THE UNIVERSITY OF MANITOBA

MINERALIZATION OF THE HIGH LAKE PLUTON AND ADJACENT COUNTRY ROCKS

by

JOHN MICHAEL PEDORA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

DEPARTMENT OF EARTH SCIENCES

WINNIPEG, MANITOBA

FEBRUARY 1976

"MINERALIZATION OF THE HIGH LAKE PLUTON AND ADJACENT COUNTRY ROCKS"

by

JOHN MICHAEL PEDORA

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

To my loving parents

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

LIST OF PLATES

ABSTRACT

The Early Precambrian High Lake pluton comprises an older, northern, porphyritic granodiorite to trondhjemite phase, and a younger, southern equigranular granodiorite to tonalite phase.

The northern phase underlies an area of about 10 sq. km and consists of a central stock flanked to the east and west by dike units. This phase intruded the metavolcanic and metasedimentary rocks of the Keewatin Group and is truncated to the east by the metasedimentary Crowduck Lake Group, which unconformably overlies it. The southern phase appears to post-date the Crowduck Lake Group.

Mineralogical variation in the northern phase is attributed to emplacement of the northern phase by a mechanism of magmatic pulses.

Chemical patterns reflect the effects of primary mineralogical variations resulting from emplacement. Alteration of plagioclase and recrystallization of groundmass may have occurred during the cooling of the pluton, or during a period of subsequent regional metamorphism.

The Keewatin Group, the northern phase, and the Crowduck Lake Group were sheared and foliated by a strong, passive deformational event. Shear fractures and tension fractures, formed during this event, provided the locus for later quartz veins and sulphide mineralization. During this deformation, the Crowduck Lake Group was tilted eastward to a nearly vertical attitude. The northern phase and country rocks were tilted also, and the present exposure of the pluton represents an oblique section through the northern phase, exposing progressively higher levels of the intrusion to the east. The absence of a tectonic foliation in the southern phase suggests it was emplaced after deformation.

Mineralization is confined to the northern phase of the High

Lake pluton and to immediately adjacent parts of the Keewatin Group, Crowduck Lake Group, and southern phase. It occurs in shear fractures and tension fractures and is zonally arranged about the southern phase. There is an inner pyrite + molybdenite + chalcopyrite zone, an intermediate pyrite + chalcopyrite zone, and an outer pyrite + gold zone. This zonal arrangement is consistent with mineralizing fluids coming from the southern phase, possibly during the late stages of its emplacement.

CHAPTER 1

INTRODUCTION

Statement of Problem

The 20 sq. km Early Precambrian High Lake pluton consists of a northern, older, porphyritic trondhjemite to granodiorite phase, and a southern, younger, tonalite to granodiorite phase. The southern phase has been interpreted as younger and is separated from the northern phase by a period of uplift, erosion, and sedimentation (Davies, 1965). The northern phase and adjacent rocks contain widespread copper, molybdenum, and gold mineralization that has been interpreted by some authors (e.g. Davies, 1965; Kirkham, 1972) as porphyry copper-type.

The objective of this study is to establish the characteristics and petrogenesis of the northern phase of the High Lake pluton, and the character and origin of mineralization that occurs in, and adjacent to it.

Location and Access

The High Lake pluton is in the Northwestern Ontario township of Ewart, about 161 km east of Winnipeg, Manitoba and 48 km west of Kenora, Ontario. Major access routes (Figures 1 and 2) to the study area are Highway 17 and the Shoal Lake road. Other routes accessible only by a 4-wheel drive vehicle are the Baubee Lake road, the High Lake road, the Trans-Canada Pipeline road, and numerous drilling roads.

Previous Work

Parsons (1912) studied the geology near the Manitoba-Ontario border, and Greer (1931) mapped the geology of the Shoal Lake (west) region, an area adjacent to the pluton. J.C. Davies (1965), of the

FIGURE 1. REGIONAL LOCATION MAP OF THE STUDY AREA

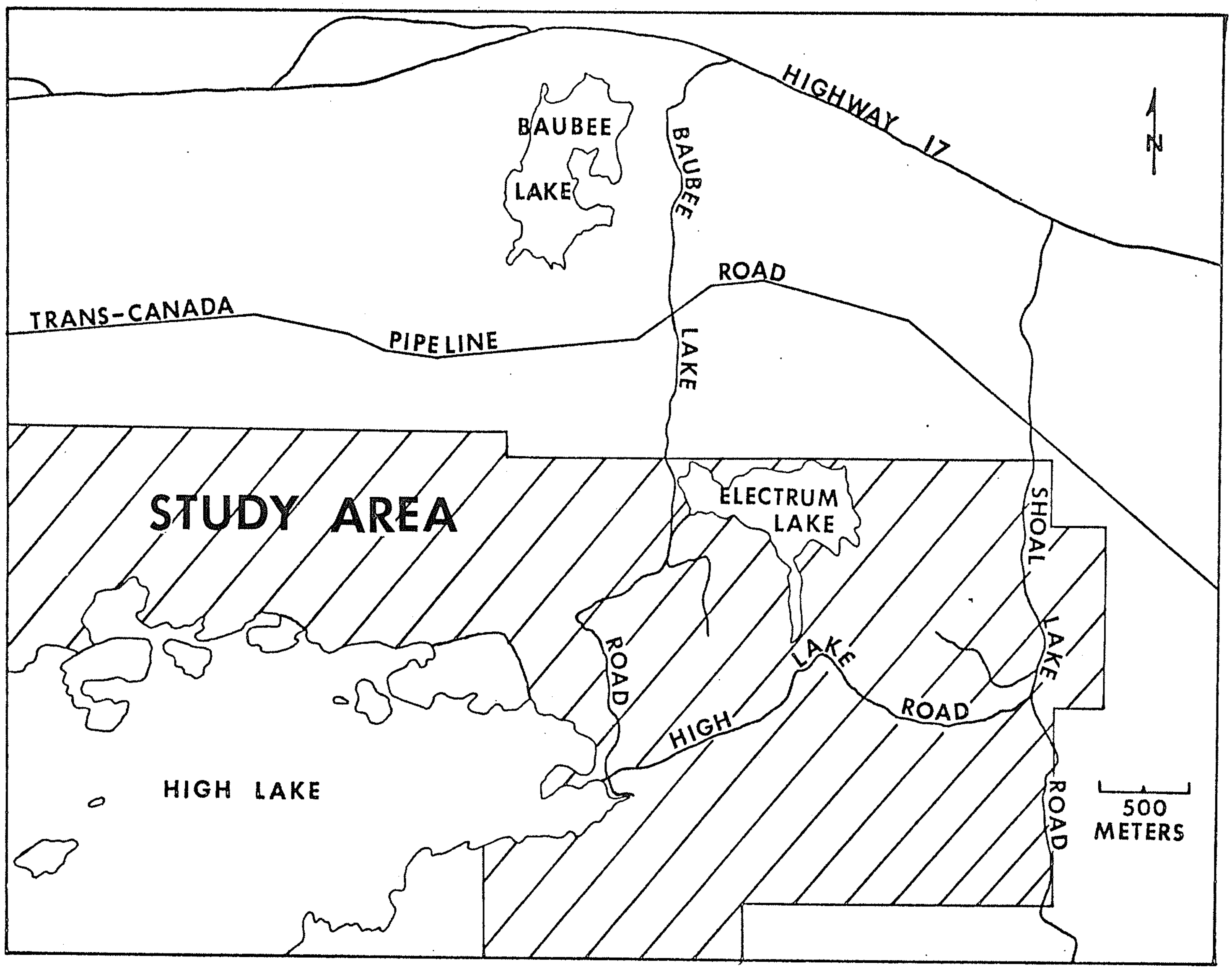


FIGURE 2. DETAILED MAP OF THE STUDY AREA

Ontario Department of Mines, mapped the pluton and adjacent areas at a scale of 1:31,680. The adjacent area in Manitoba was mapped by Springer (1952) and J.F. Davies (1954) at scales of 1:63,360 and 1:12,000 respectively.

Assessment files at the Ontario Ministry of Natural Resources Regional Geologists' Office in Kenora, Ontario contain detailed geologic maps, diamond drill logs, and assay reports of various mineral showings in the pluton. Scales of the geologic maps vary from 1:1,200 to 1:12,000.

Scope of Investigation

Three weeks in the spring and autumn of 1973 and 1974 were spent examining the pluton, and the economic and structural geology of the pluton and immediate vicinity. J.C. Davies' (1962) preliminary 1:15,840 scale geologic map, and copies of geologic maps obtained from assessment work files, aided in the investigation. One hundred eighty-five samples were collected, and most of the known mineral occurrences were examined.

Laboratory investigation included polished and thin section examination, and modal, chemical, and structural analyses.

Acknowledgements

The author gratefully acknowledges the assistance, valuable discussions, and critical reading of the manuscript by Dr. W.C. Brisbin and Dr. G.S. Clark, of the University of Manitoba, and Mr. L. King of St. Joseph Explorations Limited, Toronto. Valuable suggestions were made also by Dr. L.D. Ayres of the University of Manitoba.

The author is also indebted to Mr. C. Alcock, Mr. A. Duncan, and Mr. J. Boucha, for allowing work to be done on their property. Field assistance from Peter Cameron, David Pedora, and Garnet Wallace, typing by Mrs. J.M. Pedora and Mrs. Susan Pedora, and discussions with my colleagues at the University of Manitoba were greatly appreciated.

CHAPTER 2

GEOLOGIC SETTING

The study area is in the Kenora Block of the Early Precambrian Superior Province of the Canadian Shield (Wilson et al., 1972). Figure 3 shows the local geologic setting of the study area, and Table 1 gives the sequence of rock units. Outcrop density is about 50 percent, and best exposures are in the massive intrusive rocks north of High Lake, and the massive flows southeast of High Lake.

The oldest rocks are the metavolcanic and metasedimentary rocks of the Keewatin Group (formerly Series) Lawson (1885). In the area of Figure 3, this unit is mainly basaltic and andesitic, pillowed and massive flows with some intercalated arkose, greywacke, and reworked agglomerate. The Keewatin Group was intruded by both synvolcanic plutons and the northern phase of the High Lake pluton, with emplacement of the northern phase causing contact metamorphism and deformation. The Keewatin Group and the northern phase of the High Lake pluton are overlain in angular unconformity by the Crowduck Lake Group, which consists of conglomerate, arkosic conglomerate, argillite, cherty argillite, and tuff (Davies, 1965). The conglomerate contains porphyritic clasts that appear to be derived from dikes of the northern phase of the High Lake pluton (Davies, 1965). Mafic volcanic clasts in the conglomerate are likely derived from the Keewatin Group.

Deformation of the Keewatin Group, northern phase of the High Lake pluton, and Crowduck Lake Group has resulted in passive folds in the layered rocks with well-developed, east-trending, axial planar foliation. Folds are steeply plunging and foliation has a near-vertical dip. Regional greenschist facies metamorphism accompanied this deformation. According

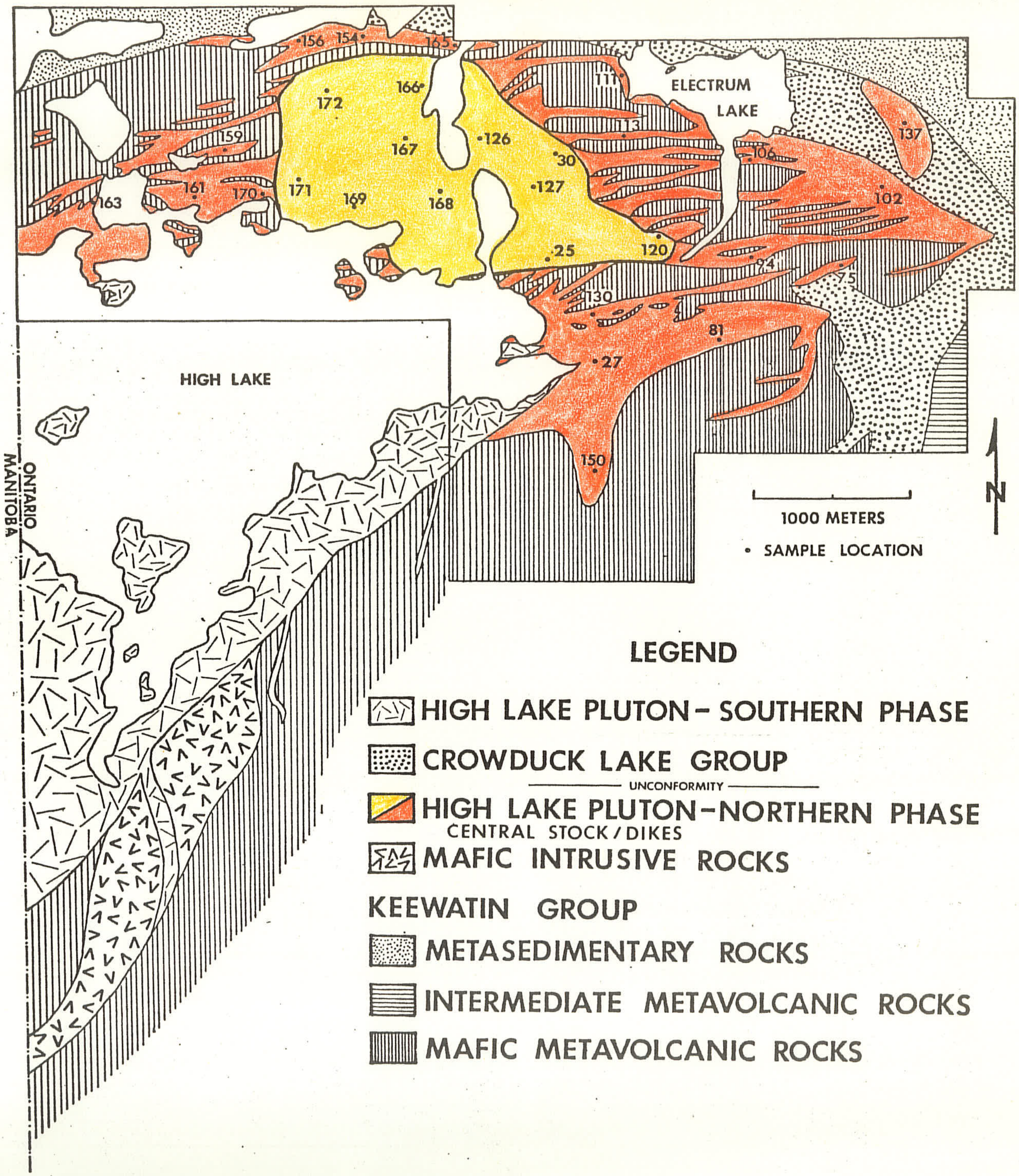


FIGURE 3. GEOLOGY (AFTER DAVIES, 1965) AND SAMPLE LOCATIONS OF THE STUDY AREA

TABLE 1

Table of Formations

CENOZOIC

Recent — Lake, stream, and swamp deposits

Pleistocene — Sand, gravel, clay

PRECAMBRIAN

Early Precambrian

High Lake pluton - southern phase

Granodiorite to tonalite, hybrid rocks

Intrusive Contact (?)

Crowduck Lake Group

Conglomerate, arkosic conglomerate, arkose, argillite, cherty argillite, reworked agglomerate, tuff

Unconformity

High Lake pluton - northern phase

Porphyritic granodiorite to trondhjemite

Intrusive Contact

Mafic Intrusive Rocks

Gabbro

Intrusive Contact

Keewatin Group

Metasedimentary rocks: arkose, greywacke, siltstone, garnet-rich greywacke, reworked agglomerate

Intermediate metavolcanic rocks: andesitic flows, andesite-dacite agglomerate

Mafic metavolcanic rocks: basaltic flows

(After Davies, 1965)

to Davies (1965), the southern phase of the High Lake pluton post-dates the Crowduck Lake Group. This phase is not deformed or metamorphosed and may be syn- or post-tectonic (Vagt, 1968).

Pleistocene and Recent sand, gravel, clay, and swamp deposits cover about 50 percent of the study area.

CHAPTER 3

HIGH LAKE PLUTON

Introduction

The High Lake pluton is an east to northeasterly-trending body that occurs in both Manitoba and Ontario. It consists of an early, northern, porphyritic phase with an areal extent of 10 sq. km and a younger, southern phase of similar extent.

Most of the field examination of this study was concentrated on the northern granodiorite to trondhjemite phase, which consists of a central stock flanked to the east and west by dike units (Figure 3). Both the stock and dikes are in sharp contact with the vertically-dipping metavolcanic and metasedimentary country rocks and shows marginal chilling.

The central stock of the northern phase is well exposed and is characterized by a pinkish weathered surface. It contains 50 - 70 percent medium-grained, anhedral to euhedral quartz, plagioclase, and biotite phenocrysts in a very fine-grained, mosaic-like groundmass. Coarse-grained microcline phenocrysts up to 6 cm long form less than one percent of the stock.

The dikes are poorly exposed, weather a light grey to white, have easterly trends, and vary in width from 3 to 60 m. They contain 50 to 70 percent medium-grained, anhedral to euhedral quartz, plagioclase, and biotite phenocrysts in a very fine-grained, mosaic-textured groundmass. Microcline phenocrysts are rare or absent. Some dikes contain secondary blue-green hornblende, which is interpreted to be the result of marginal assimilation of the host mafic metavolcanic rocks.

The southern phase of the High Lake pluton consists of equigranular tonalite, granodiorite, and hybrid rocks, and is considered younger than the northern phase. The southern phase contains some mineralization and will be discussed in conjunction with mineralization.

Structural Geology

Introduction

The Keewatin Group, the northern phase of the High Lake pluton, and the younger Crowduck Lake Group have been subjected to several deformational events, which have resulted in the development of a variety of structural features. The northern phase has been tilted and is characterized by a penetrative tectonic foliation with a cataclastic character in some areas; shear zones, shear fractures, tension fractures, quartz veins, and late joints. The Keewatin and Crowduck Lake Groups have been folded and are characterized by a penetrative foliation or schistosity, shear zones, shear fractures, tension fractures, quartz veins, and late joints.

