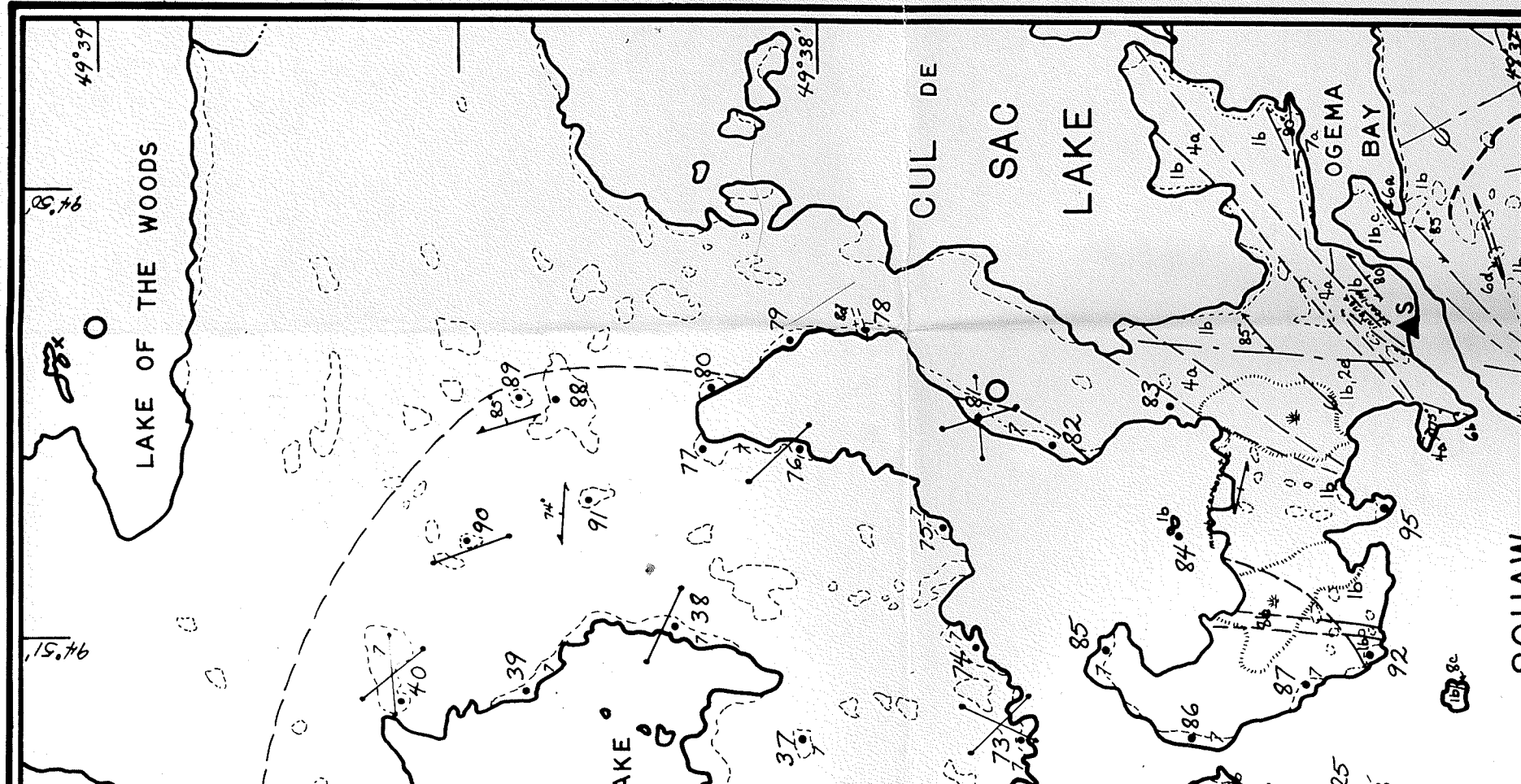
Mineral	Sample Numbers (Values in Percent)									
	25-1	38-1	59-1B	61-4	62-1	67-1	93-3	97-1	103-1	108-1B
Quartz	31.769	30.899	27.311	25.863	27.746	30.018	32.769	21.460	30.301	36.536
Orthoclase	13.011	9.281	8.989	5.476	8.257	2.213	10.018	6.123	11.612	16.348
Albite	33.791	37.186	43.141	47.074	42.907	46.966	35.500	45.505	37.145	29.324
Anorthite	0.890	6.707	1.606	3.223	0.188	13.073	3.240	14.735	1.787	0.000
Nepheline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Enstatite	5.039	5.127	4.085	4.654	5.512	2.389	3.687	5.360	3.972	2.617
Ferrosilite	1.571	0.634	0.931	0.000	2.025	0.956	2.238	1.081	2.354	0.000
Hypersthene	6.611	5.761	5.016	4.654	7.537	3.345	5.926	6.441	6.326	2.617
Diopside	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Olivine	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Apatite	0.277	0.277	0.274	0.288	0.254	0.169	0.277	0.382	0.301	0.000
Pyrite	0.000	0.000	1.259	4.928	0.000	0.105	0.000	0.000	0.000	0.657
Ilmenite	0.637	0.680	0.588	0.000	0.520	0.365	0.440	0.719	0.557	0.000
Chromite	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Magnetite	0.934	1.806	1.406	0.000	1.149	0.443	0.521	2.190	0.300	0.000
Hematite	0.000	0.000	0.000	2.218	0.000	0.000	0.000	0.000	0.000	0.781
Corundum	6.959	4.263	4.841	3.608	6.432	1.899	6.874	0.675	6.476	7.035
Calcite	5.122	3.141	5.570	0.697	5.011	1.405	4.435	1.770	5.195	5.749
O1 Prime	4.958	4.321	3.762	4.499	5.653	2.509	4.444	4.831	4.744	2.867
Neph Prime	20.274	22.312	25.885	36.401	25.744	28.180	21.300	27.303	22.287	25.694
Quartz Prime	46.938	47.214	45.821	59.100	46.792	49.640	48.450	41.272	46.741	71.439
Norm Plag	2.566	15.280	3.590	6.408	0.436	21.774	8.363	24.460	4.589	0.000

