PETROLOGY AND GEOCHEMISTRY OF THE HERON LAKE STOCK, SUPERIOR PROVINCE, WABIGOON SUBPROVINCE, NORTHWESTERN ONTARIO

PETROLOGY AND GEOCHEMISTRY
OF THE HERON LAKE STOCK, SUPERIOR PROVINCE,
WABIGOON SUBPROVINCE, NORTHWESTERN ONTARIO

by

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SCOPE AND CONTENTS:

The Heron Lake Stock is a lenticular shaped, pretectonic granitoid complex intruding the Jutten metavolcanics of the Savant Lake Greenstone Belt, Wabigoon Subprovince, Superior Province.

Mapping, petrography, and chemical analyses revealed that the stock is essentially trondhjemitic, with minor quartz diorite, granodiorite and quartz monzonite.

The trondhjemites have undergone a high degree of sericitization and saussuritization. The granodiorite unit is characterized by secondary K-feldspar and the quartz monzonites are characterized by perthite formation as a result of K-autometasomation in the late stage potash-rich fluids. Late faulting has imposed a secondary foliation along the stock's southern boundary.

K/Rb ratios suggest partial melting of lower crust/upper mantle material producing a trondhjemitic magma. Chemical variation diagrams suggest a process of magmatic differentiation and fractional crystallization.

ACKNOWLEDGEMENTS

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CHAPTER I

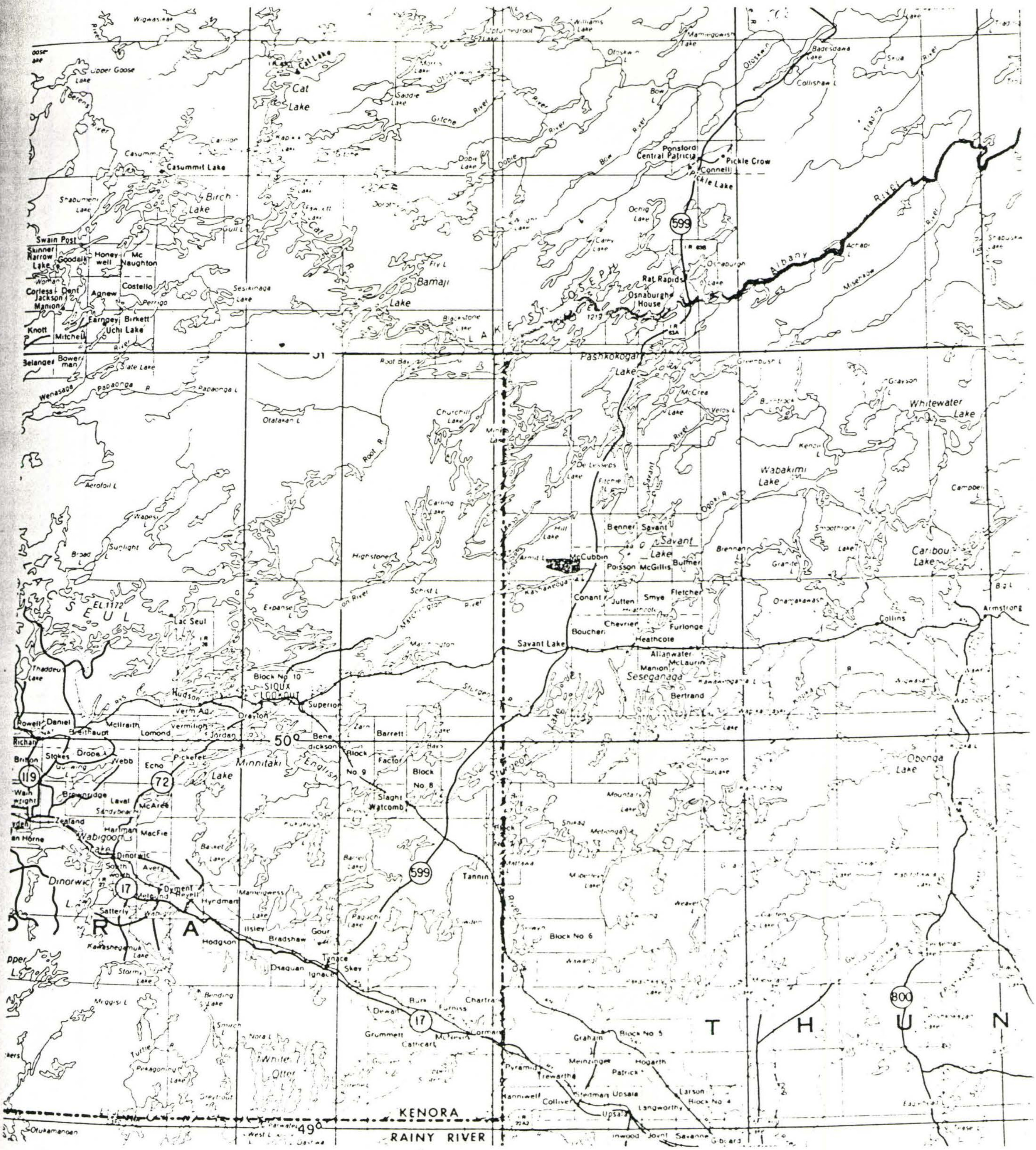
INTRODUCTION

1. Location and Accessibility

The Heron Lake Stock intrudes a sequence of mafic to intermediate metavolcanics which form part of the Savant Lake Greenstone Belt, which itself is a part of the Wabigoon Subprovince, Superior Province of the Canadian Precambrian Shield. The stock does however lie near or almost at the contact of the two subprovinces and was obviously injected along this structurally weak contact zone. The map area lies within the District of Thunder Bay and can be located on Map 2169, Sioux Lookout-Armstrong Sheet, Geological Compilation Series (Davies, et al., 1968). It can also be seen in the location map (Figure 1).

The stock itself is bounded by latitudes 50^{o} 25' N and 50^{o} 28' N, and longitudes 90^{o} 39' W and 90^{o} 48' W. The overall form of this granitic body is lenticular with the long axis trending generally parallel to the foliation of the country rock (east-west). It's length is approximately 11.6 km and the short axis trending north to south has a maximum length of 4.2 km.

The map area is situated 23 km north of Savant Lake, which is located at the junction of the Canadian National Railways and Highway 599, and is approximately 145 km north from where Highway 599 meets the Trans Canada Highway. The stock can easily be reached by float plane from Savant Lake or by driving north along Highway 599; then west along a dirt



Scale: 1 inch to 25 miles

Figure 1: Location Map (shaded area, Heron Lake Stock)

road just south of Wiggle Creek, which leads to Kashaweogama Lake, from where it can be reached by water transport.

2. Previous Work

The Heron Lake Stock was first mapped by Bond (1975), while he was carrying out the detailed mapping (1 inch to 1/4 mile) of McCubbin, Poisson and McGillis Townships. Prior to this Davies, et al. (1968), showed it to be part of a larger batholith to the northwest. The presence of a stock is also suggested by the contours of Aeromagnetic Map 1119 G (Airborne Magnetic Survey, 1961), which indicates an elongated anomously low body bounded to the north, south and east by iron formation and to the west by gneissic terrain. Only the area east of and including Heron Lake has previously been mapped in any detail and that was by Bond (1975).