As used herein, shear zones are zones of intense cataclasis, whereas shear and tension fractures are discrete fractures that occur either individually or in sets. Quartz veins fill these shear zones, shear fractures, and tension fractures. Late joints crosscut all previously mentioned structures.

Folding, Schistosity, and Shear Zones

Davies (1965) has recognized at least two different folding events in rocks adjacent to the High Lake pluton. Little is known about the first deformational event, due to strong tectonic overprinting by the second event. However, Davies (1965) suggested that this earlier stage of folding had northwest-trending fold axes.

The northern phase of the High Lake pluton is unconformably overlain by the Crowduck Lake Group to the east and northeast. Because the Crowduck Lake Group is now vertically-dipping, the underlying rock sequence, including the northern phase, has been rotated also. Consequently, if the unconformable contact, which now trends north to northwest and dips steeply, is assumed to represent the original top of the pluton, the east end of the pluton would represent the upper portion.

In the Keewatin and Crowduck Lake Groups, the second deformational event produced passive folds with easterly-trending axial surfaces and a strong axial planar schistosity. In mafic metavolcanic rocks, greywacke, and argillite, the schistosity is a result of recrystallization, but in arkose and conglomerate, it is a result of cataclasis. The northern phase is affected only by the second deformational event and has a penetrative cataclastic foliation. This foliation is well-developed in the dikes, but is less pronounced in the central stock. The foliation is parallel or sub-parallel to the contact between the northern phase and adjacent rocks, and has the same orientation in both groups of rocks.

The shear zones are parallel to the foliation and are simply zones of intense cataclasis or intense recrystallization up to 2 m wide and varying in length from 2 to 7 km (Figure 22). The shear zones occur in both the northern phase and adjacent rocks. Shear zones do not extend into the southern phase, confirming the syn- or post-tectonic emplacement of this phase suggested by Vagt (1968).

Quartz Veins in Shear and Tension Fractures

Quartz, quartz carbonate, and quartz-tourmaline veins 3 to 70 m long and 3 cm to 2 m wide are found in fractures in the northern phase and adjacent rocks. These veins occur in two predominant orientations (Figure 4). Veins which strike 090 degrees and dip 85-90 degrees north occur in fractures that are parallel to the regional foliation and are probably due to shear. Those which strike 070 degrees and dip 80 degrees northwest fill fractures that cut across the foliation and show tensional characteristics. The quartz veins filling both fracture sets are similar and apparently were emplaced at the same time. They are important because of associated mineralization.

Joints

Joints ranging from 3 to 60 m in length and with spacings exceeding 1 m, occur throughout the area, but are more abundant in the northern phase than in the adjacent rocks. Two major joint sets with orthogonal trends are present. The more pronounced set strikes 160 degrees and dips 90 degrees in the northern phase and 80 degrees northeast in the adjacent rocks. The other set strikes 070 degrees and dips 85 degrees northwest in the northern phase and 90 degrees in the adjacent rocks (Figures 5 and 6). The latter set has the same orientation as the quartz veins in Figure 4 and may represent early joints formed during regional deformation. All other joints are probably late joints, because they cut across the regional tectonic fabric.

Petrography

Introduction

The suites of samples from the northern phase were petro-

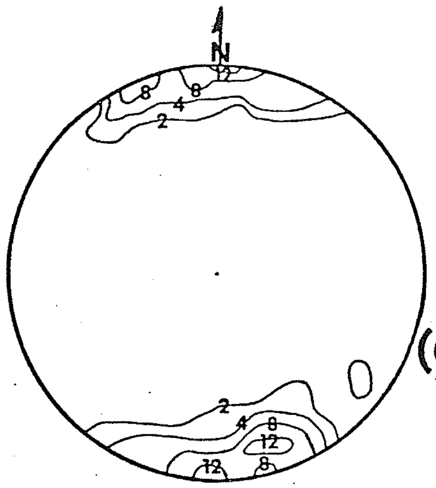


FIGURE 4.

POLES (35) TO QUARTZ VEINS (CONTOURED AT 2,4,8,12%)

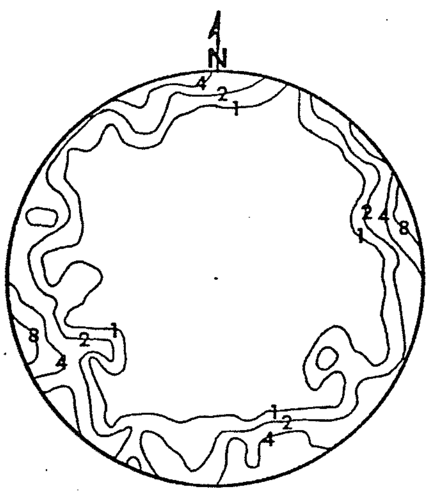


FIGURE 5.

POLES(140) TO JOINTS IN THE NORTHERN PHASE (CONTOURED AT 1,2,4,8 %)

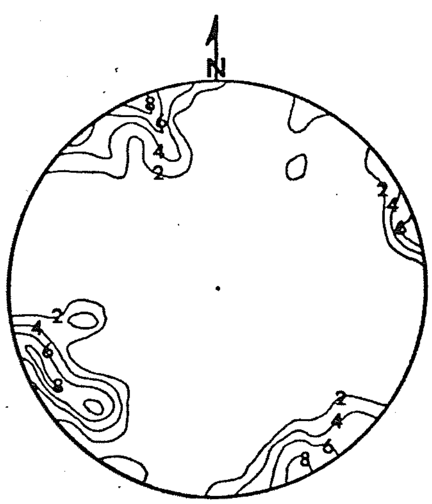


FIGURE 6.

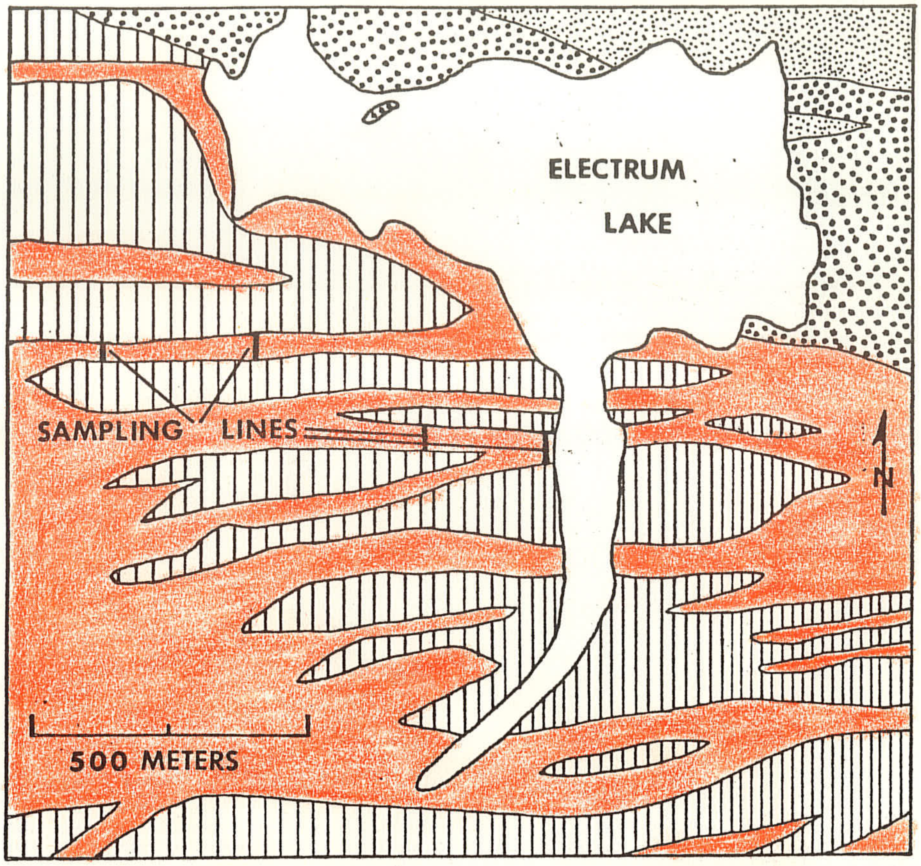
POLES(70) TO JOINTS IN THE ADJACENT ROCKS (CONTOURED AT 2,4,6,8%)

graphically examined. One suite consisted of 29 samples selected from the central stock and the centers of dikes. The location of, and modal data for these samples is given on Figure 3 and in Appendix I respectively. The second suite consisted of 25 samples collected from 4 sample groups representing cross sections of 2 dikes in the eastern dike swarm. Samples were spaced evenly across the dikes, and sample groups consisted of 5 to 7 samples, depending on the width of the dike. Sample locations and modal data are given on Figure 7 and in Appendix II respectively.

The above 54 samples were point counted on 27 mm by 46 mm thin sections. In all samples, the rock slice covered at least two-thirds of the glass slide, and 1000 points were counted using a 0.4 mm by 1.0 mm grid. Alteration minerals were recorded twice; once as the pre-alteration primary mineral and once as the alteration product.

Quartz Phenocrysts

Quartz forms anhedral, ovoid phenocrysts that range in size from 0.08 to 6.5 mm. They average 1.6 mm in both the central stock and dikes, with the coarsest phenocrysts in the eastern dike swarm and in the north central part of the stock. They are commonly strained, broken, or recrystallized due to shearing and regional metamorphism. Volume percent of quartz phenocrysts ranges from 1.6 to 25.1 percent (Figure 8, Appendix I) and averages 11.8 percent in the central stock and 12.8 percent in the dikes. The quartz phenocryst distribution has a crude concentric pattern. Phenocrysts are concentrated at, or close to the margins of the northern phase (Figure 8); towards the center of the stock and adjacent to the north contact, the concentration of quartz



LEGEND

CROWDUCK LAKE GROUP

UNCONFORMITY

HIGH LAKE PLUTON–NORTHERN PHASE

KEEWATIN GROUP

METASEDIMENTARY ROCKS

MAFIC METAVOLCANIC ROCKS

FIGURE 7. LOCATION OF SAMPLING LINES IN THE DIKES OF THE STUDY AREA

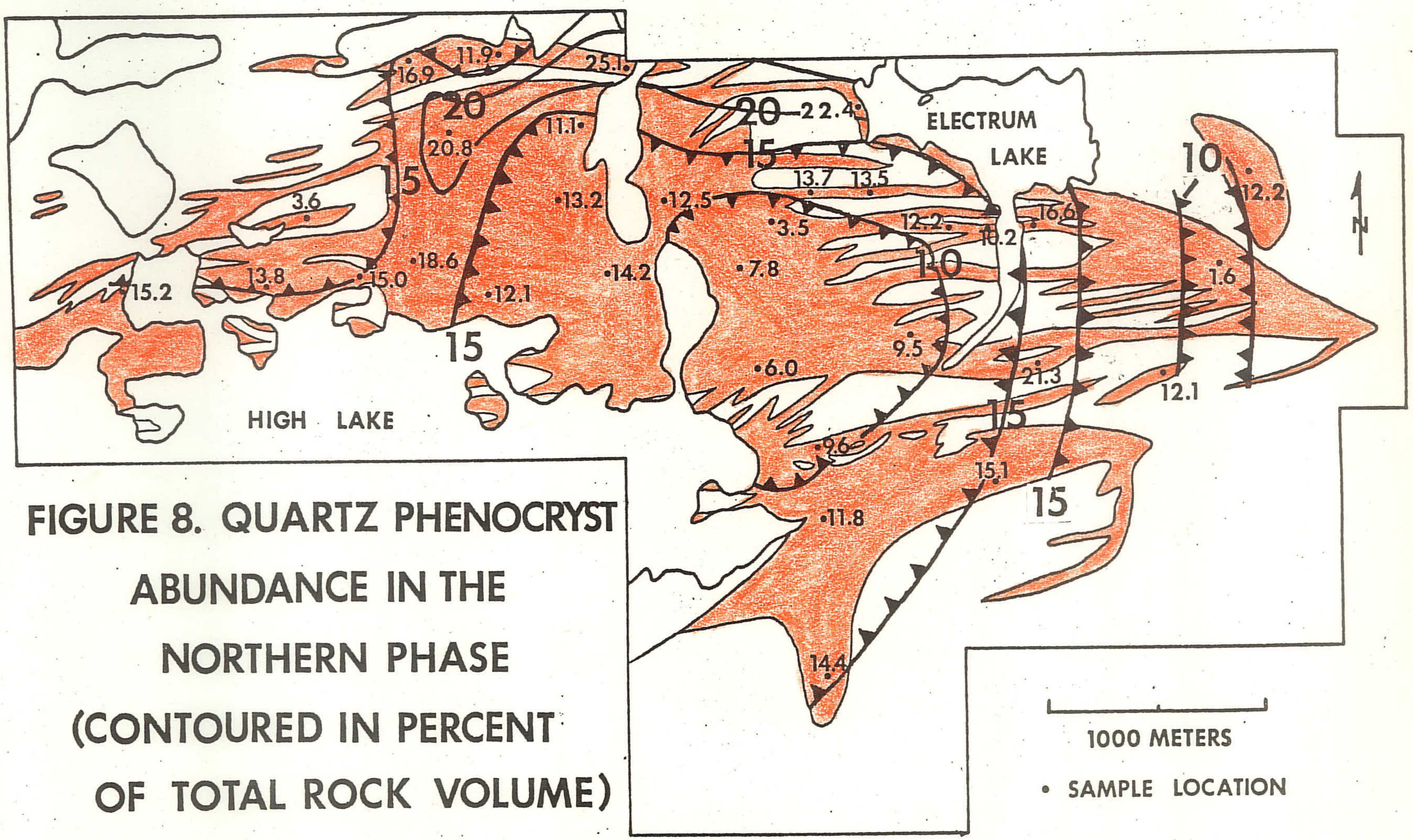


FIGURE 8. QUARTZ PHENOCRYST ABUNDANCE IN THE NORTHERN PHASE (CONTOURED IN PERCENT OF TOTAL ROCK VOLUME)

HIGH LAKE PLUTON, NORTHERN PHASE

ADJACENT ROCKS

phenocrysts is lower. The pattern of quartz phenocryst abundance conforms generally with the outline of the northern phase and with the eastern boundary between the central stock and dikes. To the southwest, the concentric pattern is interrupted by the southern phase intrusive contact.

Plagioclase Phenocrysts

Plagioclase phenocrysts are anhedral to euhedral with tabular and blocky forms that range in size from 0.08 to 10.5 mm (Plate 1). They average 1.4 mm in the central stock and 1.1 mm in the dikes. Plagioclase phenocrysts are slightly recrystallized, altered, and fractured due to regional metamorphism and shearing. They are variably altered to sericite, muscovite, epidote, clinozoisite, and carbonate. In the central stock, they have synneusis twins (Vance, 1961) and oscillatory zoning and range in composition from An_{24} to An_{32}. In the dikes, they are rarely zoned and range in composition from An_{28} to An_{39}. Volume percent of plagioclase phenocrysts ranges from 20.8 to 76.0 percent (Figure 9, Appendix I). Plagioclase phenocryst distribution is uniform in the central stock where it averages 44.6 percent, but is less regular in the dikes where it averages 52.3 percent. There is no concentric pattern as in quartz phenocryst distribution (Figure 8). Plagioclase/quartz phenocryst ratio (Figure 10) shows a crude concentric pattern centered at the eastern part of the central stock where the ratio is high. The ratio is lower except for two areas at the outer margins of the eastern and western dike swarms.

Microcline Phenocrysts

Microcline phenocrysts occur as subhedral to euhedral, tabular

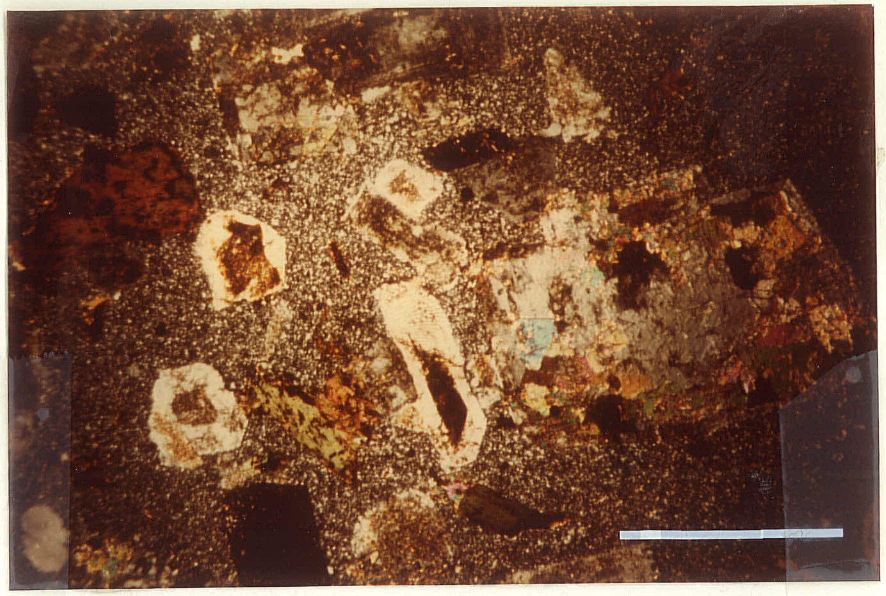


PLATE 1

Altered and zoned plagioclase phenocrysts and biotite phenocrysts in porphyritic granodiorite typical of the northern phase (crossed nicols). Bar represents 1 mm.