Mineral	Sample Numbers (Values in Percent)										
	108-2A	110-1	111-2	112-1	117-2	128-1	132-1	139-1	150-1	171-1	
Quartz	33.222	29.819	28.472	28.941	30.575	28.164	26.878	25.444	26.130	24.654	
Orthoclase	10.894	1.438	8.915	8.312	3.173	9.886	5.695	9.889	12.382	13.321	
Albite	40.847	40.884	40.639	39.740	43.841	41.125	45.896	43.626	45.345	46.252	
Anorthite	0.000	17.155	7.910	10.067	15.785	14.005	13.237	3.576	1.418	1.716	
Nepheline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Enstatite	1.762	5.689	3.907	3.565	2.898	2.691	3.071	5.124	4.048	3.047	
Ferrosilite	0.000	0.846	1.509	1.924	0.000	0.584	0.931	1.230	0.077	0.000	
Hypersthene	1.762	6.535	5.416	5.489	2.898	3.275	4.002	6.354	4.126	3.047	
Diopside	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Olivine	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Apatite	0.000	0.212	0.256	0.236	0.190	0.170	0.212	0.274	0.317	0.294	
Pyrite	0.321	0.317	0.212	0.107	0.264	0.053	0.000	0.000	0.000	0.000	
Ilmenite	0.000	0.479	0.580	0.442	0.408	0.439	0.394	0.714	0.534	0.531	
Chromite	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Magnetite	0.000	0.560	0.711	0.716	0.812	1.434	1.204	1.564	1.613	0.974	
Hematite	1.184	0.000	0.000	0.000	0.253	0.000	0.000	0.000	0.000	0.308	
Corundum	5.046	1.782	3.800	2.735	0.957	1.294	1.380	4.513	4.480	3.391	
Calcite	3.126	0.819	3.088	3.215	0.844	0.155	1.101	4.047	3.655	5.514	
Ol Prime	1.742	4.901	4.062	4.117	2.174	2.458	3.002	4.765	3.094	2.285	
Neph Prime	32.819	24.530	24.384	23.844	26.304	24.675	27.538	26.175	27.207	27.751	
Quartz Prime	65.938	47.806	46.081	46.209	48.836	45.433	46.237	44.482	45.300	43.916	
Norm Plag	0.000	29.558	16.293	20.212	26.473	25.403	22.385	7.575	3.032	3.577	

Mineral	Sample Numbers (Values in Percent)											
	194-1	206-1	242-1	267-1	294-1	296-1	299-1	307-1	312-1	326-1		
Quartz	21.887	23.710	27.906	24.727	29.207	27.360	27.856	27.571	26.040	28.623		
Orthoclase	11.218	16.033	9.535	9.938	5.549	6.379	11.194	6.728	10.685	11.749		
Albite	47.065	39.727	42.466	41.117	47.308	46.548	43.153	44.266	40.317	35.352		
Anorthite	8.868	1.783	4.643	15.182	11.663	9.887	1.561	11.526	14.947	10.429		
Nepheline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Enstatite	5.468	7.086	5.126	3.545	1.963	3.166	3.948	4.264	4.232	5.041		
Ferrosilite	0.005	0.498	1.018	0.678	0.714	1.729	0.000	1.193	0.119	1.035		
Hypersthene	5.472	7.583	6.143	4.223	2.677	4.895	3.946	5.456	4.351	6.076		
Diopside	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Olivine	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Apatite	0.336	0.402	0.211	0.233	0.169	0.190	0.316	0.234	0.233	0.277		
Pyrite	0.000	0.000	0.000	0.000	0.000	0.079	0.000	0.000	0.000	0.000		
Ilmenite	0.558	0.675	0.560	0.577	0.449	0.476	0.504	0.522	0.578	0.552		
Chromite	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Magnetite	1.527	1.803	0.714	2.058	0.873	0.536	1.763	0.815	1.587	1.678		
Hematite	0.000	0.000	0.000	0.000	0.000	0.000	0.063	0.000	0.000	0.000		
Corundum	1.217	4.961	4.120	0.974	1.214	2.480	5.166	2.420	0.903	3.410		
Calcite	1.851	3.323	3.641	0.972	0.892	1.172	4.478	0.462	0.359	1.854		
Ol Prime	4.104	5.687	4.608	3.167	2.008	3.671	2.960	4.092	3.263	4.557		
Neph Prime	28.239	23.836	25.480	24.670	28.385	27.929	25.892	26.559	24.190	21.211		
Quartz Prime	42.081	41.497	46.488	42.230	48.799	47.202	46.104	46.641	43.254	44.283		
Norm Plag	15.855	4.296	9.856	26.966	19.777	17.519	3.492	20.659	27.047	22.780		







LEGEND

CENEZOIC

RECENT

Swamp and stream deposits (unconsolidated)

PLEISTOCENE

Sand, gravel, and clay (unconsolidated)

--- UNCONFORMITY ---

PRECAMBRIAN

ARCHEAN

LATE MAFIC DIKES

9 Gabbro, diorite, lamprophyre

-----INTRUSIVE CONTACT ----

LATE FELSIC INTRUSIVE ROCKS

8a Granodiorite

- b Quartz porphyry, quartz-feldspar porphyry
- c Fine-grained granodiorite
- d Feldspar porphyry