3. Statement of Problem

In July, August and September of 1976, while under the employment of the Ontario Division of Mines, the author spent several days investigating the study area.

The purpose of the project was to produce a detailed map (1 inch to 1/4 mile) of the area indicating the internal structure of the stock and showing the distribution of various rock types. It was also hoped to establish the contact between the stock and the enclosing metavolcanics and metaconglomerate.

Roughly two hundred and fifty samples were taken and stained with sodium cobaltonitrate, to determine potassium feldspar percentage.

Of these, forty-seven representative samples were selected for thin section analysis and to aid in distinguishing differentiation patterns and chemical variations, and twenty-eight were prepared for chemical analysis.

The stocks' internal structure and that of the surrounding rocks was delineated by structural measurements made in the field.

4. Method of Mapping and Sampling

In the eastern and southern portions of the stock where landforms and outcrops were distinguishable from air photos (1 inch to 1/4 mile), a method commonly referred to as outcrop hopping was employed. Here, exposure was about 5 to 7 percent and it was rather easy to keep control so individual lines were run from outcrop to outcrop.

In the north and northwest the area was low-lying and commonly swampy. Exposure was poor (less than 3 percent) and difficult to distinguish on air photos. As such, traverses were run in straight lines towards control points, which were few in number.

The location and extent of the outcrops visited can be seen on the detailed map of the area (Plate 1). A sample locality map (Plate 2) indicates the location of the various samples upon which modal and chemical analysis was carried out.

The letter following a sample number is indicative of the extent to which that rock type occurs in an outcrop. That is a sample marked A would be the most common phase in an outcrop; B second most, etc.

CHAPTER II

GENERAL GEOLOGY

1. Regional Geology

The Savant Lake area was first visited by Moore in 1929. Later workers included Rittenhouse (1936) and Skinner (1969), both of whom established the main lithologic units and set up their own nomenclature for the various formations. However these earlier workers felt that the area was dominated by a single major synclinal fold and based their stratigraphic sequence on this. The most recent mapping in the area indicates that the folding is quite complex, and that it would be better to use an informal lithological grouping, rather than a formal stratigraphic legend (Bond, 1975). The following regional picture is summarized exclusively from Bond (1975), unless otherwise stated.

The oldest rocks in the area are mafic to intermediate metavolcanic, forming a sequence which may be as thick as 30,000 feet (9,140 m). These metavolcanics are basaltic to andesitic in composition and composed largely of pillow lavas and subsidiary massive flows that accumulated in a subaqueous environment. Overlying them is a succession of felsic to intermediate metavolcanics composed largely of a heterogeneous accumulation of medium to coarse pyroclastic material, which forms a succession that may be up to 11,000 feet (3,350 m) thick. The relationship between the two sequences is largely obscured by faulting.

Erosion following this volcanogenic period gave rise to a proximally derived metaconglomerate overlain by a thick sequence of greywacke, siltstone and cherty metasedimentary deposits. During the early history of sedimentation of these finer metasediments, iron formation was deposited as integral syngenetic units, and just north of the Heron Lake Stock it is present in possibly economic concentrations. Minor gabbroic sills were later intruded into the metasediments. These metavolcanics and metasediments have been metamorphosed to the greenschist facies regionally and to the amphibolite facies near the larger felsic intrusives.

A major orogenesis occurred towards the end of the Archean, at which time the rocks were faulted, folded and metamorphosed, with the contemporaneous intrusion of felsic plutonic batholiths and stocks of various ages. The oldest and the most highly metamorphosed is the Heron Lake Stock. Younger felsic intrusives occur throughout the area and are circular to elliptical in shape, with compositional variations from granodioritic to quartz monzonitic.

The relationships between the Savant Lake Greenstone Belt, the Wabigoon Subprovince and the granites and gneisses of the English River Subprovinces are described by Davies, et al. (1968) and Skinner (1969). A more recent compilation map of the area was prepared by the Ontario Division of Mines over the summer of 1976 and is presently in press (Breaks, personal communication). It was made available to the author and shows much more clearly the regional picture.

Faulting has affected the area to varying degrees. Minor local transverse faults with displacements of 0.5 m to 2.0 m are common and probably accompanied the major folding. They are generally clean, sharp faults with no associated shearing or silicification (Bond, 1975). Several major faults do exist and were first described by Rittenhouse (1936). Their trend is generally northeast and intense shearing is associated with them. One of them, which shall be discussed later is the Kashaweogama Lake Fault.

2. Structure

i) Internal Structure

Foliation is the main internal structural element observed in the field and generally has a NW trend. It is most prominent west of Heron Lake and increases in intensity towards the northwestern portion of the stock. Generally it is parallel to subparallel to that of the regional trend. East of Heron Lake the outcrops are essentially massive and foliations are rare to absent. Dips are vertical or steeply inclined rarely as low as 55^{o}. Only the quartz diorite unit is unfoliated. The quartz monzonite exhibits a very weak foliation, probably as a result of its very leucocratic nature. In general, the foliation observed is produced by the planar alignment of the micas, biotite and chlorite.

A secondary foliation trending ENE has developed along the southern boundary of the stock, probably in response to the Kashaweogama Lake Fault which cuts through this part of the stock and also trends in this direction. Minor ENE trending shear zones are quite common here and occasionally quartz augens were observed.

Lineations were observed in a few localities. East and northeast of Heron Lake quartz forms sublineated lenticles which stand up in moderate relief. They generally exhibit an ESE trend with a sub-vertical plunge.

In the northwestern portion of the stock several mineral lineations were obtained. They exhibited a NW trend with a shallow plunge of 10^{0} to 20^{0}.

ii) Contacts with the Supracrustals

Along seventy-five percent of its boundary the stock is in contact with amphibolite. Although no actual contact between the two was observed, amphibolite outcrops near the boundary were commonly contorted and had numerous trondhjemitic dikes crosscutting through them.

The contact with the conglomerate in the south is much more difficult to discern, mainly because of the high proportion of granitoid clasts in this unit.

The author has shown the Kashaweogama Lake Fault as forming the southern boundary and separating the intrusive from the conglomerate. Earlier workers (Davies, et al., 1968; Skinner, 1969) showed a similar relationship. Bond (1975) used the fault contact to explain a complete reversal of facing of map units in this area. That is, the mafic to intermediate metavolcanics have tops north, while the metasediments north of Kashaweogama Lake have tops south. He has the fault ending against the felsic intrusive at Heron Lake, but recently extended it to continue along the south boundary of the intrusive itself (personal communication). It should be pointed out that the conglomerate itself has been highly sheared. This will be discussed in more detail later.

CHAPTER III

PETROGRAPHY

1. Modal Analyses

Approximately 500 points were counted on each thin section. This was deemed sufficient because according to Van der Plas and Tobi (1965), the error involved would be only ±4%, and counting twice as many points would only reduce the error by ±1%. To aid in the point counting, thin sections were stained for potassium feldspar. Using these modal analyses (Table VI), plagioclase, alkali feldspar and quartz were plotted (Figure 2), according to Streckeisen (1973). This diagram, when supplemented with textural evidence and colour index (Figure 3), provided the basis for the classification of various phases within the stock.

Modal variations of the major rock units have been illustrated in Table I.