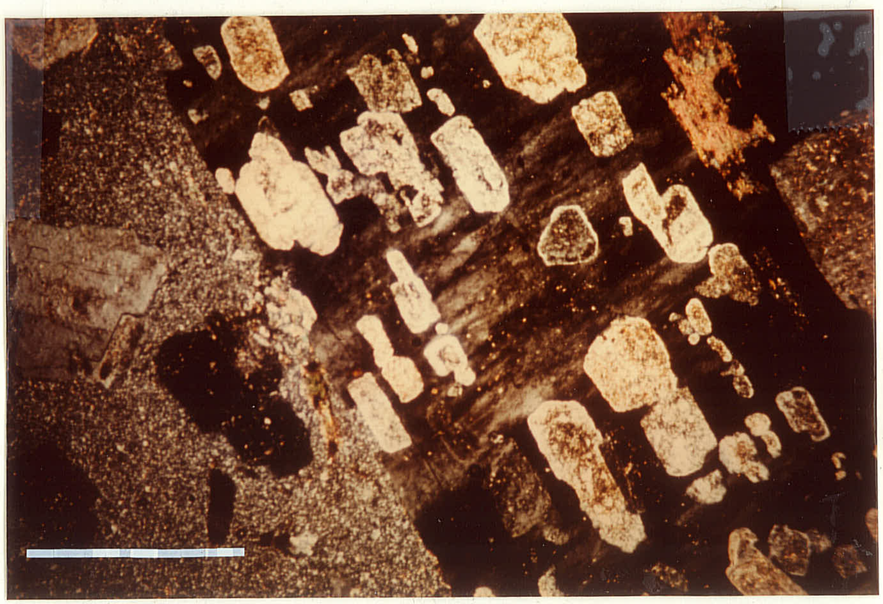


PLATE 2

Microcline phenocryst with crystallographically-aligned plagioclase inclusions and biotite inclusions (crossed nicols). Bar represents 1 mm.

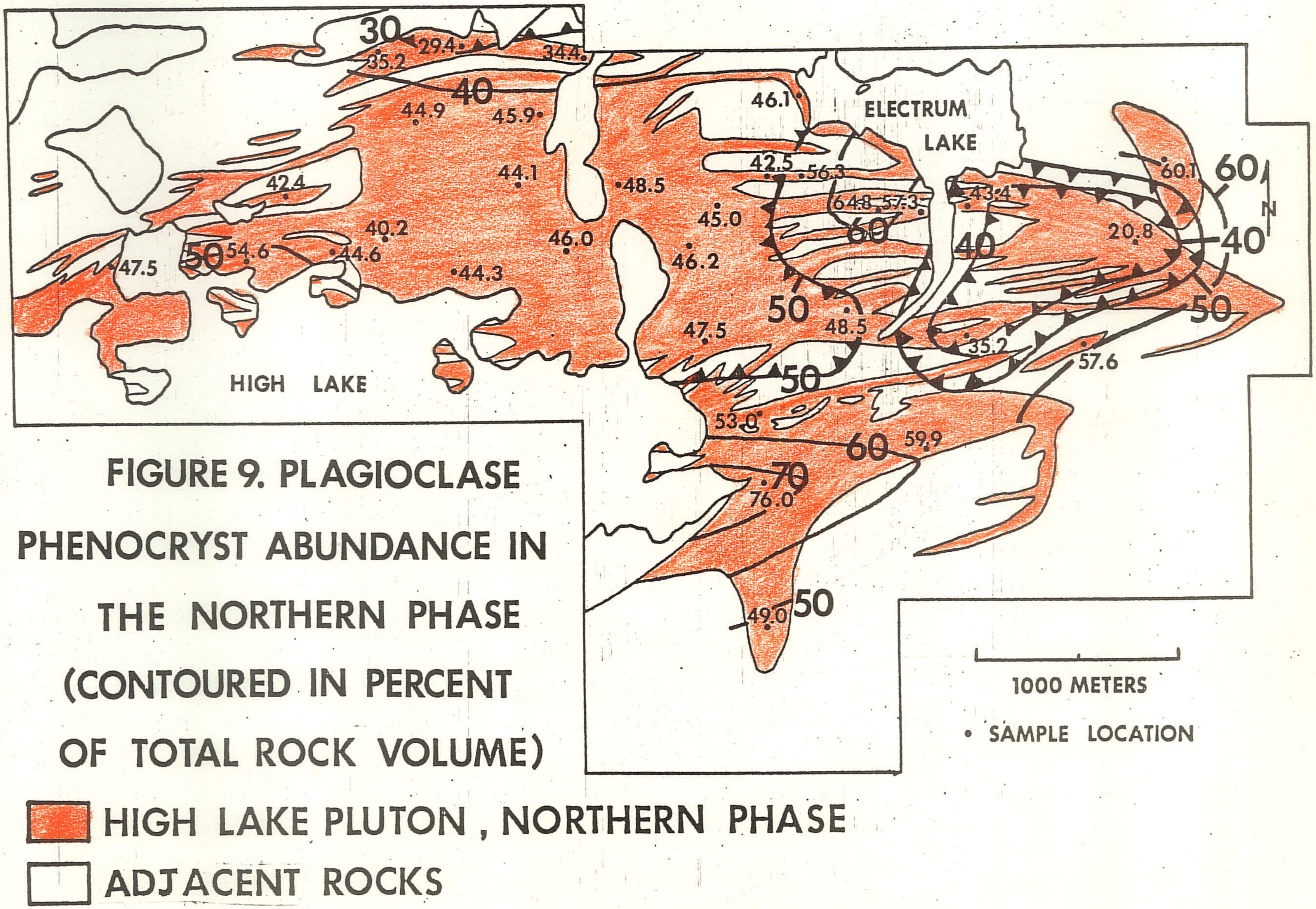


FIGURE 9. PLAGIOCLASE PHENOCRYST ABUNDANCE IN THE NORTHERN PHASE (CONTOURED IN PERCENT OF TOTAL ROCK VOLUME)

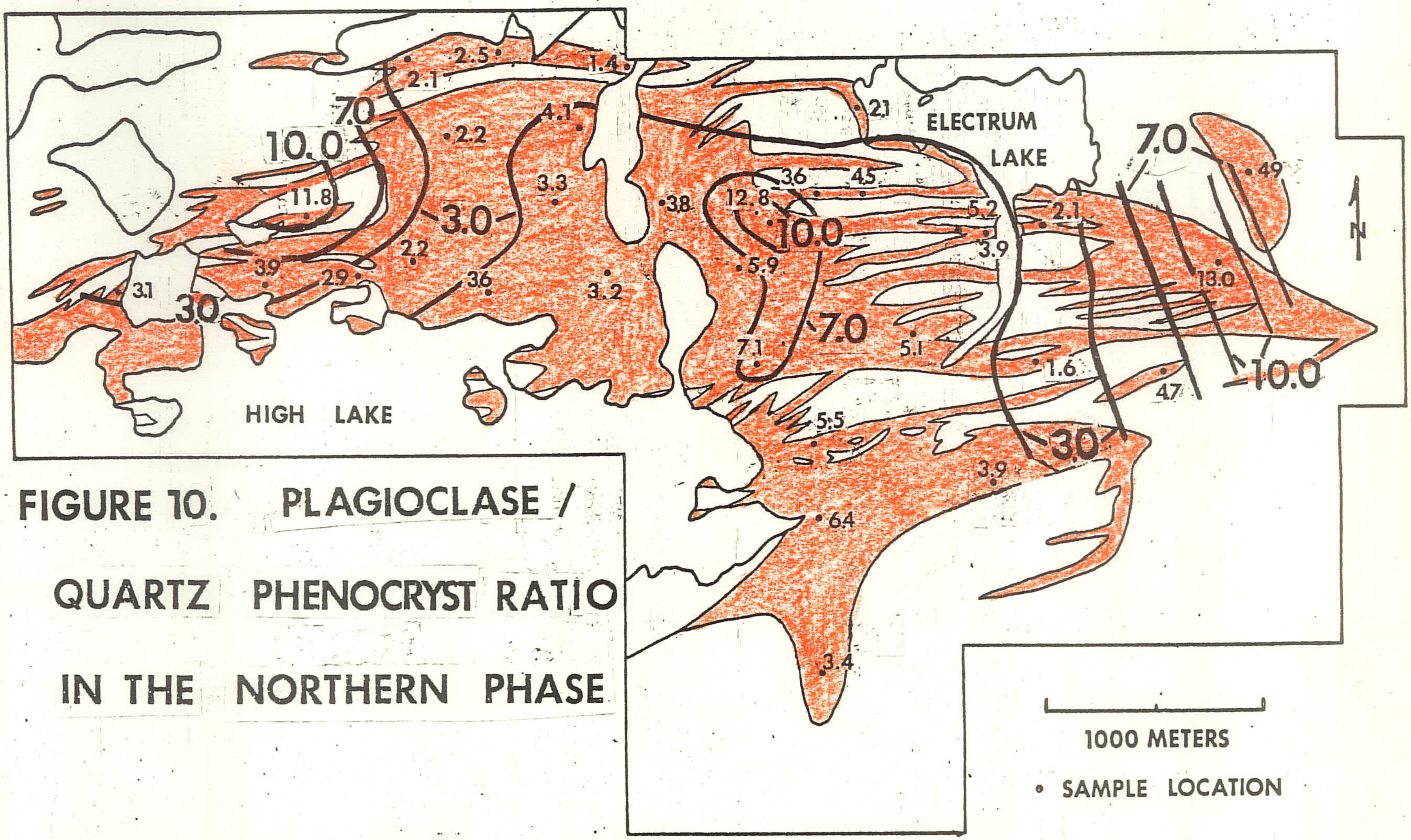


FIGURE 10. PLAGIOCLASE / QUARTZ PHENOCRYST RATIO IN THE NORTHERN PHASE

HIGH LAKE PLUTON NORTHERN PHASE

ADJACENT ROCKS

crystals up to 6 cm long in the central stock and rare subhedral, blocky crystals up to 2 cm in the dikes. They are slightly recrystallized and are characterized by large size, cross-hatched albite-pericline twinning, and the presence of crystallographically-aligned plagioclase inclusions and random quartz and biotite inclusions (Plate 2).

The maximum abundance of microcline phenocrysts is one percent in the central stock, and they decrease in abundance outward into adjacent dikes. They are absent in dikes more than 300 meters from the central stock.

Two microcline phenocrysts from different parts of the stock were examined and plagioclase inclusions were found to vary in composition from An_{24} at the rim of the microcline crystal to An_{30} in the core.

Many porphyritic granitic rocks contain microcline or orthoclase crystals that exceed 2 cm in length and are generally several times larger than co-existing plagioclase phenocrysts. The origin of these large potassic feldspar crystals has been the subject of controversy. Both magmatic (Hibbard, 1965) and metasomatic (Herz, 1970; Marmo, 1971) origins have been proposed. Hibbard (1965) suggested that the decrease in anorthite content of crystallographically-aligned plagioclase inclusions from core to rim of large microcline crystals was indicative of a magmatic rather than a metasomatic origin of the microcline. Plagioclase inclusions may be observed in metasomatic microcline, but they are not crystallographically-aligned, and do not show a similar variation in anorthite content. The outward decrease in composition of plagioclase inclusions in microcline phenocrysts of the northern phase suggests that they are magmatic.

Biotite Phenocrysts

Unaltered, brown biotite phenocrysts are anhedral to subhedral, blocky and tabular plates that vary in size from 0.08 to 2.0 mm (Plate 1). In the central stock, they average 0.20 mm, and in the dikes 0.35 mm. They are unstrained and make up 0.0 to 4.6 percent of the central stock and 0.0 to 8.0 percent of the dikes. On the average, both the central stock and dikes contain 1.2 percent biotite phenocrysts, and they are randomly distributed throughout the northern phase.

Hornblende

Blue-green hornblende is important only in some porphyritic dikes, where it forms up to 15 percent of the dike. It occurs as prismatic, elongate, and blocky, anhedral to subhedral crystals ranging in length from 0.08 to 2.3 mm, with an average length of 0.5 mm (Plate 3). Hornblende is most abundant near the margins of the dikes where quartz phenocrysts are rare and epidote alteration of plagioclase phenocrysts is common (Plate 4), and it is rare in the centers of the dikes where quartz phenocrysts are common and epidote alteration is sparse. The distribution of hornblende, the associated epidote alteration of plagioclase phenocrysts, the presence of groundmass inclusions in hornblende (Plate 3), overgrowths of hornblende on plagioclase phenocrysts, corrosion of plagioclase and quartz phenocrysts, and recrystallization of groundmass, suggest that hornblende may be secondary as a result of assimilation of mafic metavolcanic country rocks, and that there has been regional metamorphism of the dike margins.

Groundmass

The groundmass, which is composed of quartz, plagioclase,

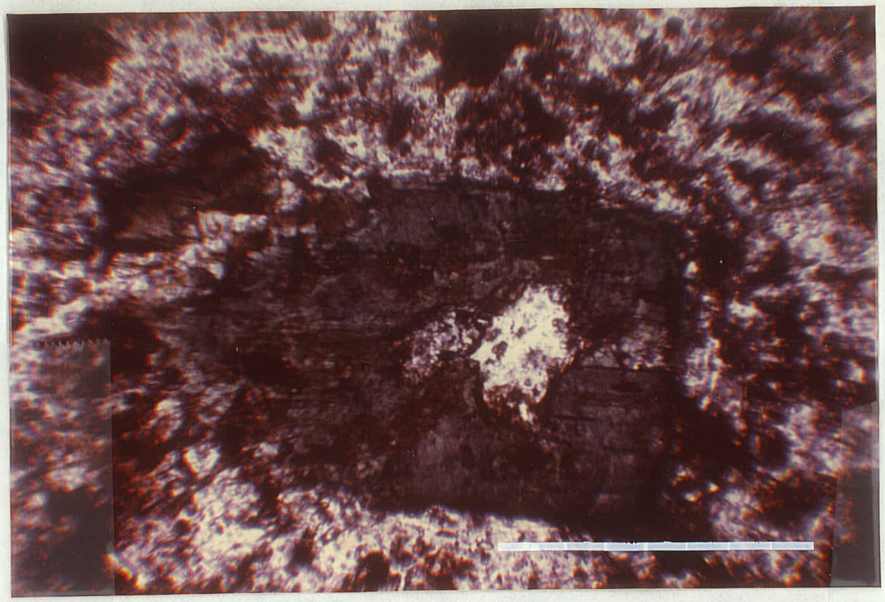


PLATE 3

Groundmass inclusions in hornblende in a dike with marginal assimilation (plane light). Bar represents 1 mm.

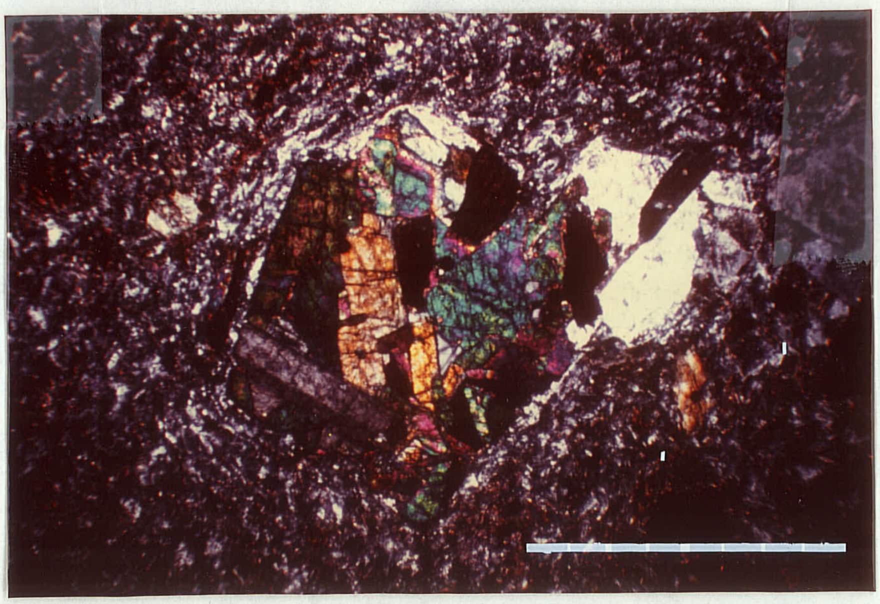


PLATE 4

Complete alteration of a plagioclase phenocryst to epidote and clinoziosite (crossed nicols). Bar represents 1 mm.

K-feldspar, and biotite, has a mosaic texture (Plate 1). In the stock, groundmass abundance ranges from 34.1 to 48.6 percent (Figure 11) and averages 40.9 percent, and grain size ranges from 0.02 to 0.06 mm (Figure 12); average grain size is 0.03 mm. In the dikes, groundmass is more variable in both grain size and abundance. Abundance ranges from 10.2 to 67.9 percent (Figure 11) and grain size from 0.03 to 0.08 mm (Figure 12). Average abundance is 31.5 percent and average grain size is 0.05 mm. Groundmass abundance shows a very uniform distribution in the central stock and a less consistent distribution in the dikes, as in plagioclase phenocrysts (Figure 9).

Groundmass grain size is smallest in a concentric zone several hundred meters from the outer margins of the pluton, and increases both inward and outward from this zone.

Alteration

Alteration of plagioclase phenocrysts (Plates 1 and 4) and groundmass feldspar (Plate 5) is ubiquitous and ranges in amount from 1.6 to 24.7 percent (Figure 13), but is generally less than 15 percent. The common alteration minerals are epidote, clinozoisite, sericite, muscovite, and carbonate, although only sericite was found in the groundmass. Muscovite was distinguished from sericite by its coarser grain size and better-developed cleavage. Alteration intensity increases progressively outward from the center of the northern phase, except at or near the outer contact in the eastern part of the pluton, where it decreases from a maximum of 20 percent to less than 10 percent.