--- INTRUSIVE CONTACT ---

EARLY FELSIC INTRUSIVE ROCKS

7 Quartz diorite

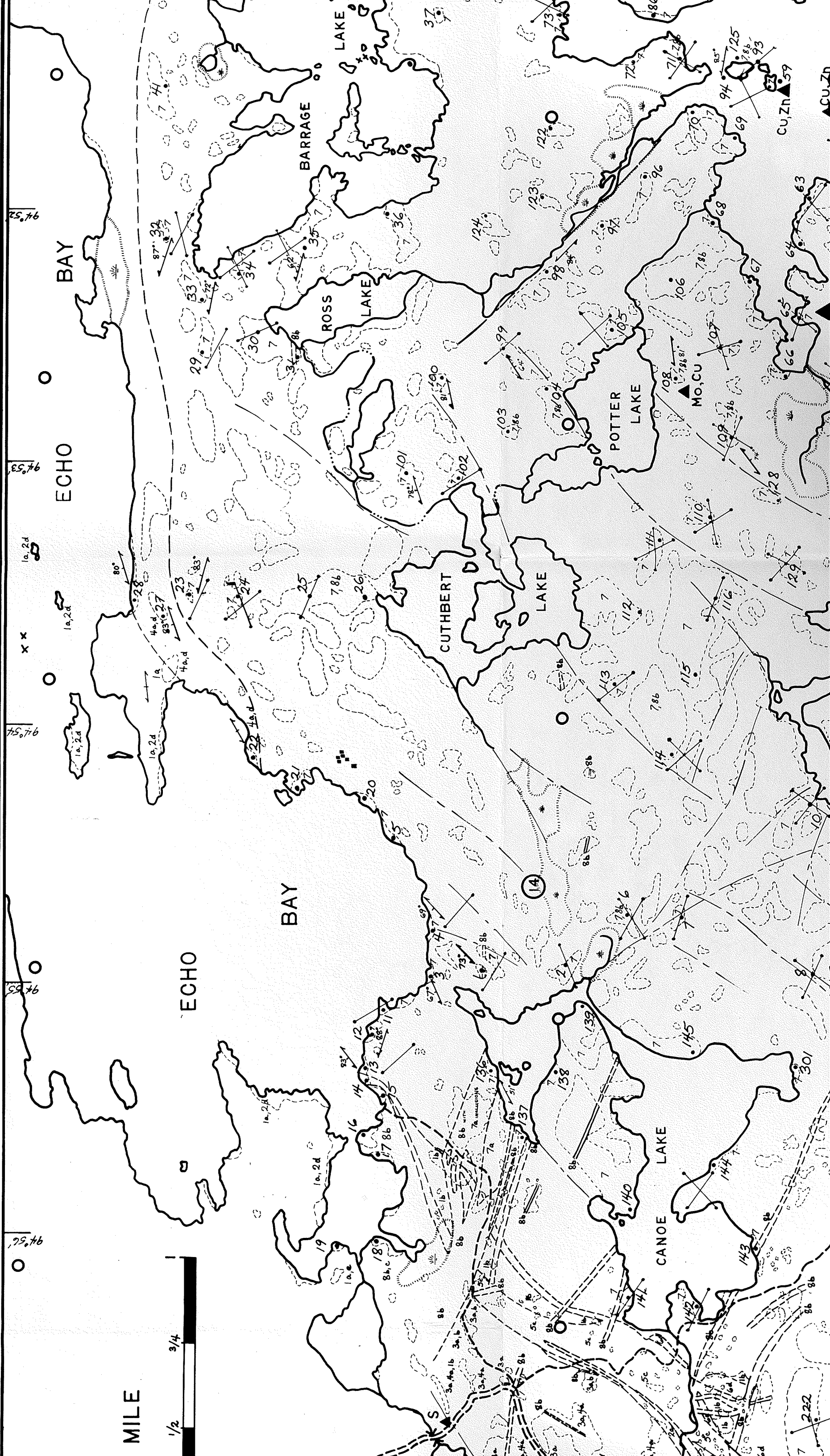
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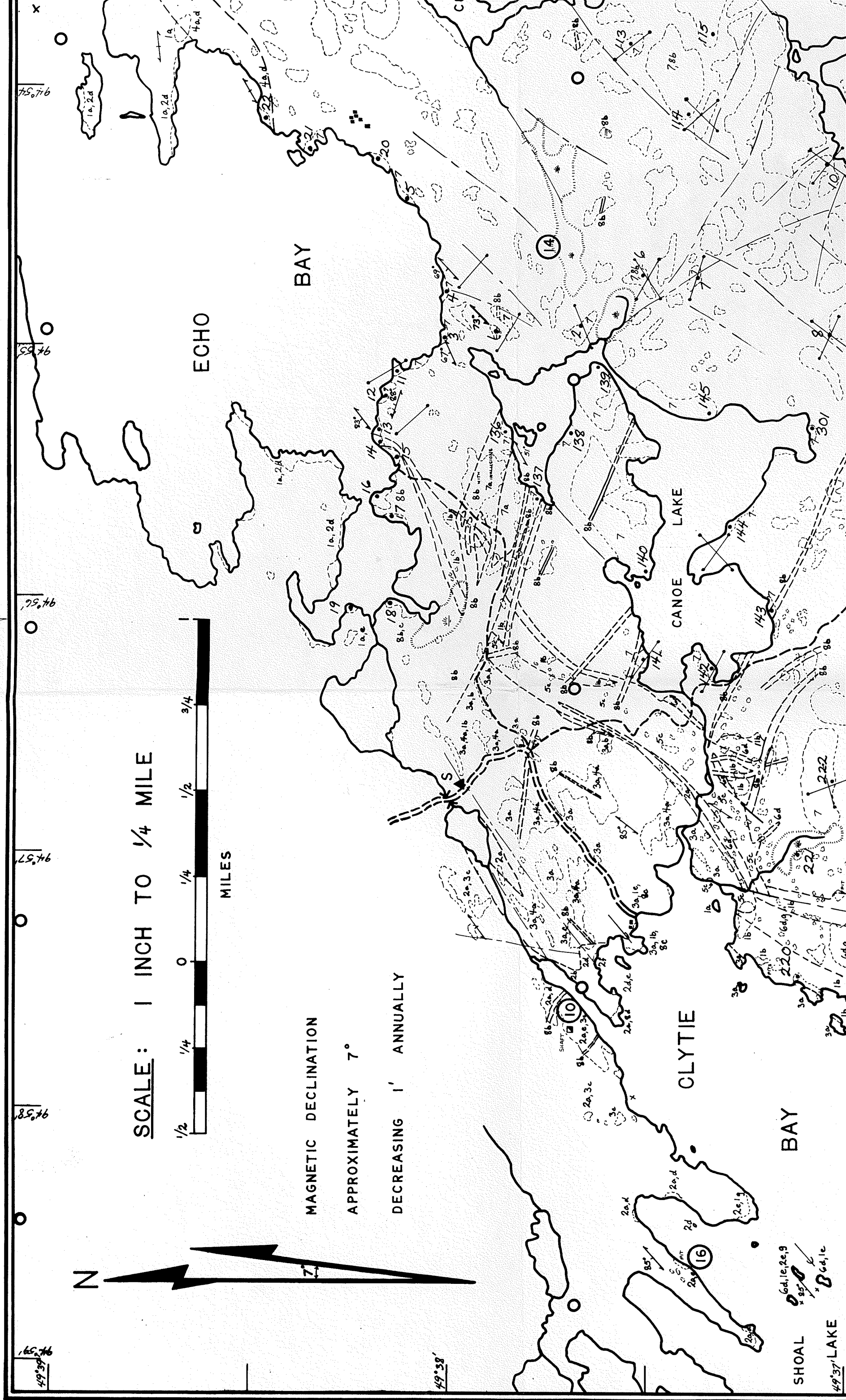
MAFIC AND ULTRAMAFIC INTRUSIVE ROCKS