2. Phase Descriptions

i) Country Rock

(a) Amphibolite

As mentioned before amphibolite is the predominant country rock surrounding the stock. In the field it is fine grained with a dark yellowish-green to black weathered surface. Occasionally amygdules

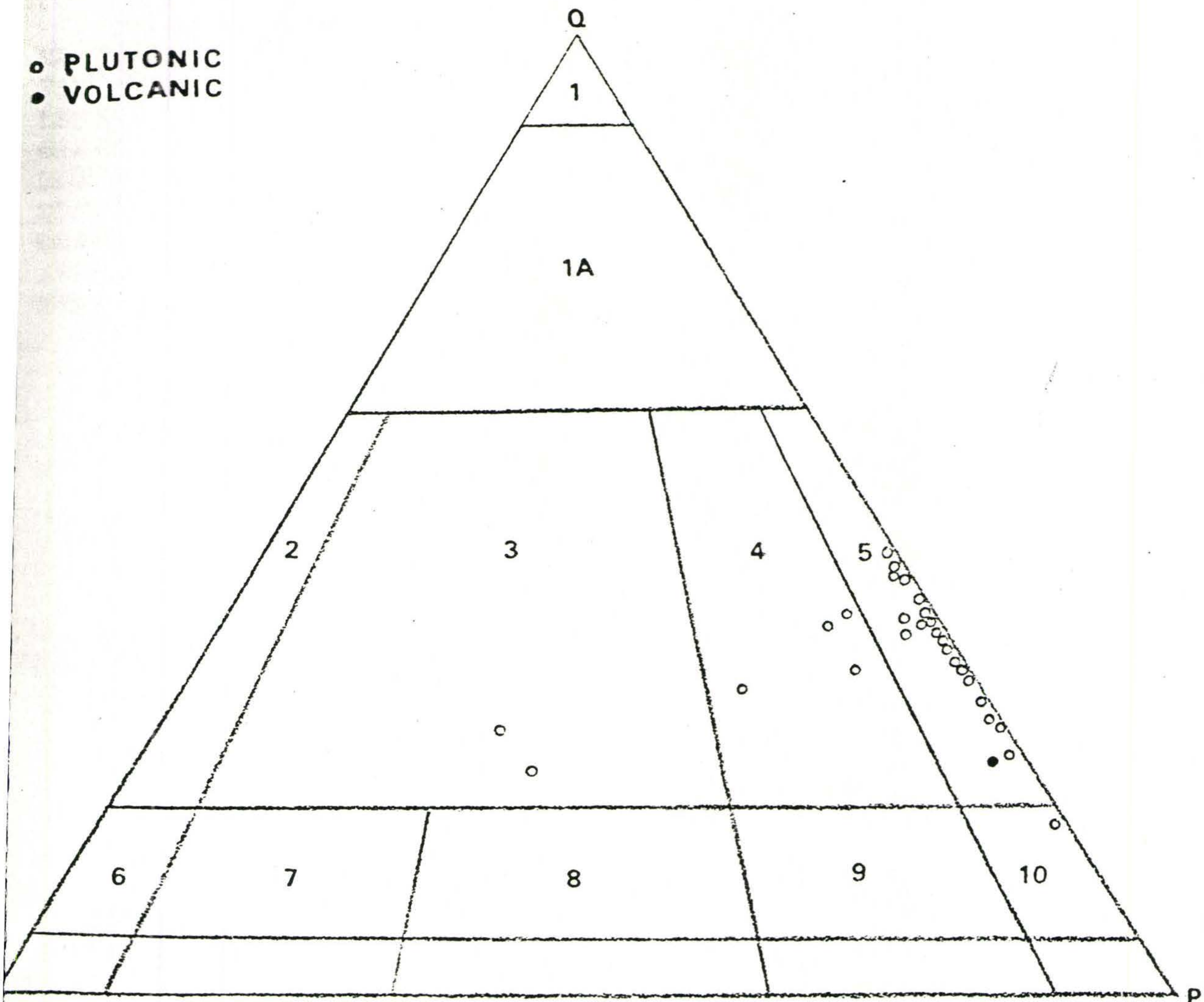


Figure 2: Quartz-Alkali feldspar-Plagioclase Diagram (IUGS, 1973)

1. Quartzolite
1A. Quartz-rich granitoids
2. Alkali-feldspar granite
3. Granite
4. Granodiorite
5. Tonalite
6. Alkali-feldspar quartz syenite
7. Quartz syenite
8. Quartz monzonite
9. Quartz monzodiorite
10. Quartz diorite