Petrography of Selected Dikes

Two dikes southwest of Electrum Lake were sampled to test for

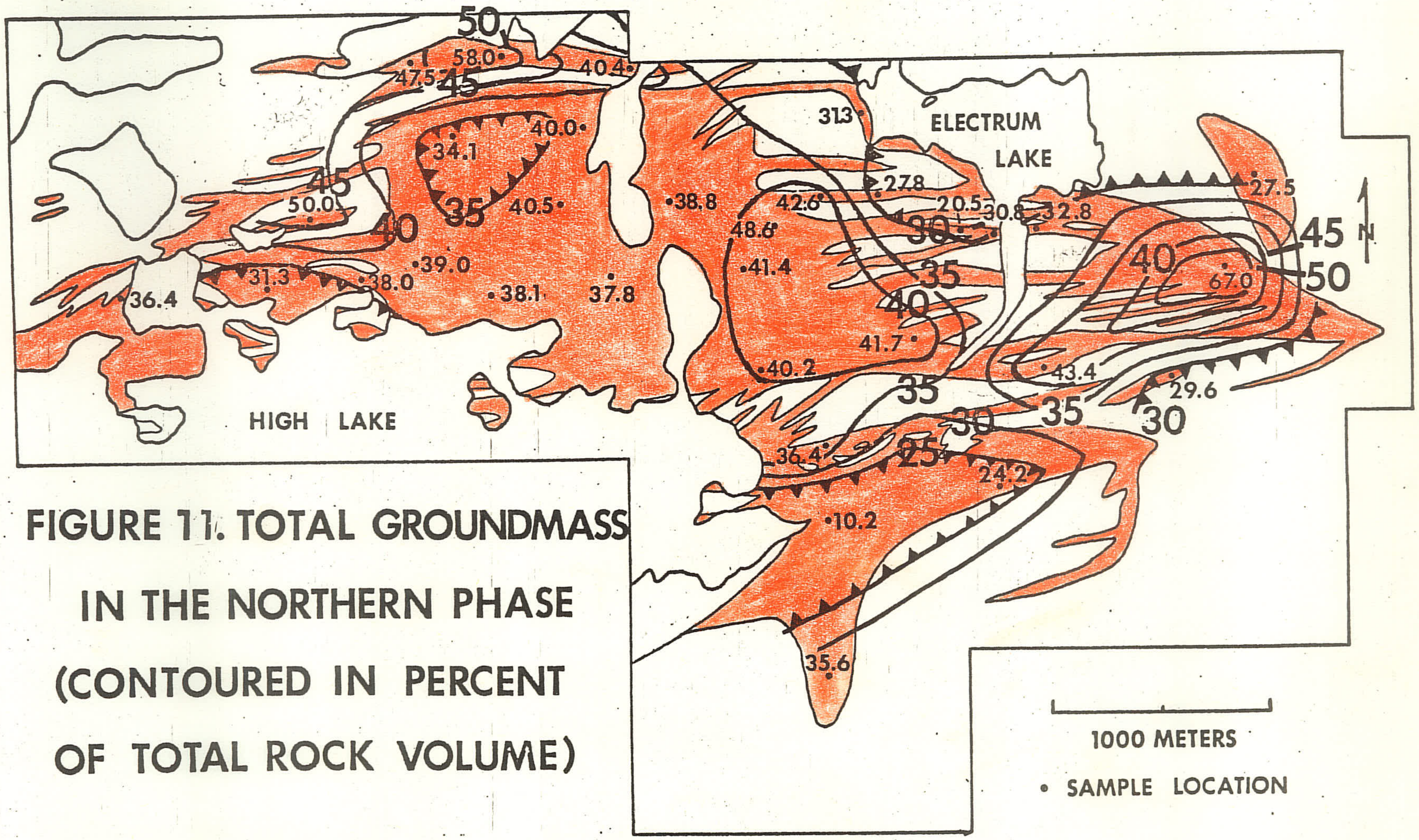


FIGURE 11. TOTAL GROUNDMASS IN THE NORTHERN PHASE (CONTOURED IN PERCENT OF TOTAL ROCK VOLUME)

1000 METERS

• SAMPLE LOCATION

HIGH LAKE PLUTON, NORTHERN PHASE

ADJACENT ROCKS

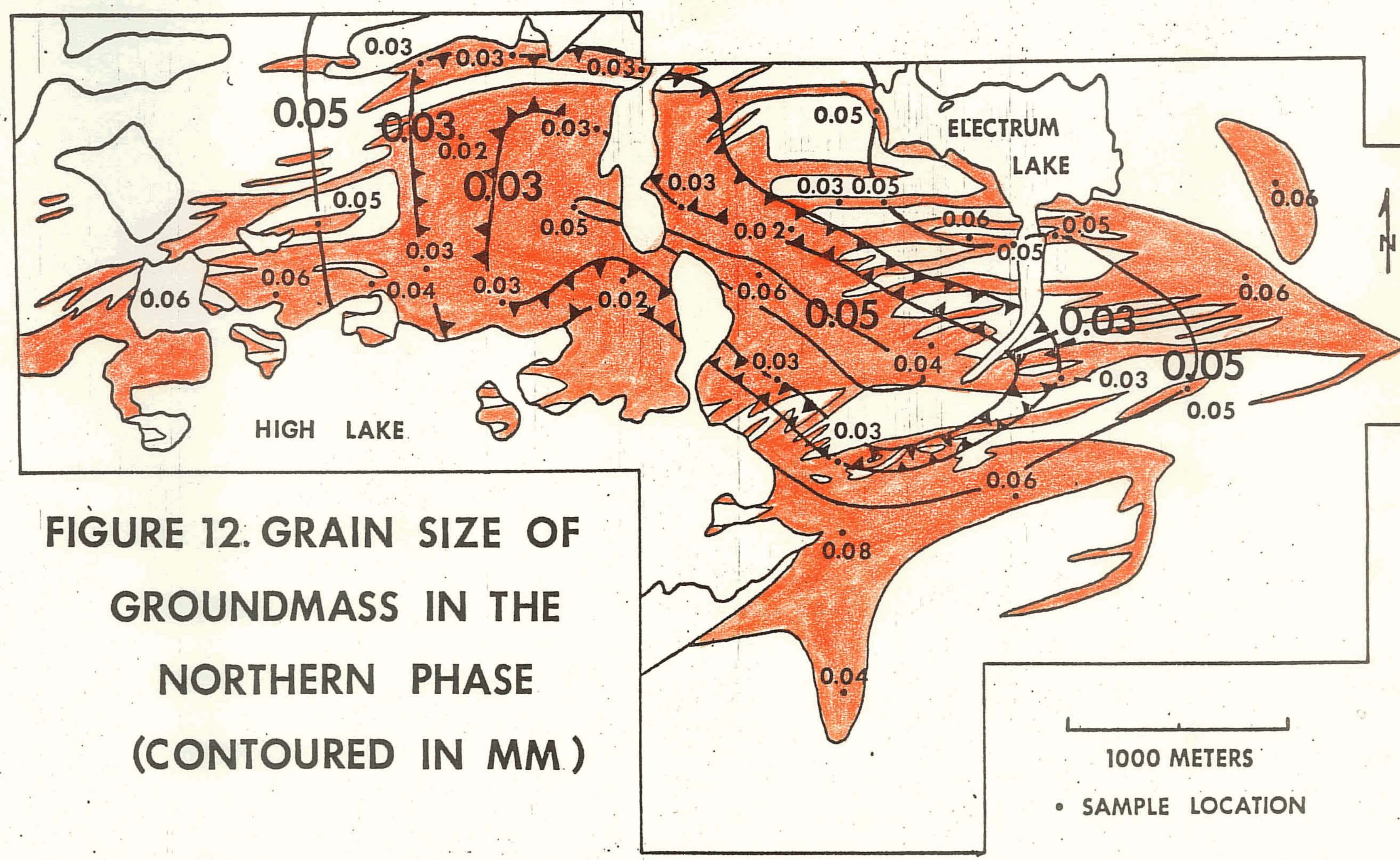


FIGURE 12. GRAIN SIZE OF GROUNDMASS IN THE NORTHERN PHASE (CONTOURED IN MM.)

HIGH LAKE PLUTON, NORTHERN PHASE

ADJACENT ROCKS

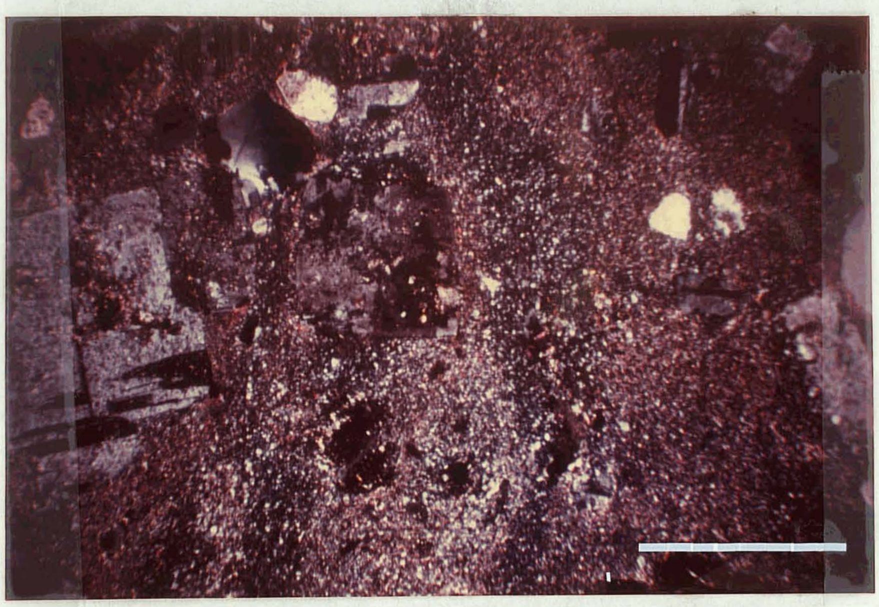


PLATE 5

Sericitic groundmass alteration (crossed nicols).
Bar represents 1 mm.

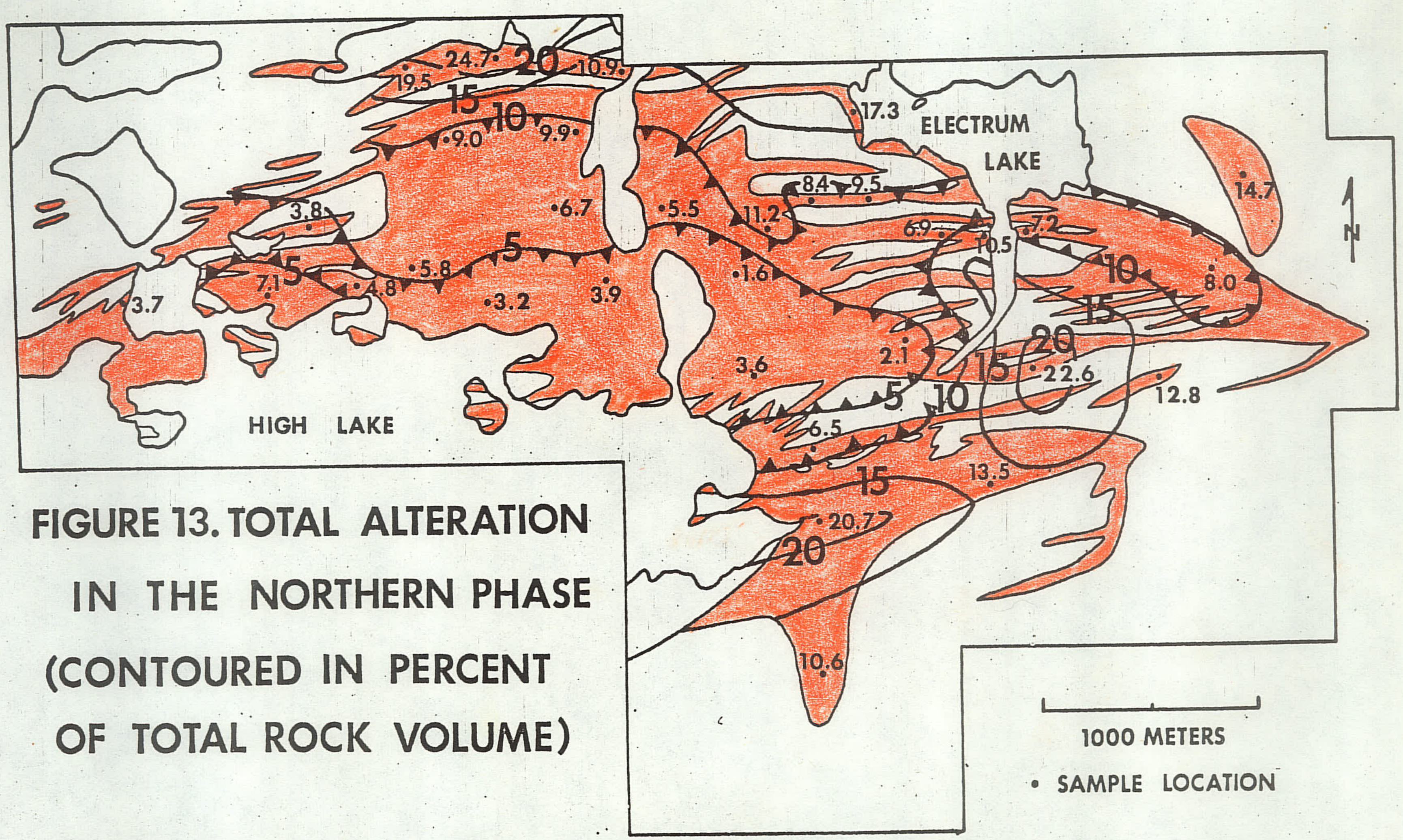


FIGURE 13. TOTAL ALTERATION IN THE NORTHERN PHASE (CONTOURED IN PERCENT OF TOTAL ROCK VOLUME)

HIGH LAKE PLUTON, NORTHERN PHASE

ADJACENT ROCKS

lateral and transverse variations in phenocrysts, groundmass, and alteration abundances (Figure 7). For both dikes, sample suites were collected along 2 northerly-trending lines 150 m apart. In the northern dike, the western line was 20 m long and the eastern line was 40 m. In the southern dike, the western and eastern lines were 30 m and 40 m respectively. Modal analyses of groundmass, quartz phenocryst, plagioclase phenocryst, and alteration abundances, and plagioclase/quartz phenocryst ratios are plotted on the composite diagram of Figure 14.

In the southern dike, alteration, quartz phenocryst, and plagioclase phenocryst abundances increase toward the center of the dike, whereas groundmass abundance decreases. The two lines show little lateral variation within the dike.

Changes across the northern dike are less symmetrical. Alteration abundance increases toward the dike center, and except for the south contact groundmass abundance decreases. Variations in quartz and plagioclase phenocryst abundances lack consistency. The south contact has an anomalously low groundmass content and high phenocryst content (Figure 14). This anomaly may be the result of either sampling a multiple dike, which was not recognized in the field, or, less likely, reactions with the wall rocks. Lateral changes in this dike are shown by differences in quartz and plagioclase phenocryst abundances between the two sample lines.

The increase in phenocryst abundance toward the centers of the dikes may reflect either progressive crystallization inward, or, more likely, flowage differentiation during crystallization. Lateral variability in quartz and plagioclase phenocryst abundances may be a

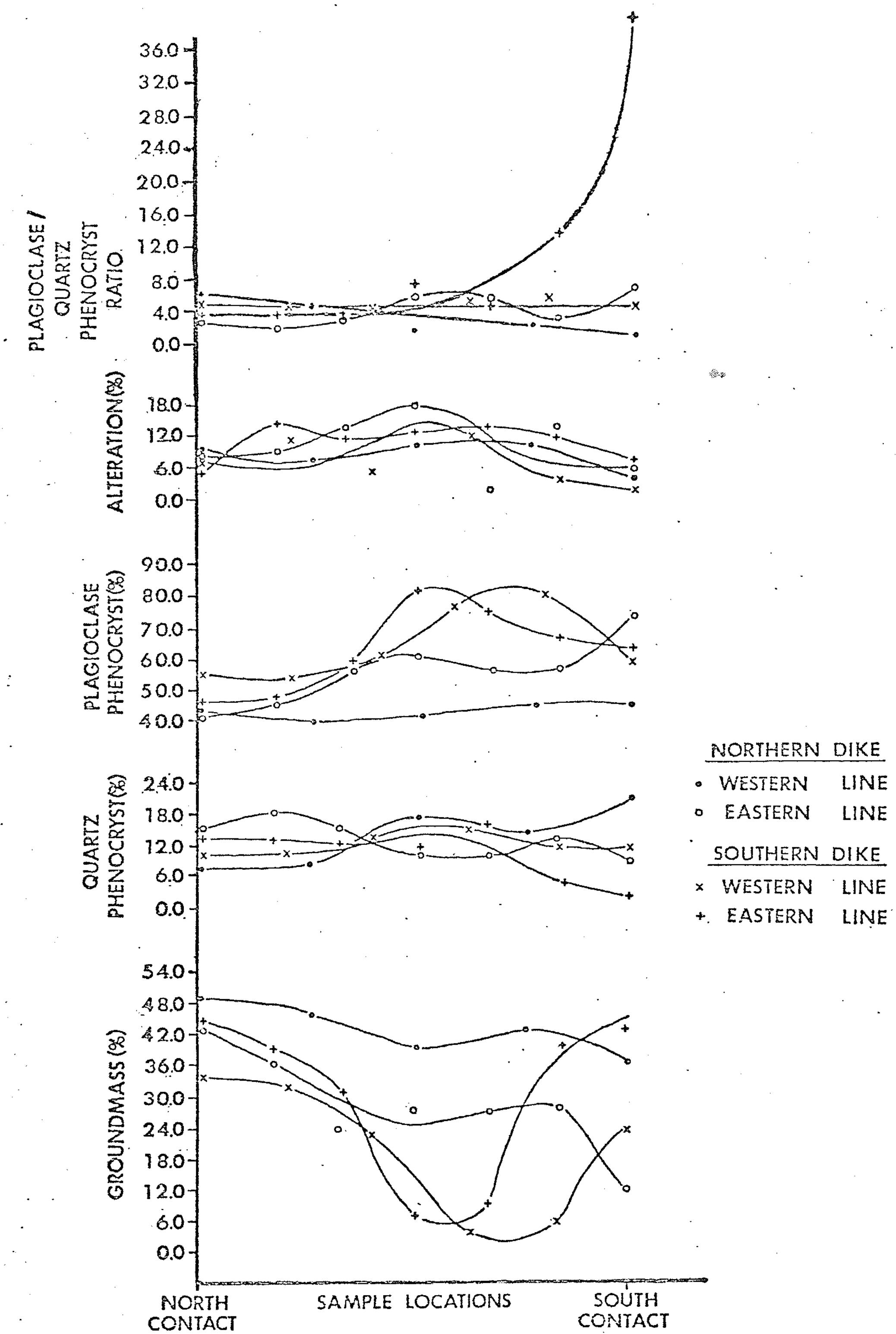


FIGURE 14. COMPOSITE GRAPHS OF MODAL DATA FROM SELECTED DIKES

result of flowage during emplacement.