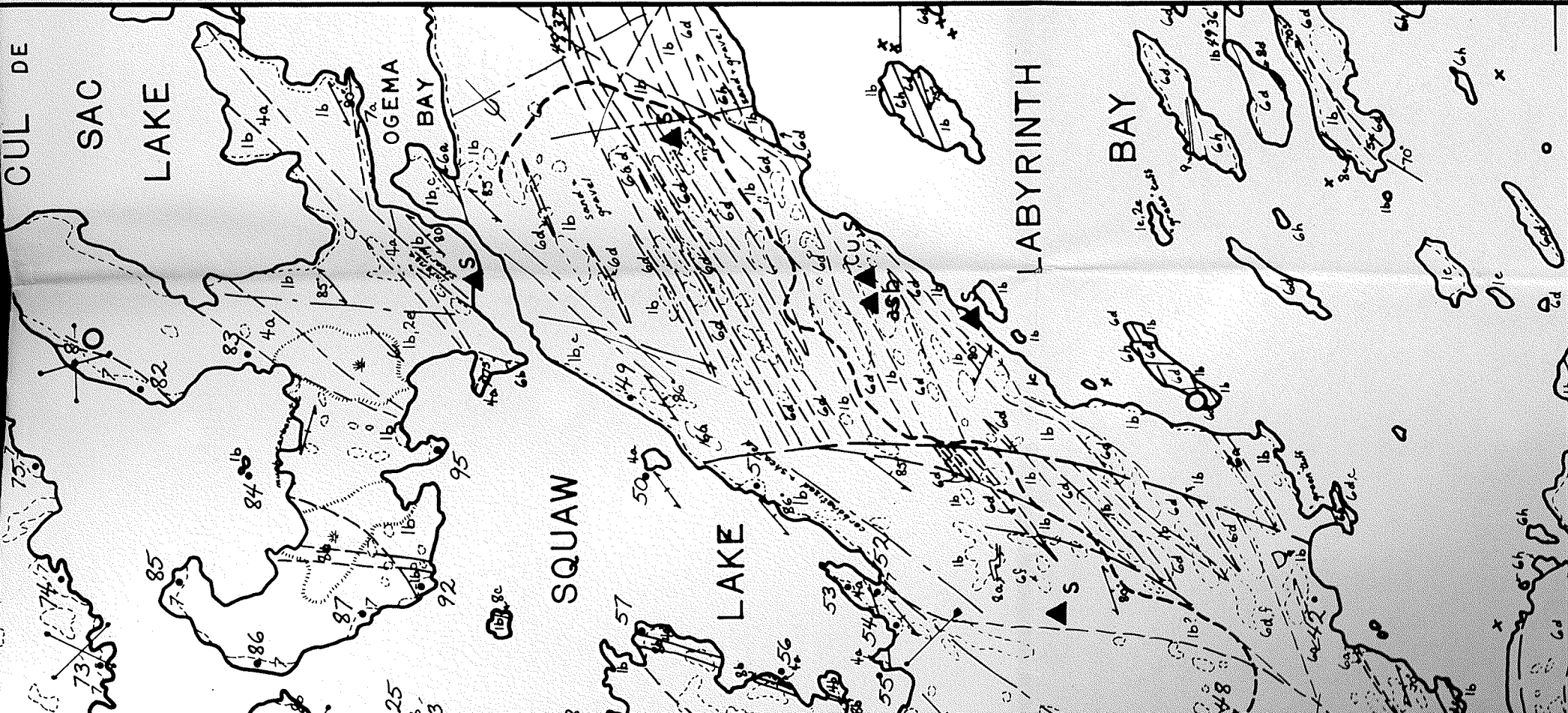
6a Amphibolite

- b Diorite
- c Quartz gabbro, quartz diorite
- d Gabbro
- e Porphyritic gabbro
- f Biotite gabbro and hornblende
- g Hornblende and pyroxenite
- h Peridotite