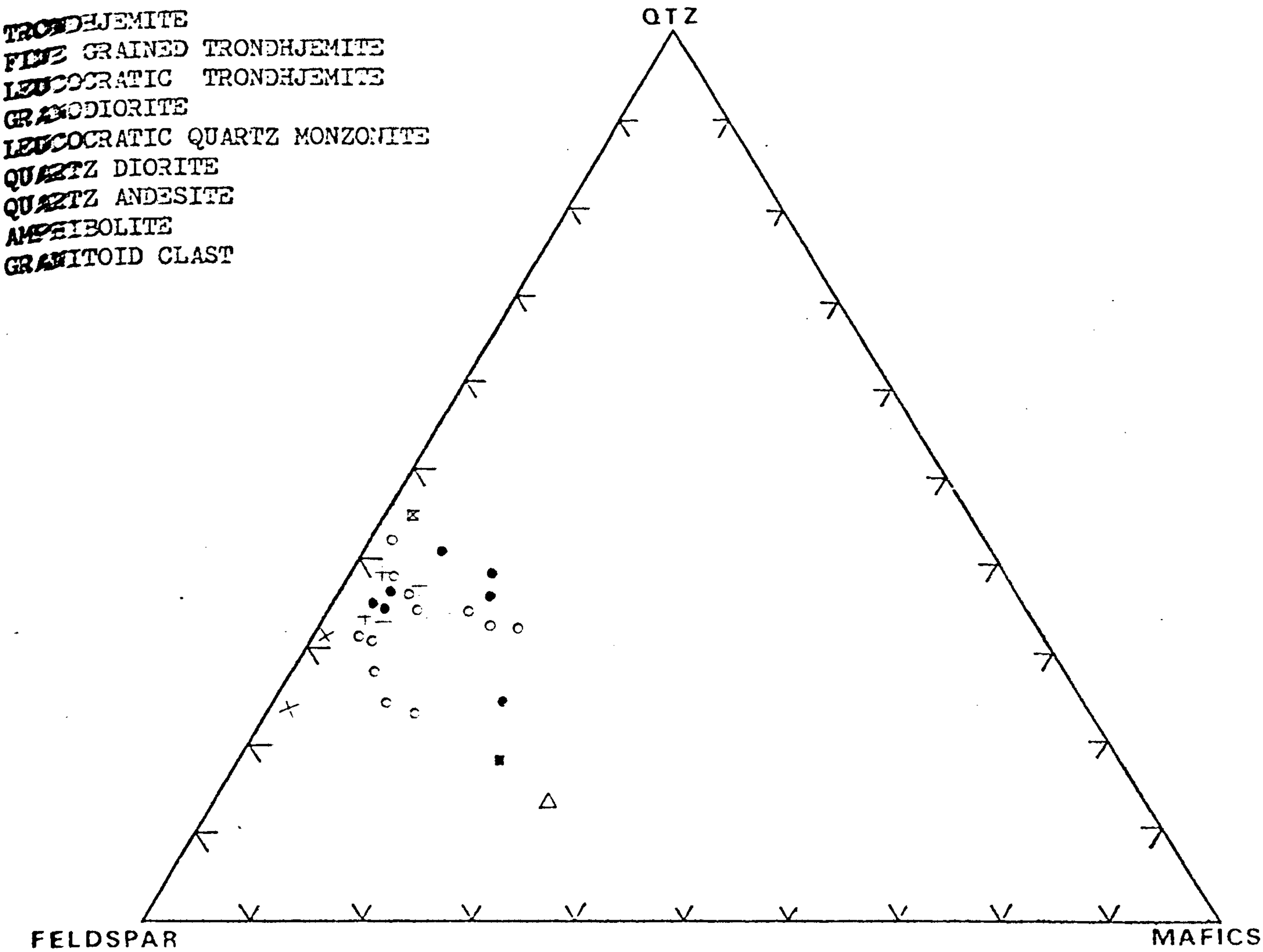


Figure 3: Quartz-Total feldspar-Total Mafic Diagram

infilled with quartz were observed and northeast of the stock contorted pillows were present. One sample was examined, RK-10-13.

Amphibolite xenoliths were commonly found throughout the stock (Figure 4). They ranged in shape from circular to lenticular and in size from a couple of metres in diameter to almost 500 metres. Two samples from the larger xenoliths were examined; RK-7-35 and RK-5-27. Where observed, the contacts between these inclusions and the stock were sharp. Trondhjemitic veins and dikes commonly crosscut these xenoliths.

In thin section this unit is holocrystalline and exhibits an allotriomorphic to hypidiomorphic granular texture.

Green to greenish-brown hornblende and minor green actinolite are the main minerals in this unit. They form subhedral, tabular to lath-like grains which generally are randomly orientated and contain minute opaque inclusions. Anhedral plagioclase laths exhibiting pericline and carlsbad twinning are interstitial to the amphiboles. They generally exhibit a weak parallelism and have been saussuritized to a minor degree. Quartz is only found in the two inclusion samples where it occurs in minor amounts as minute anhedral granules interstitial to the amphiboles. Epidote, a minor constituent in the inclusions, comprises up to 13% of the country rock sample. Here it occurs as highly birefringent, granular to columnar aggregates. Opaques are a common accessory.

(b) Conglomerate

The metaconglomerate (Figure 5) along the southern boundary of the intrusive is dominated by granitoid boulders (up to 45%) and forms

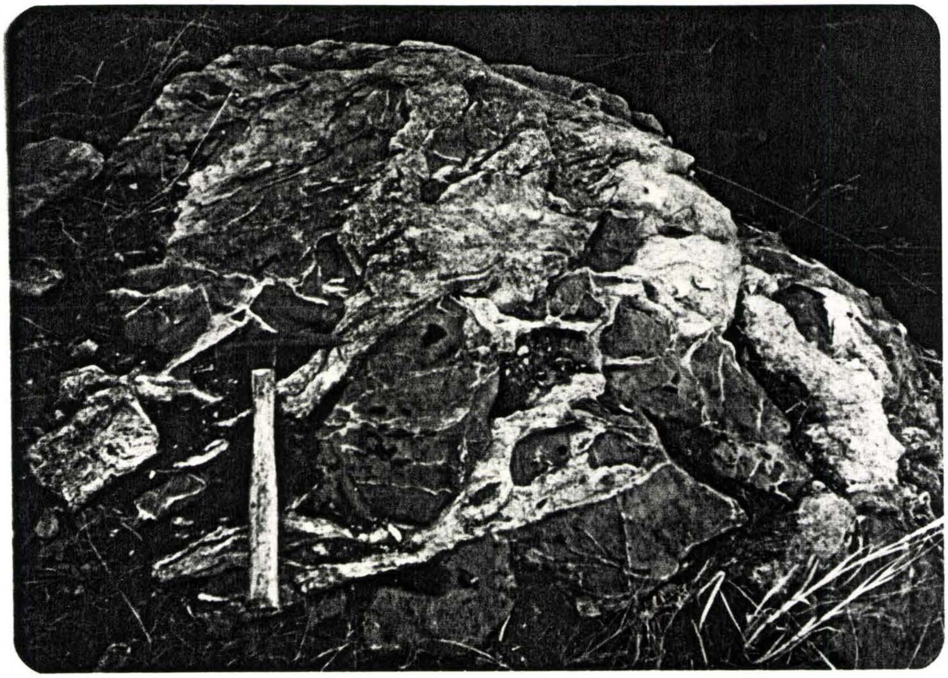


Figure 4: Mafic inclusion crosscut by trondhjemitic dikes, west of Curlew Lake

Figure 5: Typical conglomerate exposure southeast of Heron Lake

a unit which reaches a maximum width of 250 feet. Besides granitoid boulders there are also felsic to intermediate metavolcanic, mafic metavolcanic, dioritic and minor chert boulders. Matrix varies from 5 to 15%.

The granitoid clasts are essentially a medium grained trondhjemite. Although some of them are subrounded to subangular (Figure 6), most have been tectonically flattened (Figure 7). Their long axis ranges in size from 12 cm to 120 cm and their short axis from 2 cm to 45 cm. The most common size is about 40 cm by 15 cm. As these are the most competent of the clasts they have been least affected by the faulting.

The felsic to intermediate clasts (20-30%) are generally smaller than the granitic clasts (30 cm by 8 cm) and have been stretched more. However their boundaries are still distinguishable and they weather out with respect to the matrix.

Least competent are the mafic clasts (20-25%). They are highly stretched and generally wrap around the more competent felsic extrusive and intrusive clasts. Although they weather green, they do not weather out with respect to the matrix and as such their form is often difficult to distinguish. Dioritic and cherty clasts are present in minor amounts.

The matrix which weathers a greenish-gray was found by Bond (1975) to be a greywacke containing coarse grained, partially granulated quartz (2-3 mm) and plagioclase (Figure 8). Both were subangular suggesting a short history of transportation and deposition. Skinner (1969) found the matrix to be schistose and highly chloritic. In the field it appeared that the amount of quartz in the matrix and