Plagioclase/quartz phenocryst ratio shows fairly consistent values across three sampling lines, suggesting uniformity of mineralogical composition. The eastern line of the southern dike is anomalous at the southern contact.

Chemistry

Introduction

Forty-four samples were analysed for K_2O, Na_2O, CaO, total iron as Fe_2O_3, and MgO. Twenty-nine of these were from random sample locations in the central stock and dikes, and these were analysed also for copper and zinc. The remaining fifteen samples were from the four dike suites mentioned previously. Figures 3 and 7 show the sample distribution and Appendices III and IV give the analytical data.

General Chemical Variations Across the Northern Phase

Contoured diagrams for K_2O content (Figure 15), Na_2O content (Figure 16), CaO content (Figure 17), and total iron as Fe_2O_3 (Figure 18) show some major chemical constituent variations across the northern phase.

K_2O content (Figure 15) ranges from 1.38 to 3.40 percent in the central stock and 0.64 to 3.94 percent in the dikes. This figure shows only the variations of K_2O in the groundmass; samples containing large microcline phenocrysts were deleted from chemical analyses due to the unrepresentative rock volume of the phenocrysts. With the exception of one sample at the west end of the pluton, K_2O content is lowest in the eastern part of the central stock and increases progressively outward. Near the margins of the pluton there is a local reversal in this trend. The K_2O variation reflects concentration of plagioclase and biotite

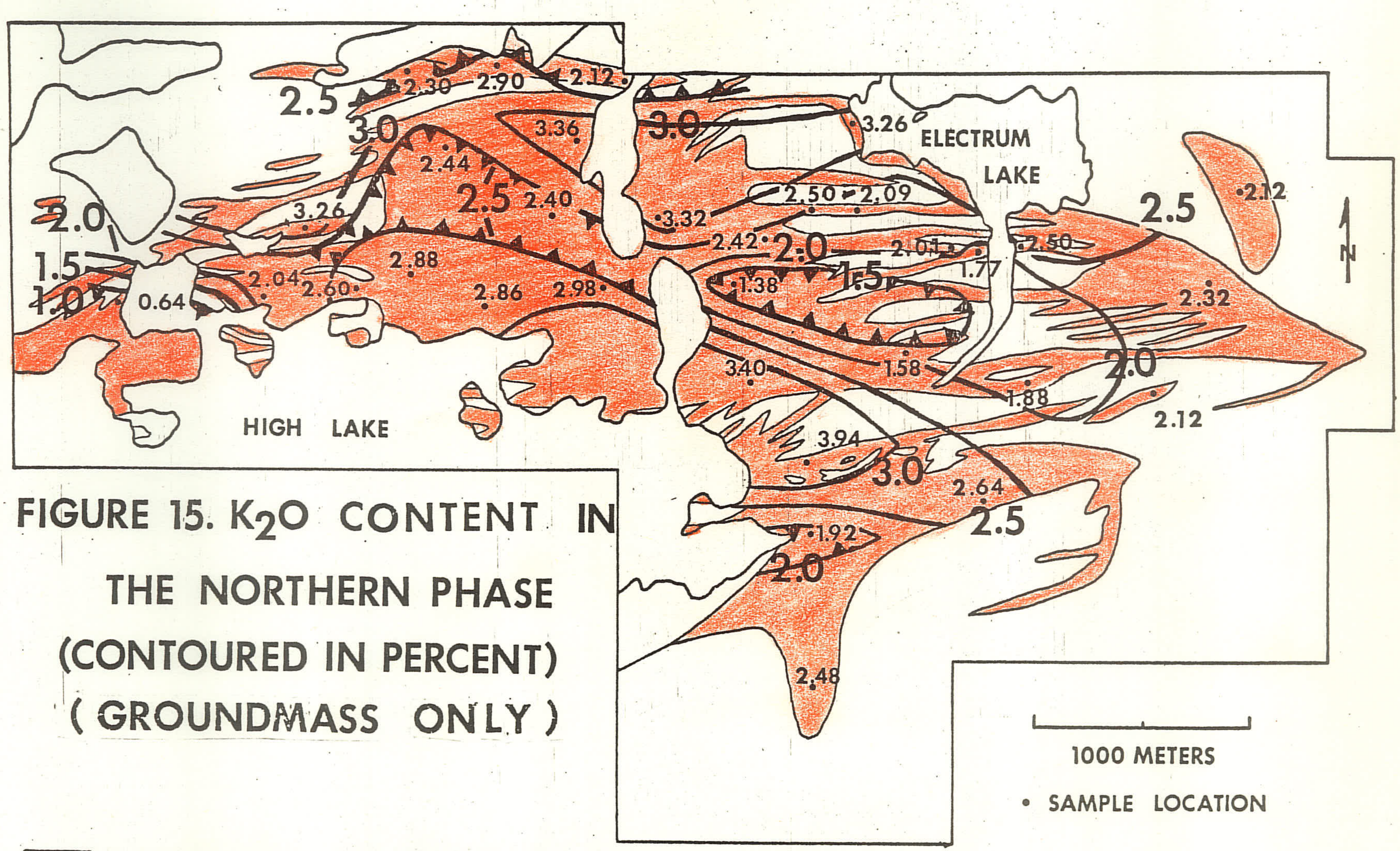


FIGURE 15. K_2O CONTENT IN THE NORTHERN PHASE (CONTOURED IN PERCENT) (GROUNDMASS ONLY)

☐ HIGH LAKE PLUTON NORTHERN PHASE

☐ ADJACENT ROCKS

phenocrysts and compositional changes in the following mineral constituents: groundmass plagioclase, biotite, and K-feldspar, and sericite and muscovite alteration.

Na_2O content (Figure 16) ranges from 4.80 to 7.20 percent in the central stock and 4.20 to 6.06 percent in the dikes. Na_2O content is greatest in the eastern part of the central stock and decreases progressively outward. The distribution of Na_2O is essentially the opposite of K_2O. The Na_2O variations are products of the variations in plagioclase phenocrysts and in groundmass plagioclase and K-feldspar.

CaO content (Figure 17) ranges from 0.32 to 2.02 percent in the central stock and 0.98 to 3.00 percent in the dikes. CaO is less regular in its distribution than Na_2O, but variations in CaO content show that the outer parts of the dike swarms are lime-enriched, the central stock has relatively lower lime, and the eastern part of the central stock has the lowest lime. CaO variation is essentially the opposite of Na_2O variation. CaO occurs in plagioclase phenocrysts, in groundmass plagioclase, and in epidote, clinozoisite, and carbonate alteration. The CaO variation undoubtedly represents variations in these constituents.

Total iron as Fe_2O_3 (Figure 18) ranges from 0.87 to 1.80 percent in the central stock and 0.98 to 3.36 percent in the dikes. In general, iron content increases outward from the eastern part of the central stock, but there is a local reversal of trend along the north margin of the pluton. These variations result from iron in biotite and plagioclase phenocrysts, in groundmass biotite and plagioclase, in disseminated crystals of iron oxide and pyrite, and in epidote alteration.

MgO ranges from 0.28 to 0.58 percent in the central stock and 0.33 to 1.88 percent in the dikes. MgO is slightly higher in the dikes

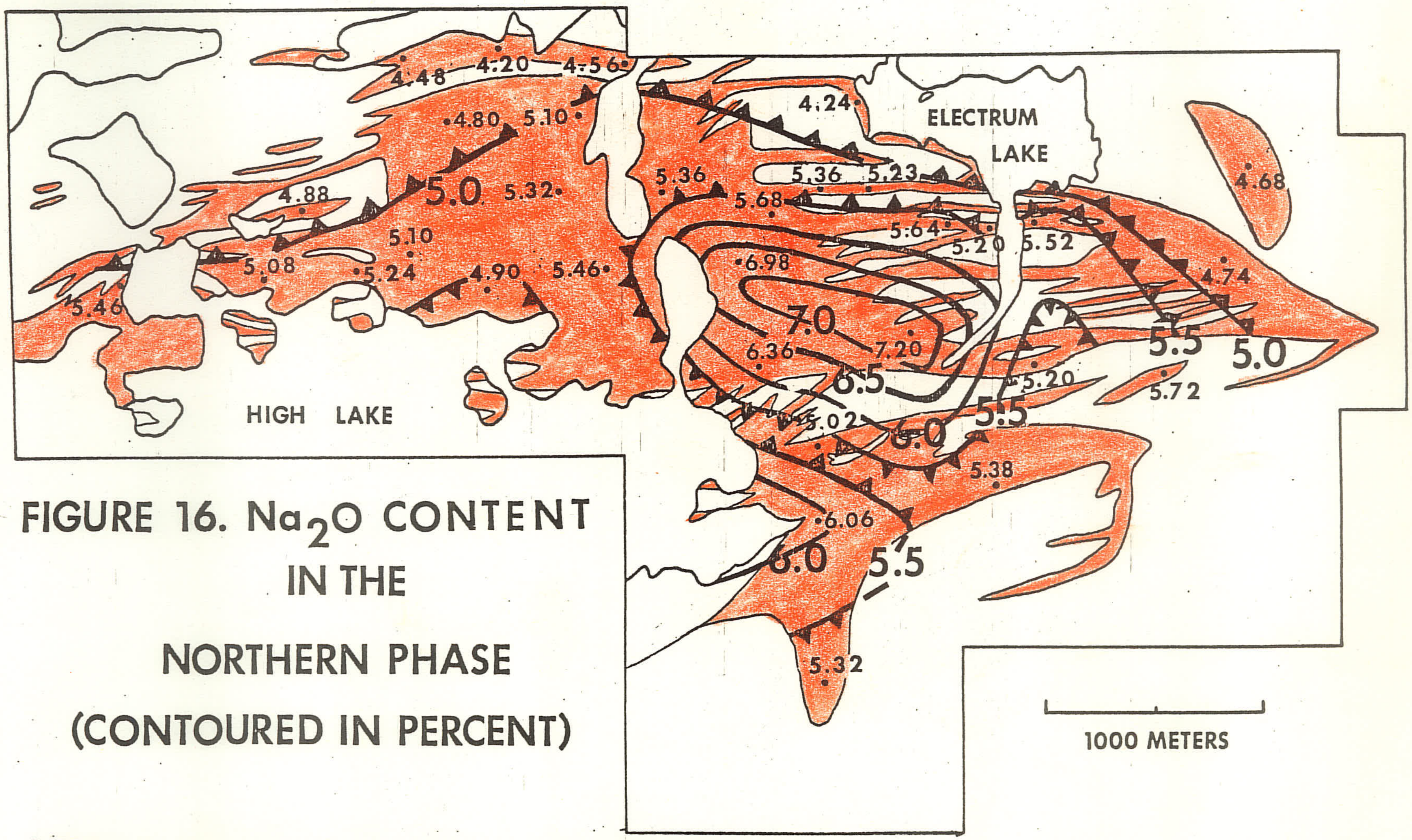


FIGURE 16. Na_2O CONTENT IN THE NORTHERN PHASE (CONTOURED IN PERCENT)

HIGH LAKE PLUTON, NORTHERN PHASE

ADJACENT ROCKS

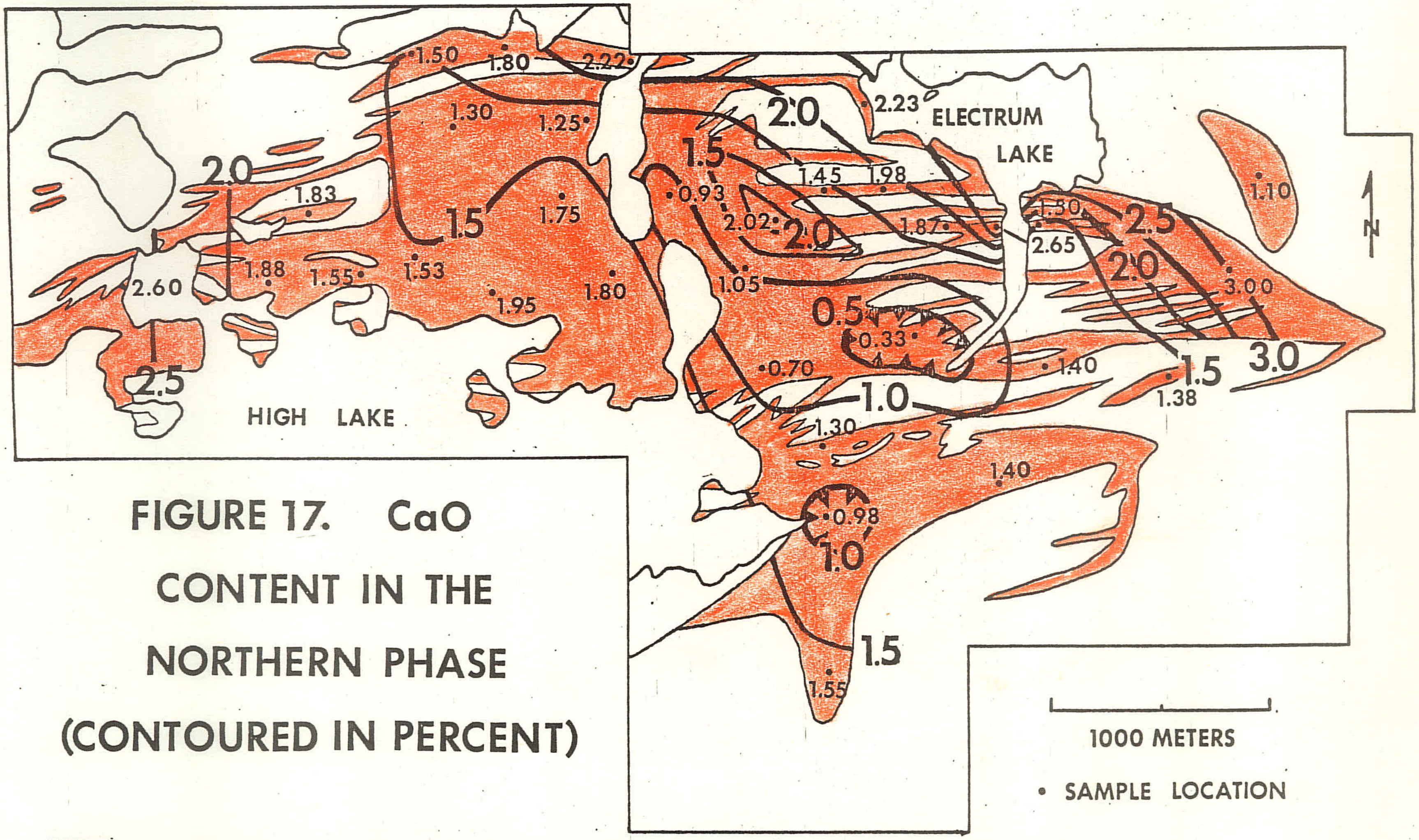


FIGURE 17. CaO CONTENT IN THE NORTHERN PHASE (CONTOURED IN PERCENT)

HIGH LAKE PLUTON, NORTHERN PHASE

ADJACENT ROCKS

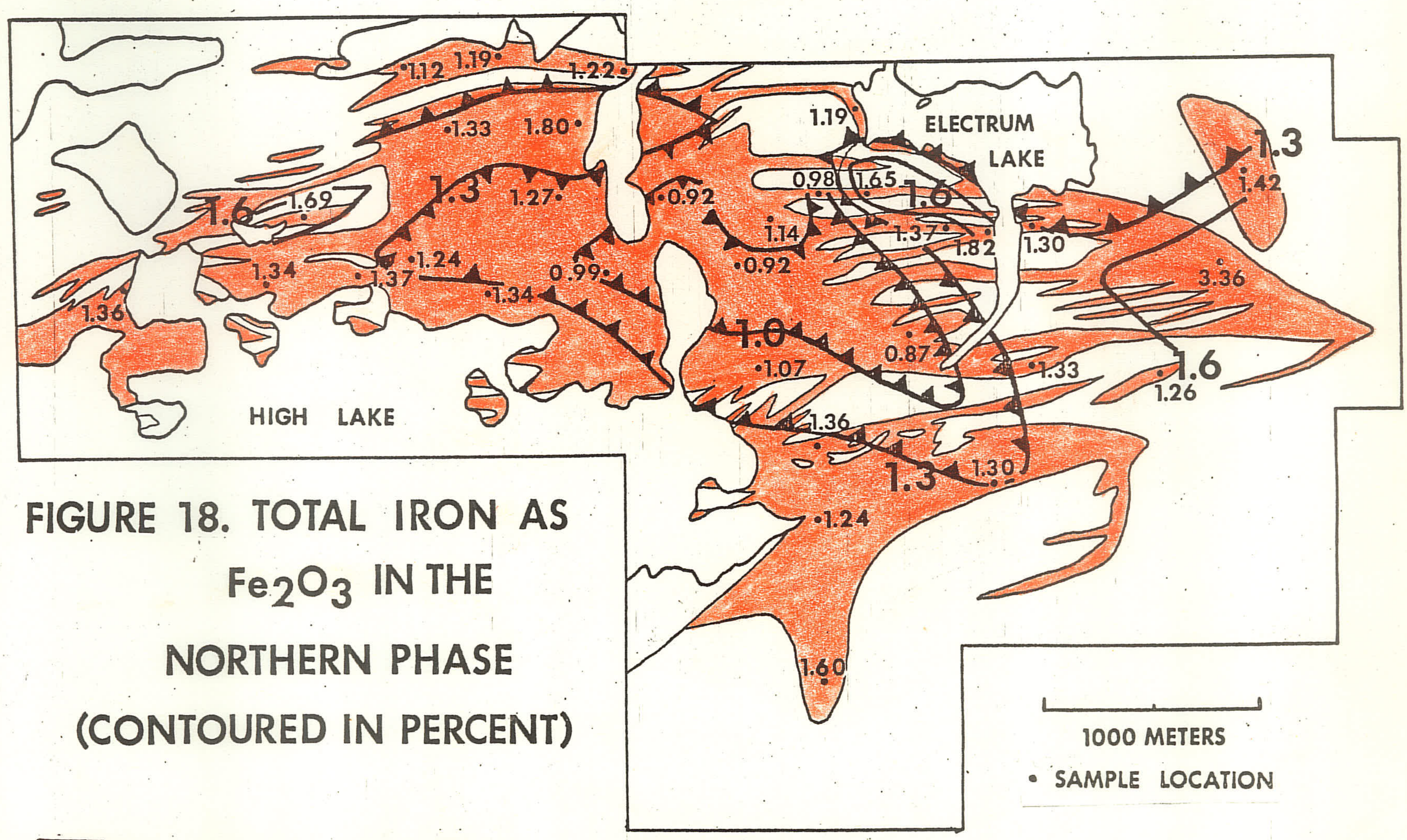


FIGURE 18. TOTAL IRON AS Fe_2O_3 IN THE NORTHERN PHASE (CONTOURED IN PERCENT)

HIGH LAKE PLUTON, NORTHERN PHASE

ADJACENT ROCKS

than in the stock (Appendix III), but shows no consistent variation within the pluton.