--- INTRUSIVE CONTACT ---







EARLY FELSIC INTRUSIVE ROCKS

 7 Quartz diorite

--- INTRUSIVE CONTACT ---

MAFIC AND ULTRAMAFIC INTRUSIVE ROCKS

 6a Amphibolite
b Diorite
c Quartz gabbro, quartz diorite
d Gabbro
e Porphyritic gabbro
f Biotite gabbro and hornblende
g Hornblende and pyroxenite
h Peridotite

--- INTRUSIVE CONTACT ---

METASEDIMENT

 5a Sandstone, volcanic sandstone
b Greywacke and tuff
c Conglomerate, volcanic conglomerate
d Slate, argillite
e Siliceous siltstone, cherty sediments

FELSIC METAVOLCANICS

 4a Quartz porphyry, rhyolite tuff
b Feldspar porphyry
c Rhyolite, rhyodacite
d Dacite, dacite tuff

FELSIC VOLCANICLASTIC ROCKS

 3a Coarse fragmental (angular)
b Coarse fragmental (rounded)
c Fine fragmental, dacite tuff

INTERMEDIATE METAVOLCANICS

 2a Andesite
b Porphyritic andesite
c Rubbly andesite and broken pillows
d Coarse fragmental and breccia
e Fine fragmental, lapillistone
f Agglomerate (rounded bombs), tuff
g Silicified andesite