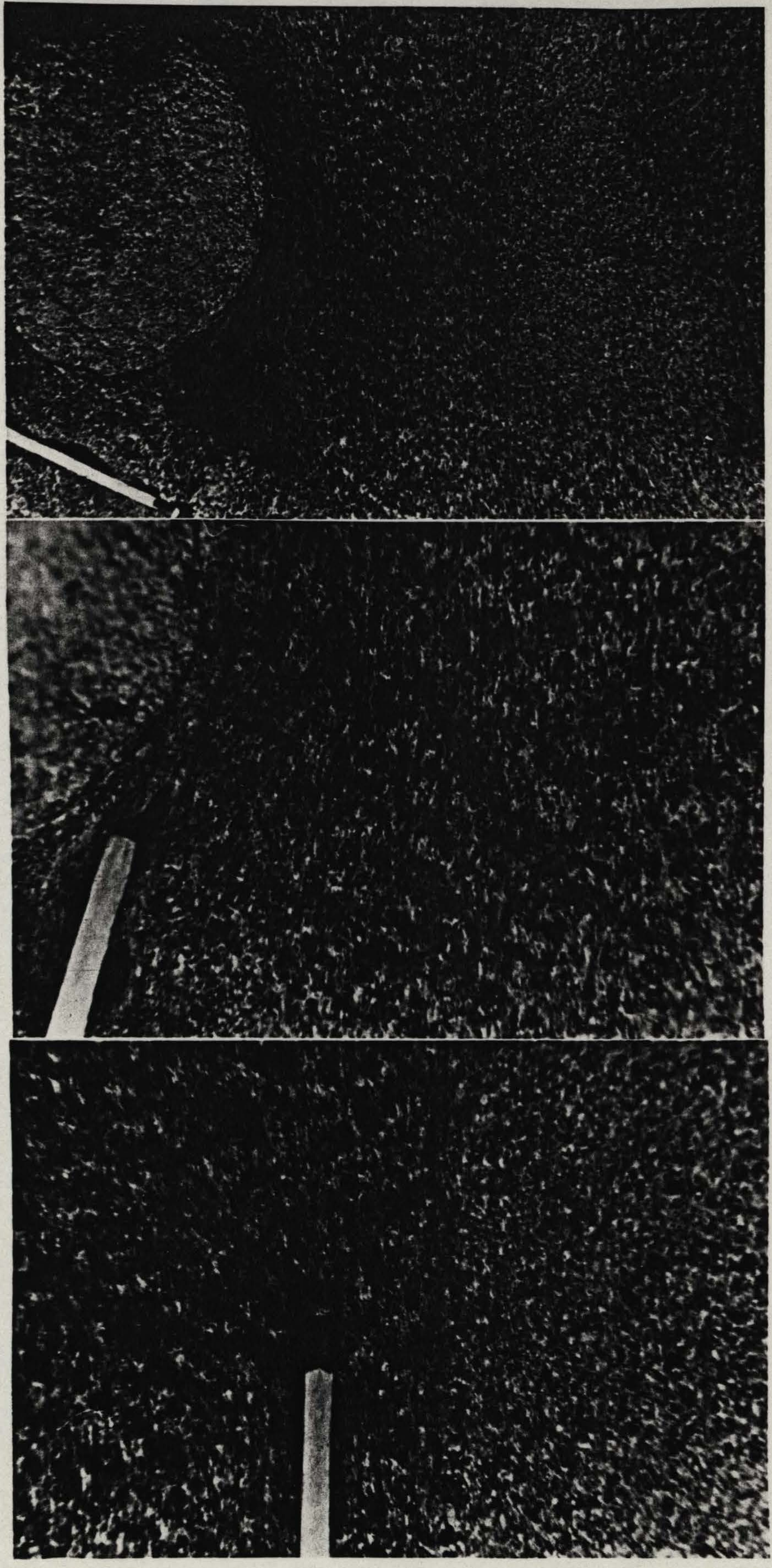


Figure 8: Close-up of coarse grained, quartz-rich matrix (identified by match in bottom photo) of conglomerate south of Curlew Lake

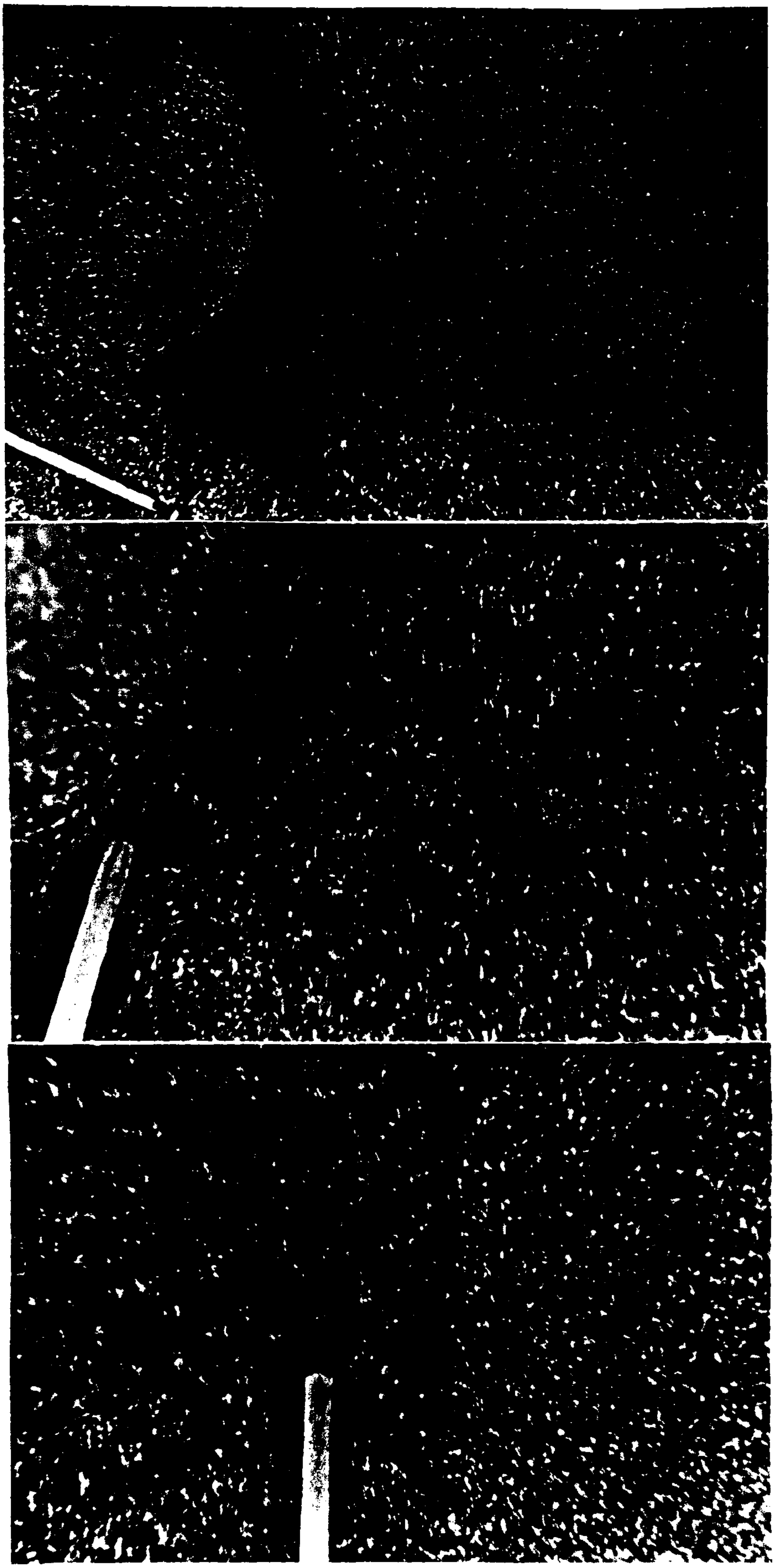


Figure 8: Close-up of coarse grained, quartz-rich matrix (identified by match in bottom photo) of conglomerate south of Curlew Lake