Copper values range from 7 to 2440 ppm. in the central stock and 7 to 61 ppm. in the dikes. Zinc values range from 6 to 24 ppm. in the central stock and 5 to 129 ppm. in the dikes. Average copper and zinc values in the pluton, excluding local anomalous areas, are 22 ppm. copper and 20 ppm. zinc. Anomalous values greater than 50 ppm. copper and 40 ppm. zinc are associated with mineral occurrences.

The triangular plot of K_2O - Na_2O - CaO (Figure 19) shows an overlap of sample points from the central stock and dikes. Average values for the stock and dikes show that the central stock has a higher total alkalis $(K_2O + Na_2O)/CaO$ ratio than the dikes. This relationship agrees with the increase in CaO content outward from the central stock (Figure 17).

Chemical Variations Across Selected Dikes

Variations of K_2O, Na_2O, CaO, total iron as Fe_2O_3 and MgO contents across the two sampled dikes in the eastern dike swarm are presented in Figure 20. The southern dike shows an increase in CaO content from dike center to margins in the eastern line. In the western line there is consistent increase across the dike from north to south. Na_2O content is highest at the center of the eastern line, and decreases from north to south across the western line. K_2O, total iron, and MgO contents generally increase from north to south. The distribution of oxides reflects internal variability in the dike. Increased total biotite abundance toward the southern contact (Appendix II) may account for, in part, variations in K_2O, total iron, and MgO.

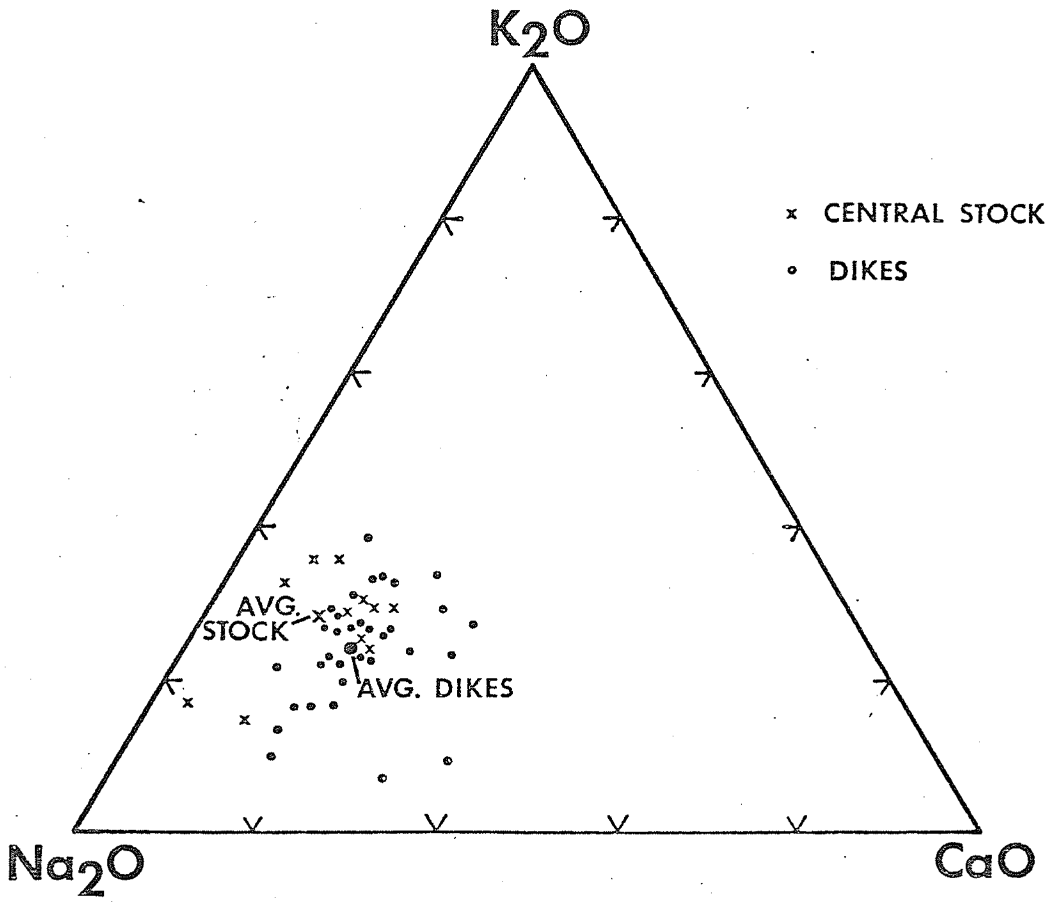


FIGURE 19. K_2O-Na_2O-CaO OF SAMPLES FROM THE NORTHERN PHASE

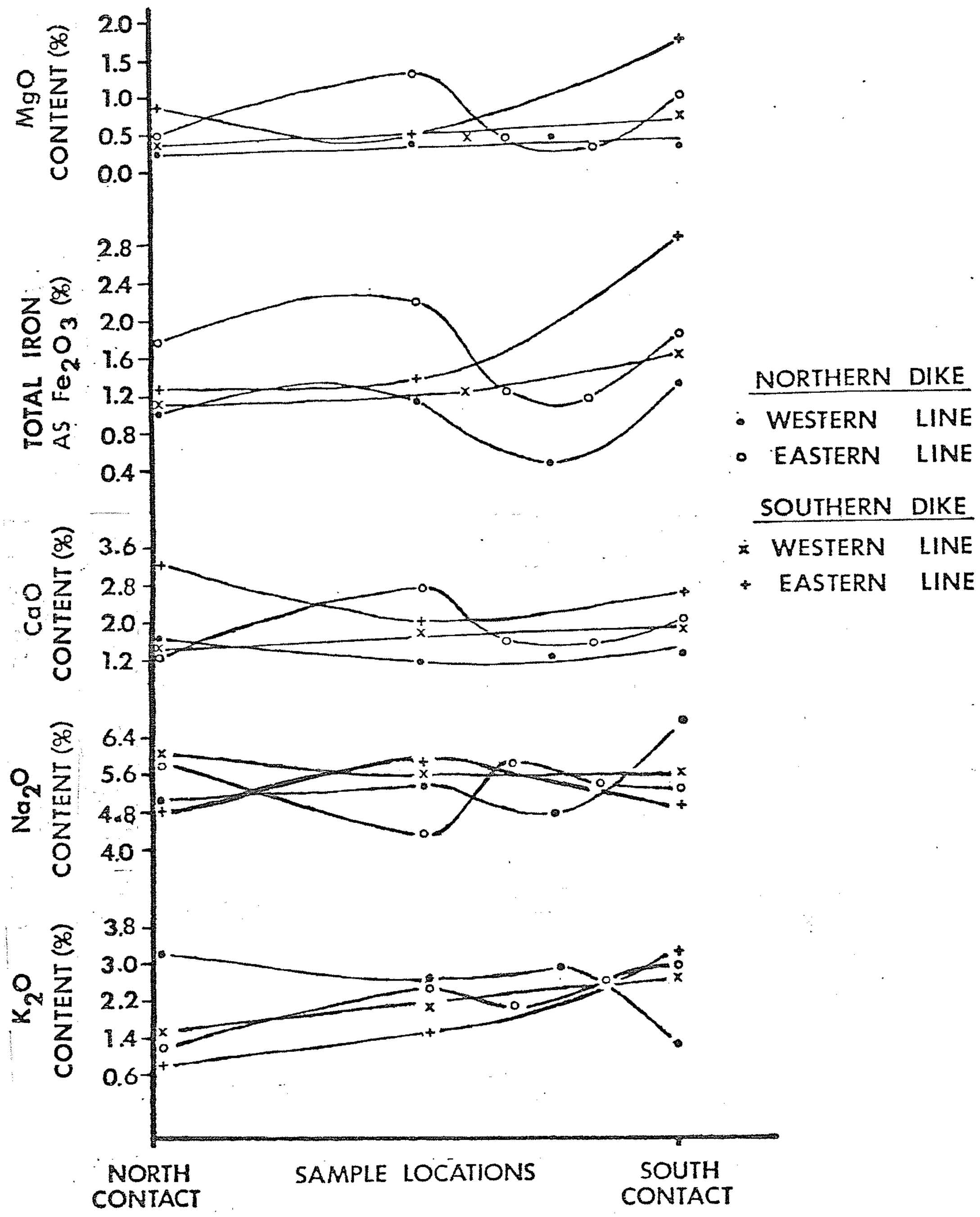


FIGURE 20. COMPOSITE GRAPHS OF CHEMICAL DATA FROM SELECTED DIKES

The eastern line of the northern dike is characterized by similar trends for CaO, K_2O, total iron, and MgO, showing highest percentages at the center of the dike. Na_2O shows the opposite trend. The western line shows a total iron distribution similar to that of the eastern line. However, all other oxides differ in their distributions. Na_2O and CaO have reverse trends in both lines, which reflects variation in plagioclase composition. Irregular distribution of oxides in the western line may be a result of primary mineralogical variation due to flow differentiation. However, consistent variation of oxides across the eastern line is similar to petrologic variations which were interpreted to be a result of a multiple dike (Figure 14).

Both dikes show an eastward increase in CaO, total iron, and MgO contents, but no apparent variation in K_2O or Na_2O contents was observed.

The triangular plot of K_2O - Na_2O - CaO (Figure 21) indicates the same compositional range as in Figure 19. But in both dikes, there is a systematic eastward decrease in the $K_2O + Na_2O$ (total alkalis) to CaO ratio. This agrees with the previously observed increase in CaO content from central stock to eastern dike swarm.

Petrogenesis of the Northern Phase

The northern phase of the High Lake pluton is characterized by porphyritic texture with a very fine-grained groundmass, sharp contacts with only minor assimilation, marginal chilling, abundant dikes peripheral to a central stock, and absence of late pegmatite dikes. Buddington (1959) has interpreted these characteristics to represent an epizonal environment of emplacement of the pluton. Emplacement of dikes in sharp contact with

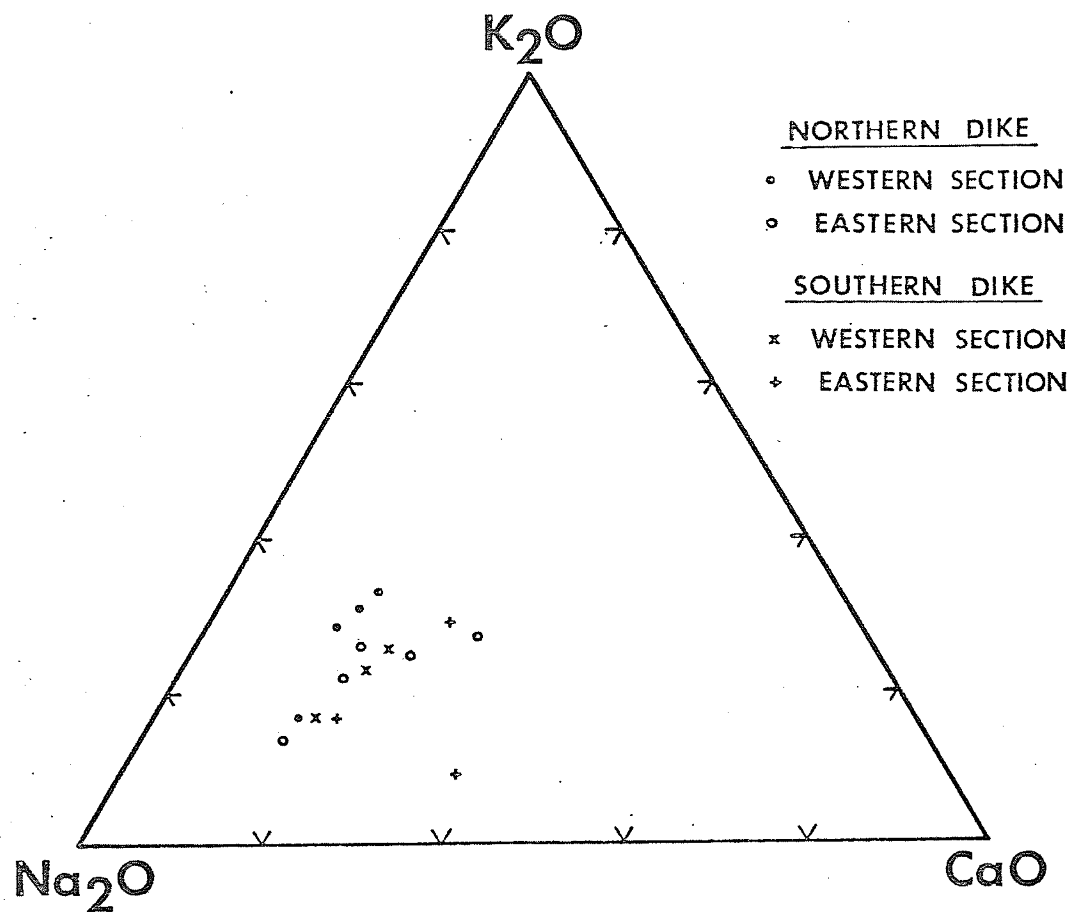


FIGURE 2 1. K_2O-Na_2O-CaO OF SAMPLES FROM SELECTED DIKES the country rocks suggests the mode of emplacement was by fracturing of the host rocks and subsequent intrusion. Further interpretation of the emplacement history can be made from variations in phenocryst content, groundmass content, and chemical patterns within the intrusion. Variations of these parameters are examined individually in the following sections.

The Effect of Tilting

As discussed previously, the Crowduck Lake Group has been tilted eastward to a near-vertical position, and the northern phase and country rocks were undoubtedly tilted also. Consequently, the present exposure of the pluton represents an oblique section through the northern phase probably exposing progressively higher levels of the intrusion to the east. However, it must be conceded that the true spatial orientation of the pluton in three dimensions is still unknown, and that the relationship between mineralogical textural and chemical variations and syn-emplacement levels within the pluton will be difficult to establish.

Interpretation of Variations in Phenocryst and Groundmass Abundances

The northern phase of the High Lake pluton is characterized by a porphyritic texture with a very fine-grained groundmass. This porphyritic texture is probably a result of slow crystallization of quartz, plagioclase, microcline, and biotite phenocrysts at depth within a magma chamber. A rapid rise of magma plus phenocrysts to an epizonal environment could result in faster crystallization and in the formation of the very fine-grained groundmass.

Quartz phenocryst abundance is characterized by a general concentric arrangement about a central area located at the eastern part of the central stock. The plagioclase phenocryst and groundmass patterns show a more restricted range in abundances in the central stock than in the dikes. The plagioclase/quartz phenocryst ratio shows a crude concentric pattern centered at the eastern part of the central stock. Two alternative explanations may be sought for this pattern: 1) the northern phase consists of a series of discrete magmatic pulses separated by short time intervals so that internal contacts between pulses are gradational. Each pulse is characterized by a slightly different abundance of phenocrysts and groundmass and by a changing ratio of plagioclase/quartz phenocrysts. The pulses were emplaced concentrically, and mineralogical variations reflect that form. Each pulse was probably concentrically emplaced pushing the previous pulse outwards. 2) Alternatively, the northern phase is a single intrusion with the mineralogical variations produced by local flow differentiation.

Interpretation of Variations in Chemical Data

The chemical patterns described in the previous chapter show the same concentric arrangement as that observed for the quartz phenocryst abundance and the plagioclase/quartz phenocryst ratio.

K_2O is more abundant stoichiometrically in K-feldspar than in biotite. However, variations in K_2O content probably reflect variations in total K-feldspar and biotite.

Na_2O and CaO are found in plagioclase. However, the distributions of Na_2O and CaO show little similarity with plagioclase phenocryst distribution (Figure 9). Furthermore, when the approximate percentage of plagioclase in groundmass is determined, Na_2O and CaO show little correlation with groundmass plagioclase distribution. Variations in

Na_2O and CaO must therefore reflect an increase in plagioclase composition outward from the eastern part of the central stock. Because the northern phase consists of magma that was differentiating at depth, the lowest plagioclase composition reflects the latest magma. Therefore, the eastern part of the central stock is later than the out parts of the dikes.

Total iron as Fe_2O_3 shows little similarity to the irregular distribution of biotite in the northern phase. However, iron variation may reflect variations in the iron content of biotite. Iron oxide, pyrite and epidote alteration may also affect the iron distribution.