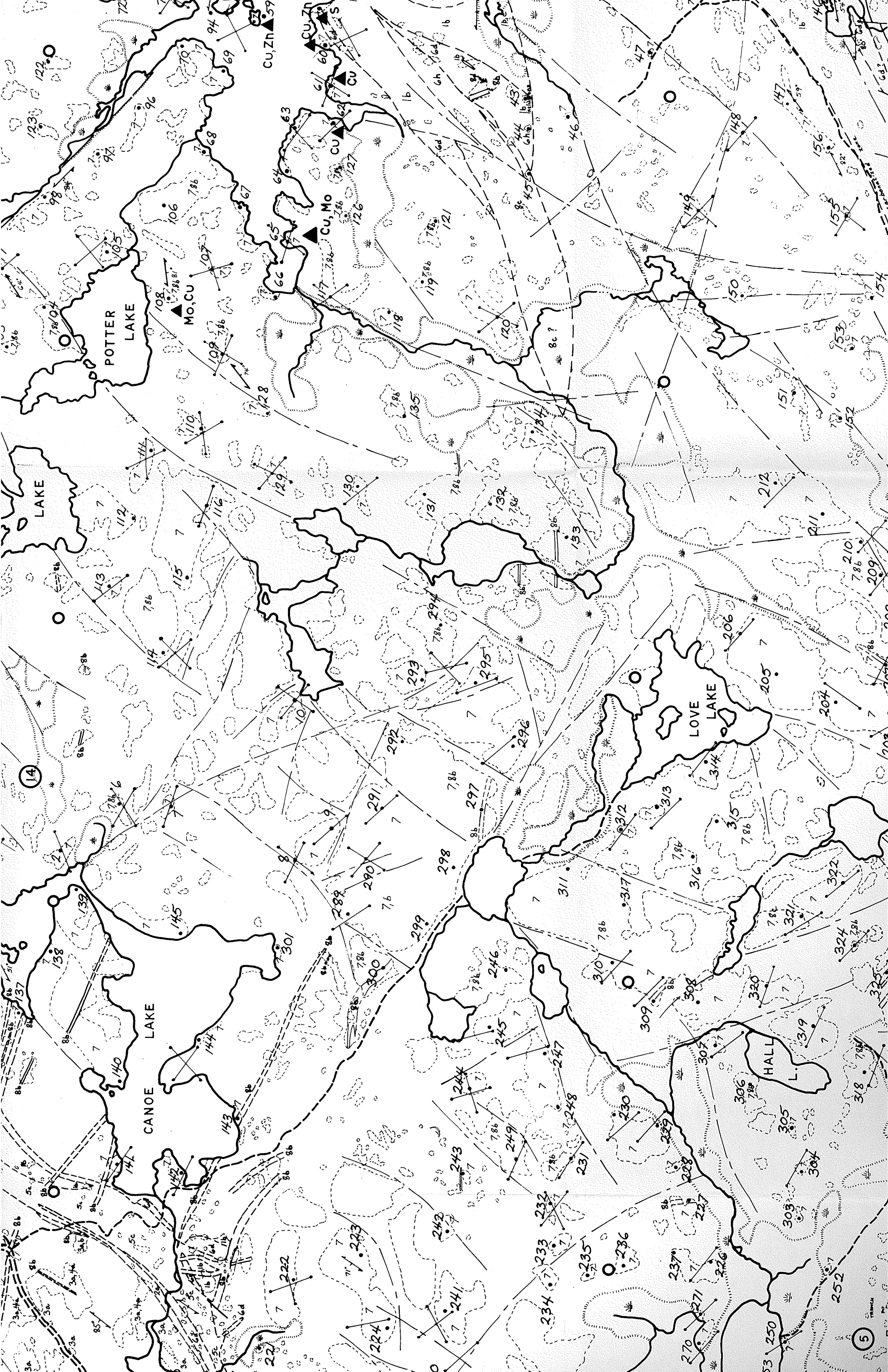
MAFIC METAVOLCANICS

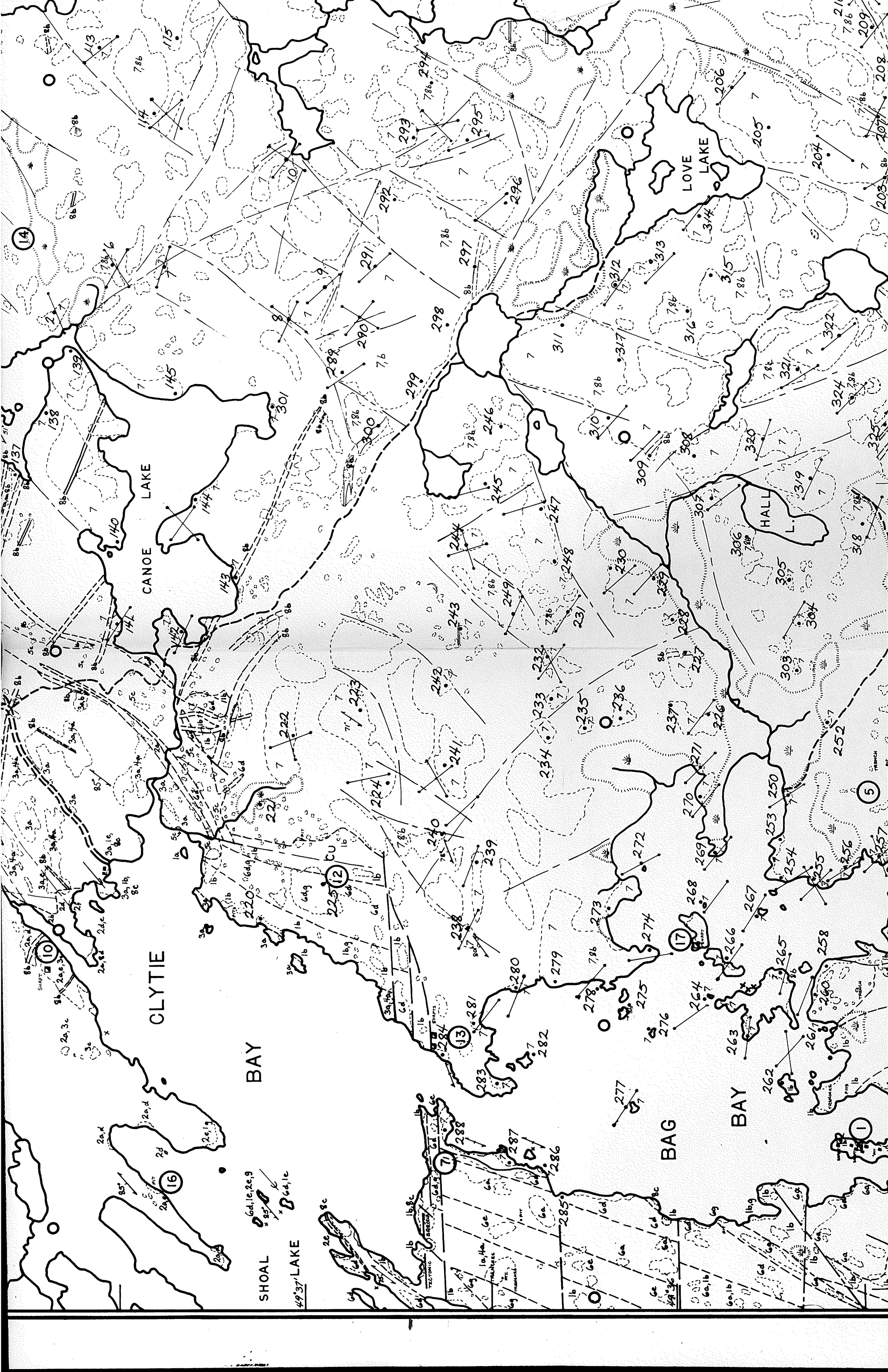
 1a Andesite
b Basalt
c Olivine basalt, medium-grained basalt, and
d Coarse fragmental and breccia
e Fine fragmental, tuff, and lapillistone
f Basalt with coarse feldspars
g Coarse flows, tuff