TABLE I

MODAL VARIATIONS OF MAJOR ROCK UNITS

	Trondhjemite Range	Fine Grained Trondhjemite Range	Granodiorite Range	Leucocratic Quartz Monzonite Range	Amphibolite Range
Quartz	20.8-41.4	23.2-39.8	31.3-36.4	22.6-30.2	0.0-4.2
Plagioclase	46.8-66.4	45.4-60.0	40.1-53.0	25.6-31.0	30.8-36.4
K-feldspar	0.0-4.8	0.7-3.8	6.8-20.4	43.2-43.6	-
Biotite	0.0-17.4	1.9-17.8	1.8-6.0	0.6-2.0	-
Chlorite	0.0-11.6	1.5-5.4	0.0-0.3	-	-
Epidote	0.0-5.2	0.2-4.2	0.0-2.4	0.4-0.8	0.4-13.4
Carbonate	0.0-1.6	0.0-1.4	0.0-0.4	-	0.0-0.2
Sphene	0.0-0.4	0.0-0.4	0.0-0.2	-	-
Muscovite	0.0-1.2	0.2-0.8	-	-	-
Amphiboles	-	-	-	-	54.0-65.3
Opaques	0.0-1.0	0.0-0.8	-	-	0.2-0.6
Allanite	0.0-0.4	-	-	-	-

trondhjemite may be used for light coloured tonalites (colour index <15), and since most of the rocks in this field comply with that condition they will be called as such.

In the field these medium grained rocks have a greyish-white weathered surface and are generally homogeneous. The intensity of foliation varies within the unit. That is, as we go from east to west across the stock, the trondhjemite goes from massive to well foliated. In the northeastern portion of the stock, where the unit is coarser grained, it forms sublineated steeply plunging lenticles.

Discontinuous chlorite and biotite stringers are commonly found in this unit, sometimes exhibiting a lensoidal habit. Also occurring in some of the outcrops are quartz pods and veinlets. Generally, this unit has a holocrystalline and inequigranular character, varying from allotriomorphic-granular to seriate. Plagioclase and quartz are the predominant minerals, with varying amounts of biotite, chlorite, microcline and epidote. Also present in trace amounts are muscovite, sphene, allanite, carbonate and opaques.

In the eastern portion of the stock plagioclase occurs as subhedral to euhedral grains varying from 0.5 mm to 2.0 mm. It has been so strongly sericitized that compositional measurements could not be done. Twinning has either been masked or more probably, destroyed by metamorphism (Spry, 1969). In the north-central part of the stock, saussurite occurs as the dominant alteration product. Here plagioclase occurs as randomly oriented subhedral laths of 1.0 mm to 2.0 mm. In a few grains carlsbad and badly deformed polysynthetic twins were observed. In the extreme northwestern portion of the stock saussuritized plagioclase occurs as randomly orientated laths with irregular grain boundaries and an average grain-size of 0.5 mm. Shredded sericite and saussurite was most abundant along fractures in the plagioclase.

Potassium feldspar occurs in minor amounts, replacing plagioclase along its grain boundaries and as minute discrete grains (>0.1 mm) of microcline interstitial to plagioclase. Some of these anhedral grains exhibit deformed polysynthetic twinning. Potassium feldspar commonly occurs along the minute fractures that occur periodically in this unit.

Quartz is found in varying amounts. Generally it forms highly recrystallized aggregates interstial to the plagioclase. The crystals are commonly fractured and exhibit a mosaic-like pattern. Occasionally sutured boundaries are well developed (Figure 9 and 10). Average size of the grains most of which exhibit undulatory extinction, is 0.1 mm. In samples RK-2-19, RK-2-21A and RK-2-22, quartz stands out in that it forms lenticular zones of up to 7 mm in length (Figure 11).

The two dominant mafic minerals are biotite and retrograde chlorite, both of which occur in varying amounts as subhedral to anhedral platy aggregates, interstitial to the plagioclase (Figures 13 and 14). Minute quartz granules are commonly intergrown with these aggregates as are muscovite flakes. Generally this rock unit has a higher mafic content in the western portion of the stock.

Epidote is generally secondary, occurring in clusters as minute anhedral flakes replacing plagioclase. However in the western portion of the stock where saussuritization is the dominant alteration process, epidote also occurs as discrete anhedral to subhedral elongated crystals, associated with biotite and interstitial to plagioclase.

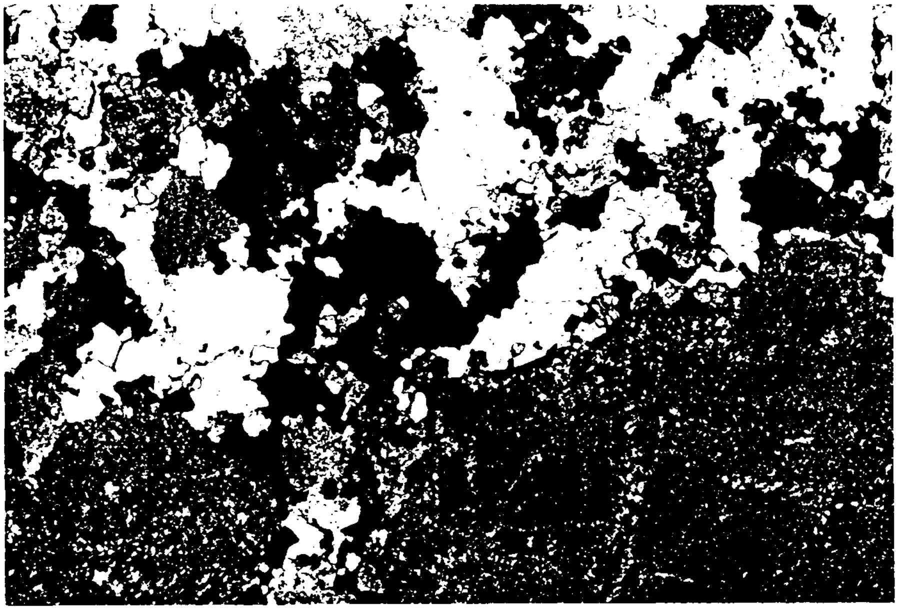


Figure 9: Sutured quartz interstitial to plagioclase (Sample RK-2-21A, XNICOLS). Magnification is 25x.

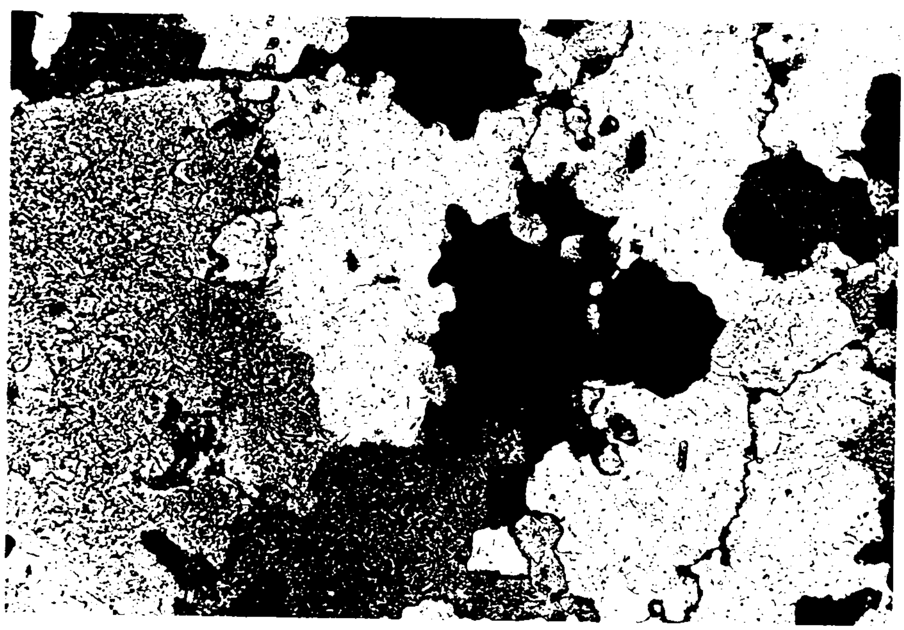


Figure 10: Close-up of above section (XNICOLS). Magnification is 63x.