Alternatively, secondary processes of metasomatism and/or metamorphism may have modified significantly the original chemical pattern. However, the degree to which the rock has been altered is moderate and the alteration assemblage represents simply a reorganization of elements rather than an addition of elements.

Interpretation of Variations in Groundmass Grain Size and in Total Alteration

Groundmass grain size (Figure 12) decreases away from the center of the pluton, but near the outer margin there is a reversal of this trend. The reduction in grain size in the central part may be related to a primary cooling effect. However, the outward increase in the margins is not consistent with a body whose marginal parts are undergoing more rapid cooling than the central portion. The distribution of total alteration (sericite + muscovite + epidote + clinoqoisite + carbonate) is characterized by a pattern (Figure 13) which displays a similar outward increase. Two possible interpretations can be placed on these marginal grain size and alteration variations. 1) Water present in the country rocks during emplacement of the northern phase may have been added during cooling of the pluton. Subsequent recrystallization and alteration could have been a cooling phenomenon.

2) Alternatively, these variations could be accounted for by a later metamorphic event occurring after consolidation of the pluton. In the latter case, the increase in grain size would be a recrystallization effect and the alteration would be metamorphic. Recrystallization of the margins of plagioclase phenocrysts and of groundmass, observed in the northern phase, may be interpreted as metamorphic.

CHAPTER 4

MINERAL OCCURRENCES

Introduction

In the course of the investigation, 35 of the 38 known mineral occurrences were examined. A summary of these showings is given in Table 2 (in pocket). A location map of all occurrences, their corresponding mineralization, and shear zones is given on Figure 22.

The sulphide minerals in their order of abundance are: pyrite, chalcopyrite, arsenopyrite, molybdenite, pyrrhotite, malachite, and azurite. Magnetite, gold, and silver are present locally. Pyrite and arsenopyrite occur as disseminated single euhedral to anhedral crystals in quartz veins, in shear fractures, and in tension fractures, whereas chalcopyrite and pyrrhotite occur as veinlets in quartz veins, in shear fractures, and in tension fractures. Malachite and azurite are weathering products of chalcopyrite. Molybdenite is found as thin films on shear and tension fracture surfaces and in quartz veins.

At the present time, none of the mineralization is of ore grade, but several mining companies have explored the High Lake - Electrum Lake area in the past. The mineral occurrences are widely distributed, but they all have a shear fracture, tension fracture, or quartz vein control. Figure 22 shows the relationship of mineral occurrences classified by mineralogy to the location of shear zones. The area of intense shearing south of Electrum Lake contains many of these occurrences.

Occurrence of Sulphide and Other Minerals

The mineralization in the northern phase and adjacent rocks can be classified into 3 groups according to different assemblages of sulphide

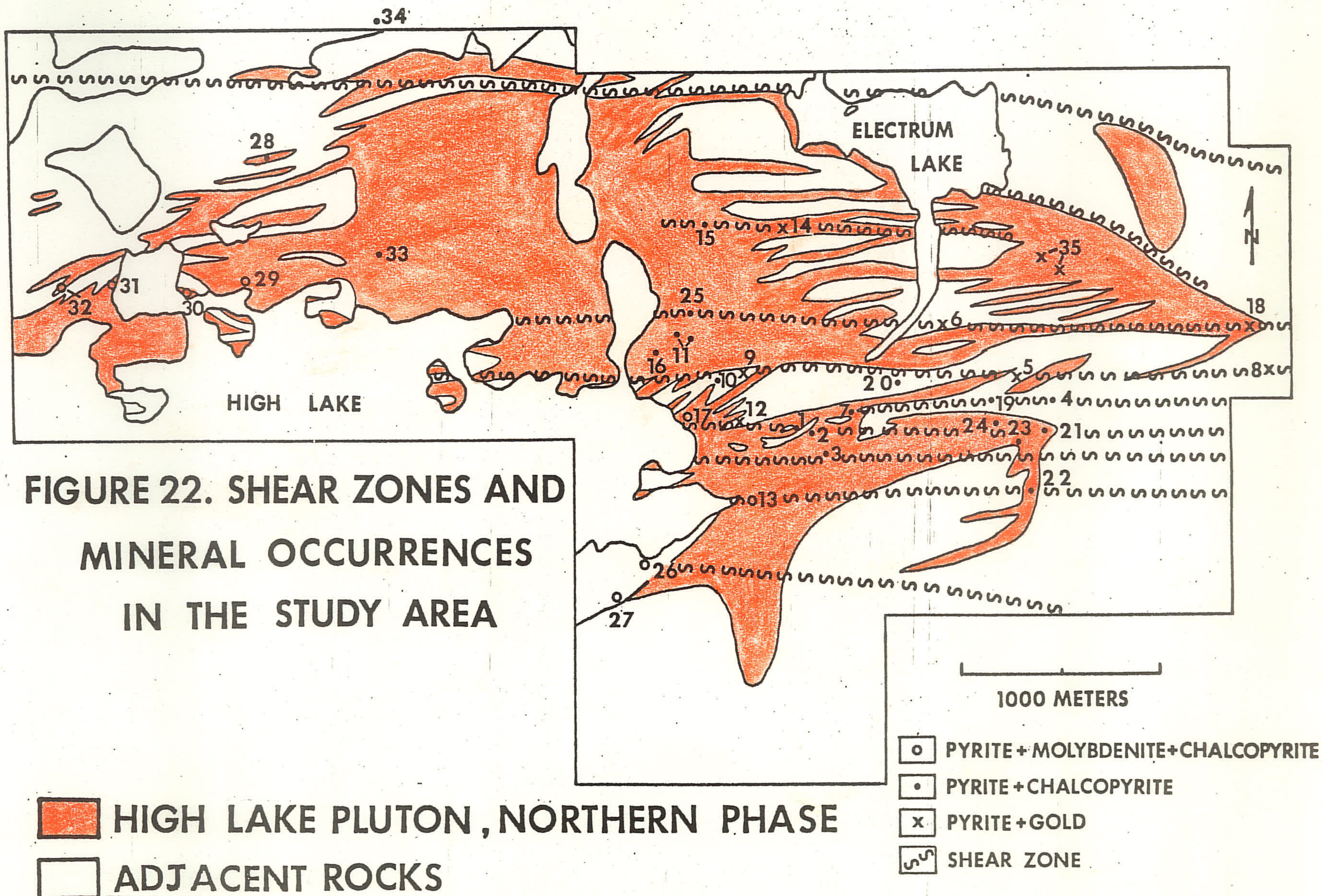


FIGURE 22. SHEAR ZONES AND MINERAL OCCURRENCES IN THE STUDY AREA

and precious metals:

1) Pyrite + molybdenite + chalcopyrite.
2) Pyrite + chalcopyrite.
3) Pyrite + gold.

Pyrite + molybdenite + chalcopyrite occurrences are found in quartz veins within shear fractures and within tension fractures oblique to shearing in the northern phase of the High Lake pluton. These occurrences are found also in quartz veins within fractures in the southern phase adjacent to the northern phase. The sulphide minerals occur as follows: pyrite as disseminations in veins, molybdenite as films on fractures in the veins, and chalcopyrite as irregular patches in the veins. All of these occurrences are found close to the northern phase - southern phase contact.

Pyrite + chalcopyrite occurrences, that contain minor magnetite and gold, occupy syn-deformational shear and tension fractures, which may have been early joints in both the northern phase and mafic metavolcanic country rocks. Pyrite, magnetite, and gold occur as disseminations in, or adjacent to fractures, and chalcopyrite forms massive veinlets. Mineralized quartz veins locally occur in the fractures. These occurrences are found in a zone that is 200 - 800 m from the northern phase - southern phase contact.

Pyrite + gold occurrences are found in quartz and quartz-tourmaline veins within shear fractures and within tension fractures in the northern phase, mafic metavolcanic rocks, and Crowduck Lake Group conglomerate. Pyrite occurs as disseminations and gold as microscopic disseminations in the veins. This group of occurrences is farthest from the northern phase - southern phase contact.

All mineralization occupies shear and tension fractures which post-date the northern phase and the unconformably overlying Crowduck Lake Group, and some is found in the marginal zone of the southern phase.

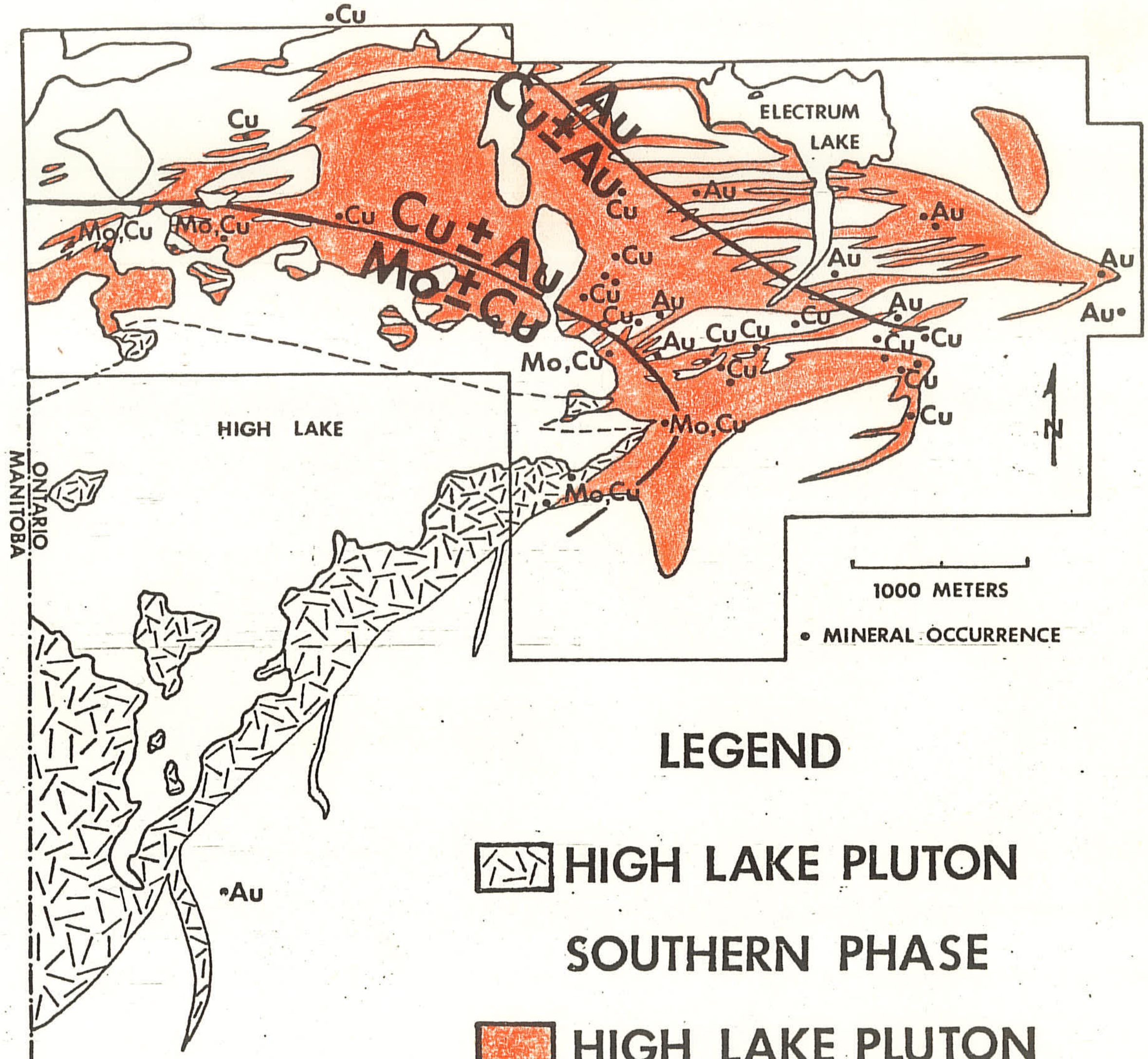
CHAPTER 5

GENESIS OF MINERALIZATION

Mineralization in the northern and southern phases is arranged in compositional zones with respect to the northern phase - southern phase contact (Figure 23): an inner zone of pyrite + molybdenite + chalcopyrite - bearing quartz veins occurring in and adjacent to the southern phase, an intermediate zone of pyrite + chalcopyrite veinlets and disseminations, and minor pyrite + chalcopyrite - bearing quartz veins, and an outer zone of pyrite + gold - bearing quartz-tourmaline veins occurring in both the northern phase and adjacent rocks. In places, the veins occur at the contact between the northern phase and mafic metavolcanic rocks or conglomerate.

Mineral zoning about the southern phase probably reflects a temperature gradient away from the southern phase (Park and MacDiarmid, 1970; Lowell and Guilbert, 1970). High temperature minerals would precipitate first and closest to the heat source, whereas low temperature minerals would precipitate last and farthest from it. Park and MacDiarmid (1970) state that molybdenite occurs in a higher temperature environment than gold. Stanton (1972) suggests that chalcopyrite has a wide range of temperatures of deposition and can occur with molybdenite or gold. The observed arrangement of minerals is consistent with these suggestions and with a decreasing temperature away from the southern phase. The elements may have originated from the southern phase or were remobilized from other rocks by the southern phase.

The contention of Davies (1965) and Kirkham (1972), that mineralization within the northern phase has a porphyry copper origin, now must be considered as doubtful. Despite the fact that the northern



LEGEND

HIGH LAKE PLUTON SOUTHERN PHASE

HIGH LAKE PLUTON NORTHERN PHASE

ADJACENT ROCKS

FIGURE 23. RELATIONSHIP OF MINERALIZATION TO THE SOUTHERN PHASE OF THE HIGH LAKE PLUTON

phase hosts the disseminated copper mineralization, this mineralization appears to be related instead to the intrusion of the southern phase and occurs in late shears and shear and tension fractures cutting the northern phase and Crowduck Lake Group. The absence of zonal pervasive alteration of the northern phase and of widespread disseminated mineralization (indicated by background copper content with the exception of mineral occurrences) suggest that the northern phase is not a porphyry copper deposit.

CHAPTER 6

SUMMARY OF INTERPRETATIONS

The emplacement of the High Lake pluton and its subsequent mineralization, as interpreted from this study, is as follows:

1) The central stock and dikes of the northern phase were emplaced into an epizonal environment by fracturing of the mafic metavolcanic host rocks and subsequent intrusion. Patterns of quartz phenocryst, plagioclase phenocryst, and groundmass abundances are attributed to emplacement of the northern phase by a continuous series of magmatic pulses.

2) Patterns of K_2O, Na_2O, CaO, and total iron generally reflect primary mineralogical variations.

3) The northern phase was exposed by a period of erosion which resulted in subsequent deposition of the Crowduck Lake Group.

4) The Crowduck Lake Group and older rocks were tilted and an oblique section through the High Lake pluton, overlain by the nearly vertical-dipping Crowduck Lake Group is now observed. A period of regional deformation resulted in development of an easterly-trending penetrative foliation, shear zones, easterly-trending shear fractures, and crosscutting tension fractures.

5) The age relations of the southern phase of the High Lake pluton with the deformational event are not known, but the lack of shearing in the southern phase suggests that it may have been emplaced during or after deformation.

6) Mineralization in the northern phase is zonally arranged with respect to the southern phase (the possible heat source) and appears to be related to a late stage of emplacement. The metals may have originated from the southern phase.

REFERENCES CITED

Buddington, A.F.
1959: Granite emplacement with special reference to North America; Geol. Soc. Am. Bull., Vol. 70, pp. 671-747.

Davies, J.C.
1962: Ewart Township, District of Kenora; Ontario Department of Mines, Preliminary Geological Map No. P.144.

1965: Geology of the High Lake-Rush Bay area, District of Kenora; Ontario Department of Mines, Geological Report No. 41.

Davies, J.F.
1954: Geology of the West Hawk Lake-Falcon Lake area; Manitoba Mines Branch, Publication No. 53-4.

Greer, L.
1931: Geology of the Shoal Lake (west) area, District of Kenora; Ontario Department of Mines, Vol. 39, Pt. 3.

Herz, N.
1970: Gneissic and igneous rocks in the Quadrilatero Ferrifero, Minas Gerais, Brazil; U.S.G.S. Prof. Pap. 641-B.

Hibbard, M.J.
1965: Origin of some alkali feldspar phenocrysts, and their bearing on petrogenesis; Am. Jour. Sci., Vol. 263, pp. 245-261.

Kirkham, R.V.
1972: Geology of copper and molybdenum deposits; Geol. Surv. Canada, Pap. 72-1, Part 1, pp. 82-87.

Lawson, A.C.
1885: Report on the geology of the Lake of the Woods region; Geol. Surv. Canada, Ann. Rept., Vol. 1, Pt. cc.

Lowell, J.D. and Guilbert, J.M.
1970: Lateral and vertical alteration-mineralization zoning in porphyry ore deposits; Econ. Geol., Vol. 65, pp.373-408.

Marmo, V.
1971: Granite petrology and the granite problem; Elsevier Publishing Co., New York, 244 p.

Park, C.F. and MacDiarmid, R.A.
1970: Ore Deposits; W. H. Freeman and Company, San Francisco, 522 p.

Parsons, A.L.
1912: Goldfields of Lake of the Woods, Manitou, and Dryden; Ontario Bureau of Mines, Vol. 21, Pt. 1.

REFERENCES CITED (cont'd)

Springer, G.D.
1952: Geology of Rennie-West Hawk Lake area; Manitoba Mines Branch, Publication No. 50-6.

Stanton, R.L.
1972: Ore Petrology; McGraw-Hill, New York, 713 p.

Vagt, G.O.
1968: The Tectonic Significance of Some Intrusive Rocks in the Kenora-West Hawk Lake area, Ontario; unpublished M. Sc. Thesis, University of Manitoba, Winnipeg, Manitoba.

Vance, J.A.
1961: Polysynthetic twinning in plagioclase; Am. Miner., Vol. 46, pp. 1097-1119.