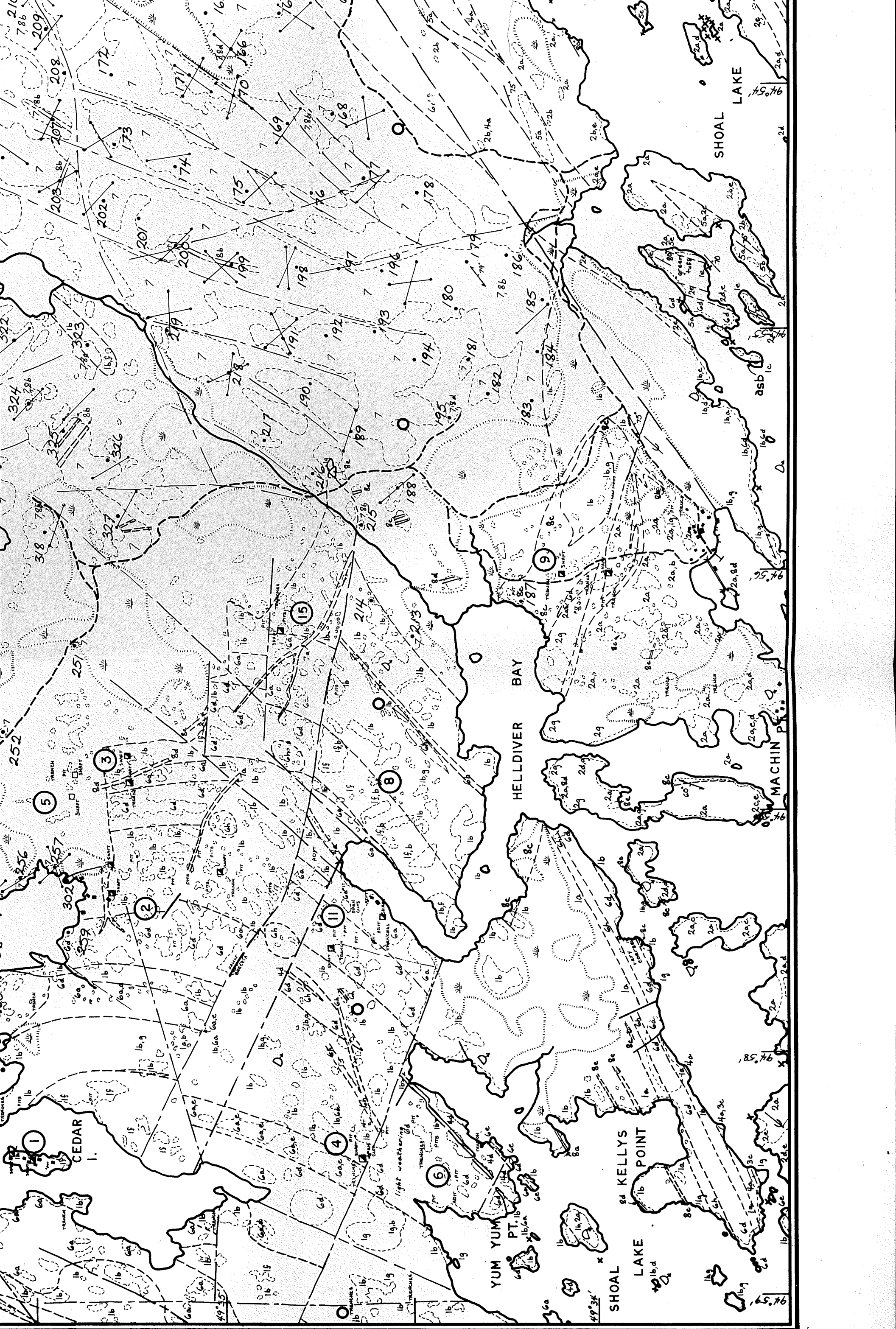
MAP SYMBOLS

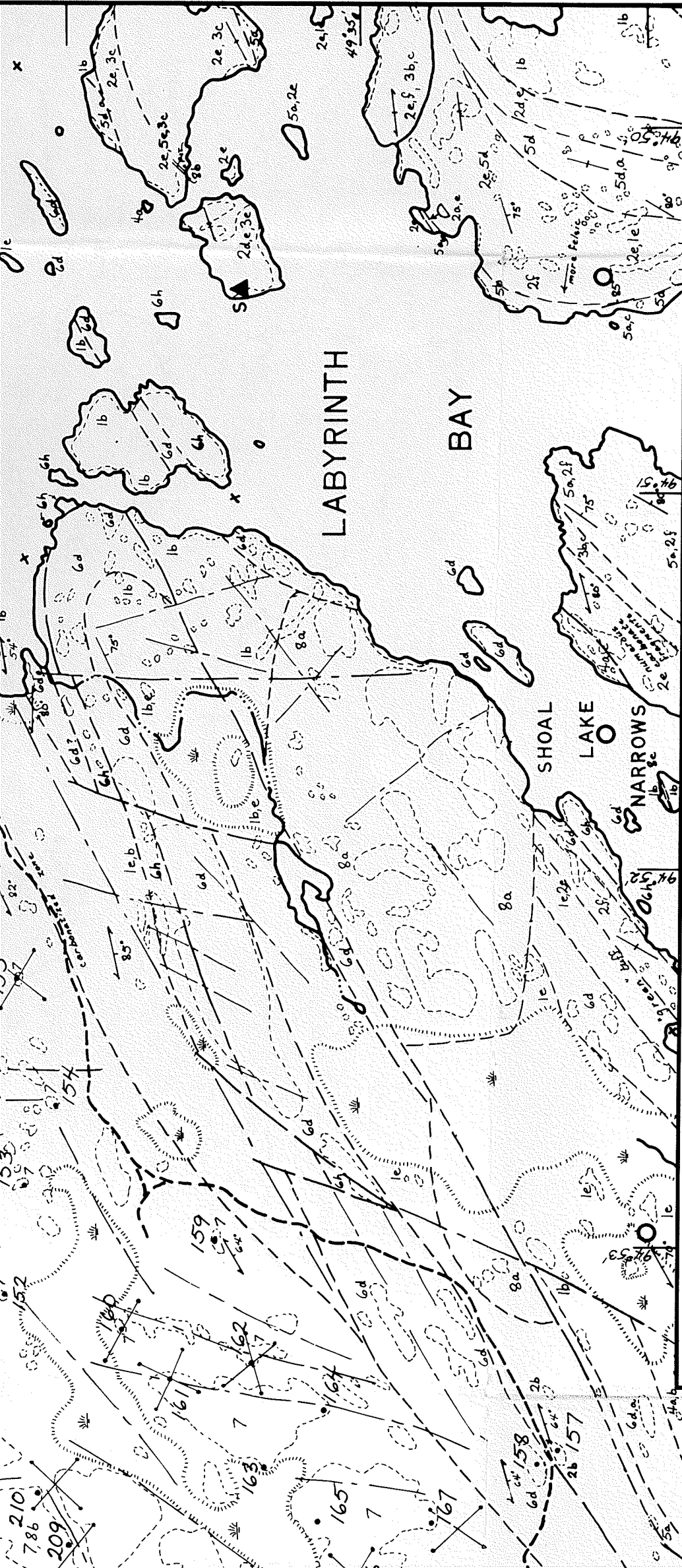
GEOLOGICAL

MINING









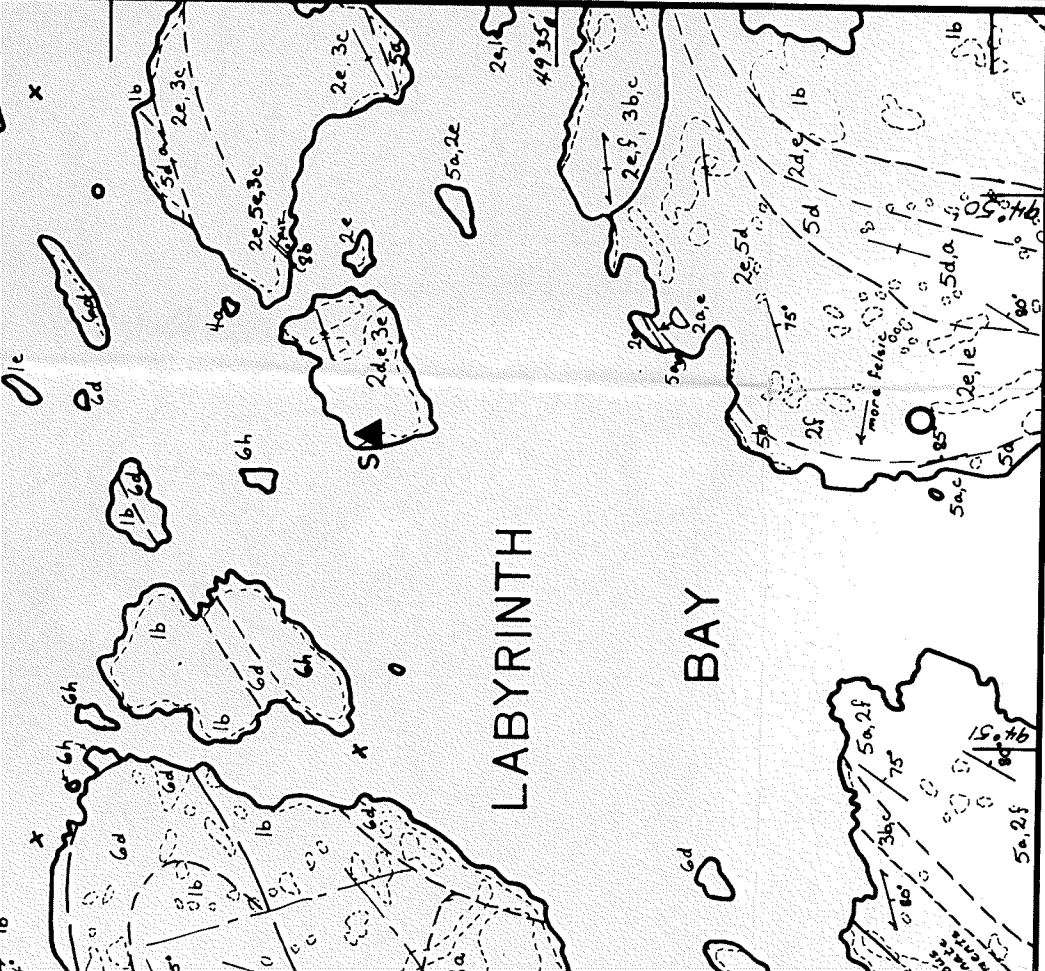
GEOLOGY OF THE CANOE LAKE STOCK AND ADJACENT ROCKS - SHOAL LAKE AREA, NORTHWESTERN ONTARIO

COMPILED FROM ONT. DEPT. MINES PRELIMINARY MAPS P.528
AND P.594 (DAVIES, 1969; 1970) AND THIS FIELD STUDY
SUE W. CAMPBELL, 1973

- GEOLOGICAL SYMBOLS
- Glacial striations of ice known
 - Area of bedrock
 - Area of swamp
 - Pillow lava: known
 - Bedding, top (inclined, vertical)
 - Schistosity, vertical
 - Foliation: (vertical)
 - Major fracture (vertical)
 - Geological boundary (defined, assumed)
 - Fault: (assumed)
 - Air photo line

- KENORA PROSPECTORS
1. Cedar Island Mine
 2. Mikado Mine
 3. Bullion No. 2
 4. Nankipoo Mine
 5. Sirdar Mine
 6. Yum Yum Mine
 7. Sirdar Point Mine
- HOPKINS, P.E.
LINDSTROM, A.J.

asb
Au
Cu



NOE LAKE STOCK S - SHOAL LAKE ERN ONTARIO

S PRELIMINARY MAPS P.528
AND THIS FIELD STUDY
ELL, 1973

MAP SYMBOLS

GEOLOGICAL		MINING	
	Glacial striae; (direction of ice known)		Shaft
	Area of bedrock outcrop		Showings; (sulfides, specific metal sulfides)