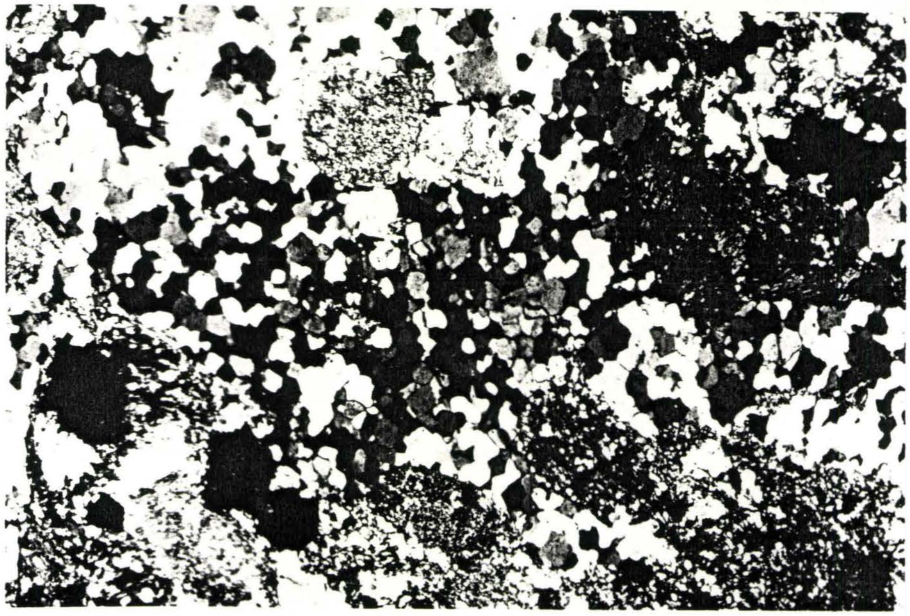


Figure 11: Lenticular quartz aggregates interstitial to highly altered plagioclase (Sample RK-2-19, XNICOLS). Magnification is 25x.

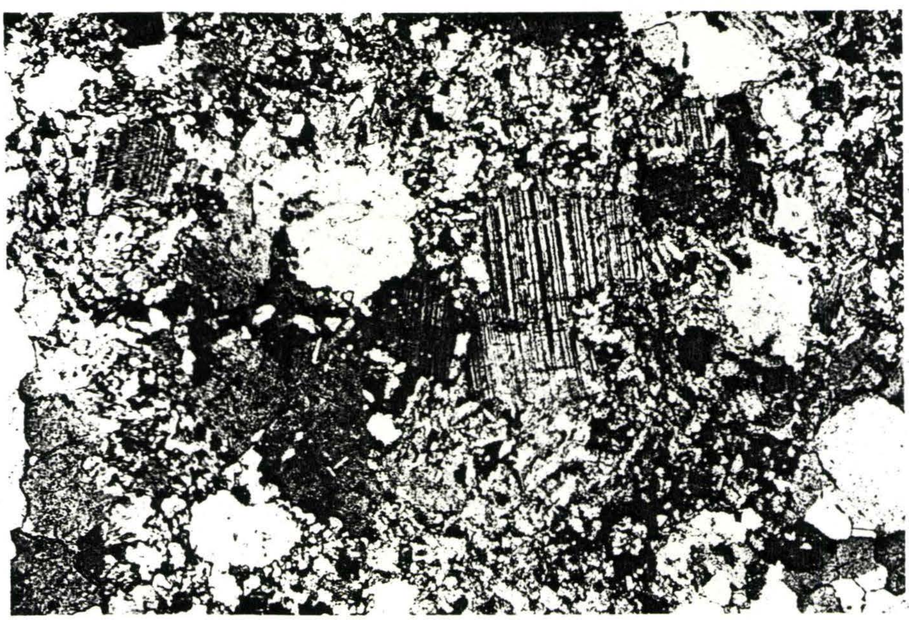


Figure 12: Sericitized and saussuritized plagioclase exhibiting weak twinning (Sample RK-10-3, XNICOLS). Magnification is 63x.

Figure 13: Chlorite clot interstitial to large highly altered plagioclase (Sample RK-3-16B, Plain Light). Magnification is 63x.

Figure 14: Deformed and altered biotite clot from coarse grained trondhjemite, in the northeast corner of the stock (Sample RK-2-19, Plain Light). Magnification is 63x.

Allanite,sphene and opaques are subhedral to euhedral and occur in trace amounts (Figures 15 and 16). However in hand specimen pyrite ranged up to 2%.

iii) Fine Grained Trondhjemite

This fine grained chilled margin is most predominant along the south-central boundary of the stock where it is in contact with the conglomerate. It is much more leucocratic here than along the north-western boundaries where it is in contact with amphibolites. The exact boundary between this unit and the main trondhjemitic phase is at times irregular and difficult to ascertain because of the intrusive nature of the latter. This fine-grained trondhjemite has a dirty-white weathered surface and is commonly found as inclusions in the main trondhjemitic phase. Shearing occurs locally as does the development of augens. Once again the intensity of foliation increases to the west.

Generally, this unit is holocrystalline and has a hypidiomorphic granular texture. Plagioclase and quartz are the predominant minerals with varying amounts of biotite, chlorite, microcline and epidote. Accessory sphene, muscovite and carbonate are also present.

Texturally this unit is finer grained than the main trondhjemitic phase, but mineralogically it is very similar. However, one of the samples from near the southeastern boundary of the stock did exhibit good cataclastic texture in the form of augened quartz aggregates and pronounced kink banding (Figures 17 and 18).

iv) Leucocratic Trondhjemite

This very fine grained phase has a white weathered surface and

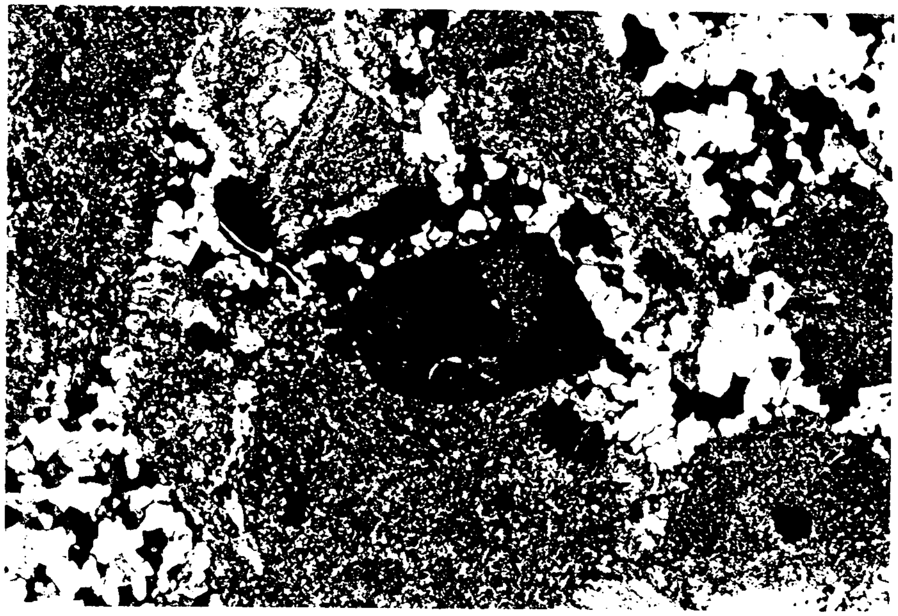


Figure 15: Euhedral allanite, lenticular quartz aggregates and highly altered plagioclase (Sample RK-2-22, XNICOLS). Magnification is 63x.