Wilson, H.D.B., Brisbin, W.C., McRitchie, W.D., and Davies, J.C.
1972: Archean geology and metallogenesis of the western part of the Canadian Shield, Guidebook for Excursions A33 and C33, 24th International Geological Conference, Montreal, 63 p.

APPENDIX I

MODAL DATA FROM THE NORTHERN PHASE

	SAMPLE	% PHENOCRYSTS QUARTZ	PLAGIOCLASE	BIOTITE	K-FELDSPAR	% GROUNDMASS BIOTITE	QUARTZ FELDSPAR	% OPAQUES	% ALTERATION	An	PLAGIOCLASE/ QUARTZ PHENOCRYST RATIO
CENTRAL STOCK	25	6.0	47.5	-	-	0.2	40.0	6.3	3.6	30	7.1
	30	3.5	45.0	-	0.1	7.5	41.1	2.7	11.2	-	12.8
	120	9.5	48.5	-	0.3	1.1	40.4	-	2.1	29	5.1
	126	12.5	48.5	-	0.2	1.0	37.8	-	5.5	30	3.8
	127	7.8	46.2	4.6	-	4.8	46.6	-	1.6	32	5.9
	166	11.1	45.9	3.2	0.2	3.8	36.2	0.6	9.9	27	4.1
	167	13.2	44.1	0.6	1.5	2.4	38.1	0.1	6.7	30	3.3
	168	14.2	46.0	2.2	-	1.8	36.0	0.2	3.9	26	3.2
	169	12.1	44.3	1.7	3.3	1.7	36.4	0.5	3.2	28	3.6
	171	18.6	40.2	2.1	-	0.8	38.2	0.1	5.8	25	2.2
	172	20.8	44.9	-	-	2.9	31.2	0.2	9.0	24	2.2
DIKES	27	11.8	76.0	1.0	-	1.4	8.8	1.0	20.7	28	6.4
	75	12.1	57.6	0.5	-	2.3	27.3	0.3	12.8	28	4.7
	81	15.1	59.9	0.7	-	2.0	22.2	0.1	13.5	30	3.9
	94	21.3	35.2	-	-	0.4	43.4	0.1	22.6	34	1.6
	102	1.6	20.8	8.0	-	10.1	56.9	2.6	8.0	-	13.0
	106	16.6	43.4	-	-	4.7	28.1	-	7.2	-	2.1
	111	22.4	46.1	-	0.2	2.5	28.8	-	17.3	-	2.1
	113	8.8	60.7	-	-	1.1	29.4	-	19.6	37	6.9
	130	9.6	53.0	-	1.0	1.3	35.1	0.3	6.5	-	5.5
	137	12.2	60.1	-	0.2	0.3	27.2	-	14.7	39	4.9
	150	14.4	49.0	0.6	-	2.1	33.5	0.4	10.6	30	3.4
	154	11.9	29.4	-	0.4	3.2	54.8	0.3	24.7	-	2.5
	156	16.9	35.2	-	0.3	3.4	44.1	0.1	19.5	25	2.1
	159	3.6	42.4	3.8	0.1	2.5	47.5	0.1	3.8	30	11.8
	161	13.8	54.6	-	-	1.1	30.2	0.3	7.1	31	3.9
	163	15.2	47.5	0.5	0.2	4.6	31.8	0.2	3.7	29	3.1
	165	25.1	34.4	-	0.1	2.7	37.7	-	10.9	26	1.4
	170	15.0	44.6	-	1.4	2.4	35.6	1.0	4.8	24	2.9

alteration is not included in the modal percent

APPENDIX II

MODAL DATA FROM SELECTED DIKES

		% PHENOCRYSTS				% GROUNDMASS		%	%		PLAGIOCLASE/QUARTZ PHENOCRYST
	SAMPLE	QUARTZ	PLAGIOCLASE	BIOTITE	K-FELDSPAR	BIOTITE	QUARTZ FELDSPAR	OPAQUES	ALTERATION	An	RATIO
NORTHERN DIKE WEST LINE	1	7.0	43.0	1.0	0.1	1.0	48.5	0.4	8.4	31	6.1
	2	8.9	41.4	0.6	1.2	1.0	44.8	2.1	7.2	-	4.6
	3	17.4	41.9	-	-	0.9	38.7	0.2	10.8	28	2.4
	4	14.6	42.9	-	-	1.1	41.3	0.1	10.7	31	2.9
	5	20.5	43.1	-	-	2.5	33.2	0.2	4.9	30	2.1
NORTHERN DIKE EAST LINE	1	14.6	41.7	0.6	-	2.0	40.8	0.3	7.5	28	2.8
	2	18.5	45.7	-	-	1.5	34.3	-	8.4	28	2.5
	3	16.3	56.4	1.0	-	0.5	23.3	2.5	12.2	30	3.5
	4	11.0	60.3	0.4	-	2.6	25.0	0.7	17.6	-	5.5
	5	10.5	57.8	4.8	0.6	1.0	25.2	0.1	2.5	29	5.5
	6	14.0	57.4	0.5	-	-	28.0	0.1	13.5	29	4.1
	7	9.9	74.8	5.0	-	1.5	8.8	-	5.0	28	7.6
SOUTHERN DIKE WEST LINE	1	10.8	56.1	0.1	-	2.0	30.8	0.2	7.1	32	5.2
	2	10.6	55.7	2.4	-	0.7	30.4	0.2	11.3	35	5.2
	3	12.9	60.8	3.4	-	-	22.9	-	5.7	30	4.7
	4	14.8	80.1	0.2	0.6	0.5	33.7	0.6	12.0	29	5.4
	5	12.8	78.6	2.6	-	1.0	4.8	0.2	3.8	32	6.1
	6	11.5	57.6	3.4	1.2	4.0	22.1	0.2	1.5	36	5.0
SOUTHERN DIKE EAST LINE	1	13.2	41.2	0.8	-	2.0	42.7	0.1	3.6	31	3.1
	2	12.0	47.6	2.5	-	5.0	32.7	0.2	14.7	31	3.9
	3	15.1	52.1	0.5	-	2.0	29.5	0.8	13.2	30	3.5
	4	10.9	80.7	-	-	1.5	6.0	0.9	12.3	29	7.4
	5	14.7	71.6	4.0	-	1.0	8.7	-	13.3	27	4.9
	6	3.8	54.0	1.4	-	5.0	35.4	0.4	11.2	30	14.2
	7	1.4	53.7	1.0	-	5.0	38.8	0.1	5.4	31	38.9

alteration is not included in the modal percent

APPENDIX III

CHEMICAL DATA FROM THE NORTHERN PHASE

	SAMPLE	K_2O (%)	Na_2O (%)	CaO (%)	MgO (%)	TOTAL IRON AS Fe_2O_3 (%)	COPPER (ppm.)	ZINC (ppm.)
CENTRAL STOCK	25	3.40	6.36	0.70	0.28	1.07	2440	18
	30	2.42	5.68	2.02	0.53	1.14	22	24
	120	1.58	7.20	0.33	0.28	0.87	20	6
	126	3.32	5.36	0.93	0.30	0.92	30	9
	127	1.38	6.98	1.05	0.45	0.92	172	10
	166	3.36	5.10	1.25	0.58	1.80	12	12
	167	2.40	5.32	1.75	0.45	1.27	7	9
	168	2.98	5.46	1.80	0.35	0.99	8	9
	169	2.86	4.90	1.95	0.43	1.34	10	22
	171	2.88	5.10	1.53	0.33	1.24	52	7
	172	2.44	4.80	1.30	0.53	1.33	32	12
DIKES	27	1.92	6.06	0.98	0.40	1.24	61	48
	75	2.12	5.72	1.38	0.35	1.26	11	23
	81	2.64	5.38	1.40	0.45	1.30	12	24
	94	1.88	5.20	1.40	0.53	1.33	24	9
	102	2.32	4.74	3.00	1.88	3.36	12	68
	106	2.50	5.52	1.50	0.40	1.30	17	22
	111	3.26	4.24	2.23	0.45	1.19	28	129
	113	1.90	5.88	1.88	0.43	1.02	18	10
	130	3.94	5.02	1.30	1.03	1.36	49	35
	137	2.12	4.68	1.10	0.68	1.42	10	22
	150	2.48	5.32	1.55	0.58	1.60	18	28
	154	2.90	4.20	1.50	0.38	1.19	10	29
	156	2.30	4.48	1.80	0.45	1.12	10	26
	159	3.26	4.88	1.83	0.50	1.69	7	13
	161	2.04	5.08	1.88	0.33	1.34	30	6
	163	0.64	5.46	2.60	0.38	1.36	52	5
	165	2.12	4.56	2.22	0.58	1.22	7	12
	170	2.60	5.24	1.55	0.35	1.37	26	6

ANALYSES BY R. HILL (U. OF MANITOBA)

BY X-RAY FLUORESCENCE AND ATOMIC ABSORPTION

APPENDIX IV

CHEMICAL DATA FROM SELECTED DIKES

	SAMPLE	K_2O (%)	Na_2O (%)	CaO (%)	MgO (%)	TOTAL IRON AS Fe_2O_3 (%)
NORTH DIKE WEST LINE	1	3.18	5.02	1.64	0.33	1.06
	3	2.57	5.22	1.28	0.37	1.16
	4	2.68	4.73	1.36	0.47	0.42
	5	1.57	6.47	1.53	0.35	1.30
NORTH DIKE EAST LINE	1	1.12	5.85	1.28	0.49	1.76
	4	2.50	4.18	2.84	1.30	2.19
	5	2.03	5.63	1.70	0.43	1.24
	6	2.40	5.32	1.72	0.39	1.19
	7	2.42	5.18	2.38	0.98	1.86
SOUTH DIKE WEST LINE	1	1.43	6.00	1.57	0.41	1.14
	4	2.10	5.43	1.85	0.46	1.20
	6	2.50	5.50	2.18	0.72	1.60
SOUTH DIKE EAST LINE	1	0.77	4.83	3.23	0.82	1.26
	4	1.48	5.93	1.87	0.42	1.33
	7	3.05	4.85	2.85	1.66	2.86

ANALYSES BY R. HILL (U. OF MANITOBA)

BY X-RAY FLUORESCENCE AND ATOMIC ABSORPTION

DESCRIPTION OF MINERAL

OCCURRENCE	HOST ROCK	TREND	LENGTH	WIDTH	SULPHIDES PRESENT	% SULPHID IN ROCK
1	Porphyritic dike	094/65NE	3.0 m.	1.0 m.	Pyrite Chalcopyrite	5-20%
2	Porphyritic dike	060/68NE	1.8 m.	1.0 m.	Pyrite Chalcopyrite	2-3%
3	Porphyritic dike	074/78NE	1.8 m.	1.0 m.	Pyrite Chalcopyrite	5-10%
4	Conglomerate	082/75SE	6.0 m.	3.0 m.	Pyrite Pyrrhotite Chalcopyrite	10%
5	Basalt	100/75NE	1.8 m.	1.0 m.	Pyrite	1%
6	Basalt	110/83NE	15.0 m.	10.0 m.	Arsenopyrite Pyrite Chalcopyrite	5-10%
7	Basalt-dike contact	060/ ?	2.0 m.	1.2 m.	Pyrite	2-3%
8	Conglomerate	-	3.0 m.	1.2 m.	Arsenopyrite Pyrite	2-3%
9	Basalt	040/78NW	30.0 m.	10.0 m.	Pyrite Chalcopyrite	5-10%
10	Basalt	-	6.0 m.	1.5 m.	Pyrite Chalcopyrite	5%
11	Central stock	078/65NW	60.0 m.	30.0 m.	Chalcopyrite Pyrite	5%
12	Basalt	068/85NW	3.4 m.	1.2 m.	Pyrite	5-10%
13	Porphyritic dike	106/90	50.0 m.	1.8 m.	Molybdenite Pyrite Chalcopyrite	5-20%
14	Porphyritic dike	140/ ?	2.4 m.	1.2 m.	Pyrite	2%
15	Central stock	060/65NW	60.0 m.	6.0 m.	Pyrite Chalcopyrite	10%
16	Central stock	082/75NW	50.0 m.	15.0 m.	Chalcopyrite Pyrite	5%
					Molybdenite	

	[illegible] dike	[illegible]/90	3.0 m.	1.2 m.	Pyrite Chalcopyrite	5-10%
18	Porphyritic dike	082/80SE	3.4 m.	1.5 m.	Pyrite	5-10%
19	Conglomerate	88/90	3.4 m.	1.0 m.	Pyrite	5-10%
20	Basalt	-	1.8 m.	1.0 m.	Pyrite Chalcopyrite	2%
21	Porphyritic dike	074/90	2.4 m.	1.0 m.	Pyrite Chalcopyrite	5%
22	Porphyritic dike	070/75SE	2.4 m.	1.0 m.	Pyrite Arsenopyrite	5-10%
23	Porphyritic dike	070/90	1.8 m.	1.0 m.	Pyrite	5%
24	Porphyritic dike	062/78SE	3.0 m.	1.2 m.	Pyrite	5%
25	Central stock	085/85SE	1.8 m.	1.2 m.	Chalcopyrite Pyrite	10-15%
26	Southern phase	-	15.0 m.	1.5 m.	Pyrite Chalcopyrite Molybdenite	4%
27	Southern phase	048/85NW	6.0 m.	1.5 m.	Molybdenite Pyrite Chalcopyrite	3%
28	Porphyritic dike	-	3.0 m.	1.2 m.	Pyrite Chalcopyrite	25-50%
29	Porphyritic dike	082/80NW	1.6 m.	1.0 m.	Molybdenite Pyrite Chalcopyrite	2%
30	Porphyritic dike	075/80NW	2.1 m.	2.0 m.	Chalcopyrite Pyrite Arsenopyrite Molybdenite	2%
31	Porphyritic dike	105/78SW	1.8 m.	1.0 m.	Pyrite Molybdenite Chalcopyrite	2%
32	Basalt-dike contact	100/85NE	3.0 m.	1.0 m.	Chalcopyrite Molybdenite Pyrite	2%
33	Central stock	-	3.4 m.	1.2 m.	Pyrrhotite Pyrite Chalcopyrite	25-50%
34	Basalt	080/68SE	1.8 m.	1.2 m.	Pyrite	2-3%
35	Porphyritic dike Basalt-dike contact	105,160	45.0 m.	1.7 m.	Pyrite Pyrrhotite Chalcopyrite	10%

TABLE 2

OCCURRENCES IN THE STUDY AREA

ES	RELATIVE % OF EACH SULPHIDE	HABIT	ASSAYS	DISTANCE FROM NORTHERN PHASE
	99% Pyrite 1% Chalcopyrite	disseminated and shear-filling	-	-
	99% Pyrite 1% Chalcopyrite	disseminated and shear-filling	-	-
	99% Pyrite 1% Chalcopyrite	disseminated and shear-filling	-	-
	80% Pyrite 18% Pyrrhotite 2% Chalcopyrite	shear-filling	-	-
	100% Pyrite	quartz vein in shear	-	3 m.
	95% Arsenopyrite 4% Pyrite 1% Chalcopyrite	quartz vein in shear	50.0 gm./tonne gold and 38.4 gm./tonne silver over a 0.65 m. core length	-
	100% Pyrite	quartz vein	-	-
	80% Arsenopyrite 20% Pyrite	quartz vein	9.9 gm./tonne gold over a 2.0 m. width and 110 m. length	120 m.
	99% Pyrite 1% Chalcopyrite	shear-filling	4.8 gm./tonne gold over 7.3 m.	60 m.
	99% Pyrite 1% Chalcopyrite	shear-filling	-	30 m.
	70% Chalcopyrite 30% Pyrite	shear-filling	0.25-0.50% copper	-
	100% Pyrite	shear-filling	-	30 m.
	50% Molybdenite 45% Pyrite 5% Chalcopyrite	quartz vein in shear	52,000 tonnes of 0.68% molybdenite over a 360 m. length and a 12 m. width	-
	100% Pyrite	quartz vein	-	-
	98% Pyrite 2% Chalcopyrite	disseminated and shear-filling	8.0-10.0 gm./tonne gold over a 4.6 m. core length, and 0.63-0.94% copper over a 50 m. length, 1.6 m. width, and 33 m. depth	-
	80% Chalcopyrite 20% Pyrite	shear-filling	0.25-0.50% copper	-
	70% Molybdenite			

Pyrite Chalcopyrite	quartz vein		
Pyrite	quartz vein	-	-
Pyrite	shear-filling	-	30 m.
Pyrite Chalcopyrite	shear-filling	-	30 m.
Pyrite Chalcopyrite	shear-filling	-	-
Pyrite Arsenopyrite	shear-filling	-	-
Pyrite	disseminated and shear-filling	-	-
Pyrite	disseminated and shear-filling	-	-
Chalcopyrite Pyrite	shear-filling	0.25-0.50% copper	-
Pyrite Chalcopyrite Molybdenite	quartz vein	0.47% molybdenite and 0.64-1.60 gm./tonne gold over 0.72 m.	100 m.
Molybdenite Pyrite Chalcopyrite	quartz vein	-	50 m.
Pyrite Chalcopyrite	quartz vein	-	-
Molybdenite Pyrite Chalcopyrite	quartz vein	-	-
Chalcopyrite Pyrite Arsenopyrite Molybdenite	quartz vein	-	-
Pyrite Molybdenite Chalcopyrite	quartz vein	-	-
Chalcopyrite Molybdemite Pyrite	quartz vein	-	-
Pyrrhotite Pyrite Chalcopyrite	shear-filling	1.0% copper, 0.96 gm./tonne gold, and 1.28 gm./tonne silver over a 100 m. length and a 2.0 m. width	-
Pyrite	shear-filling	-	60 m.
Pyrite Pyrrhotite Chalcopyrite	quartz veins in tension fractures	4 zones averaging 46 m. long, 1.7 m. wide, and 71 m. deep, with 31,000 tonnes at an average grade of 9.9 gm./tonne	-