	Area of swamp		Old mining property
	Pillow lava; (top is known)	MISCELLANEOUS	
	Bedding, tops unknown; (inclined, vertical)		Numbered location of geological field station and sample location
	Schistosity; (inclined, vertical)		Old logging trail or winter trail
	Foliation; (inclined, vertical)		Gravel road
	Major fracture trends (vertical)		Old buildings, abandoned or still in use
	Geological boundary; (defined, assumed)		Small bridge
	Fault; (assumed)		Reef or rock at shallow water depth
	Air photo lineament		

OLD MINES AND PROPERTIES

KENORA PROSPECTORS AND MINERS, LIMITED OLYMPIA MINES INCORPORATED

1. Cedar Island Mine	Au
2. Mikado Mine	Au
3. Bullion No. 2 Mine	Au
4. Nankipoo Mine	Au
5. Sirdar Mine	Au
HOPKINS, P.E.	
6. Yum Yum Mine	Au
LINDSTROM, A.J.	
7. Sirdar Point Mine	Au
OCCURRENCES	
8. Bullion No. 1 Mine	Au
9. Gold Coin Mine	Au
10. Great Northwest Mine	Au
11. Olympia Mine	Au
12. Clytie Bay Property	Cu
OCCURRENCES	
13. Crown Point Mine	Au
14. Great Granite Mine	Au
15. Imperial Mine	Au
16. Indian Joe Mine	Au
17. Tycoon Mine	Au

MINERAL AND METAL OCCURRENCES

asb		asbestos	Zn		zinc
Au		gold	Mo		molybdenite
Cu		copper	S		sulfides