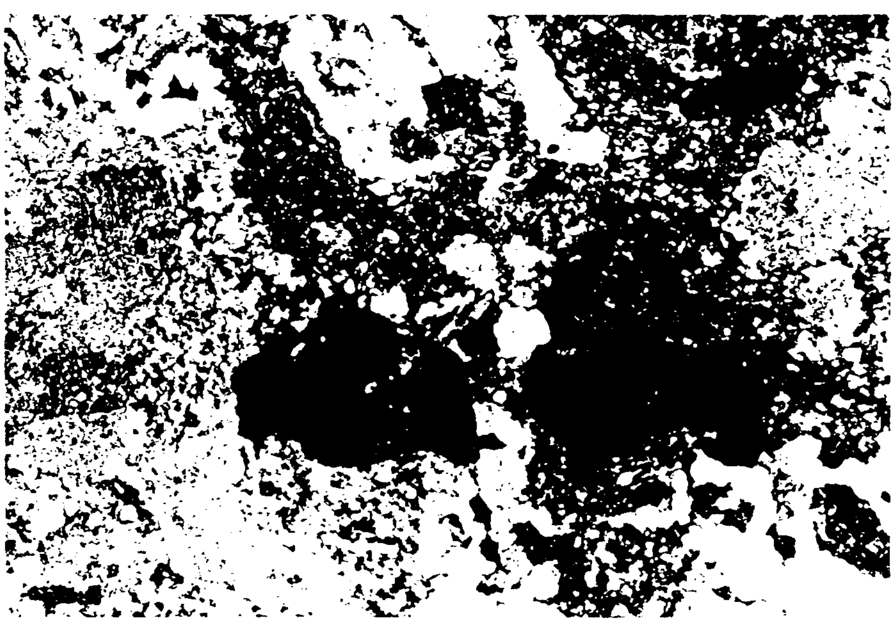


Figure 16: Opaques (pyrite) in main trondhjemitic phase (Sample RK-2-5, XNICOLS). Magnification is 25x.

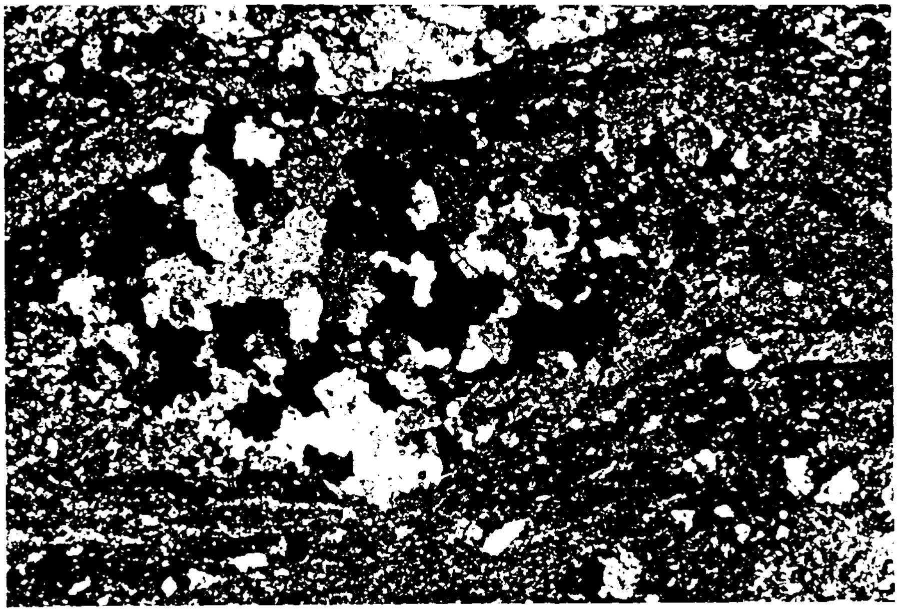


Figure 17: Augened quartz aggregate in a sheared zone from the southeastern boundary of the stock (Sample RK-2-4, XNICOLS). Magnification is 63x.

Figure 18: Well developed kink banding from the above section XNICOLS). Magnification is 63x.

commonly occurs as intrusive veinlets, of 2 to 6 cm in width in and around Curlew Lake. It is slightly discordant to the foliation (by 5^{o} to 10^{o}), quite homogeneous, and has less than 3 percent mafics. No selvages were observed along the veinlet margins. Due to its apanetic nature no thin section analysis was attempted.

v) Granodiorite

This medium grained unit has a typical white weathered surface. It occurs as a homogeneous and generally massive, but weakly foliated elliptical body east of Heron Lake where it encompasses approximately 1.5 square km. It is also found as the main rock unit in a large, well foliated outcrop along the southern part of Curlew Lake (RK-7-12). The latter contains more potassium feldspar as well as quartz monzonite dikes.

The major minerals are plagioclase, potassium feldspar and quartz. Mafics occupy less than 6% of this unit which has a holocrystalline and inequigranular character varying from hypidiomorphic granular to seriate.

Plagioclase is the major mineral. It is heavily sericitized and forms subrounded to tabular grains of up to 1.5 mm in diameter. Any twinning has been masked by the alteration.

In the main granodiorite unit potassium feldspar content ranges from 6 to 10% and appears to be secondary, in that it is replacing the plagioclase. It occurs as irregular shaped anhedral to subhedral grains with an average diameter of 0.7 mm. Polysynthetic twinning forms a quadrille structure and is evident in some of the grains and suggestive of microcline.

Sample RK-7-12 is of special interest in that it contains a high amount of potassium feldspar and plots on figure 2 very near the granite - granodiorite boundary. Here the potassium feldspar, microcline, is much more distinct because of its lack of alteration. These subhedral crystals are generally replacing the plagioclase, as well as containing inclusions of it. Also present to a minor amount (less than 3%) is flame and string perthite.

Quartz occurs as minute granules of varying sizes and forms anhedral aggregates interstitial to the feldspars. The individual grains commonly exhibit undulose extinction and some are fractured. Anhedral biotite and minor amounts of associated retrograde chlorite occur as randomly orientated irregular grains interstitial to the feldspars. Subhedral epidote and sphene are common accessories, as is carbonate.

vi) Leucocratic Quartz Monzonite

This unit occurs as a small homogeneous intrusive plug (1/2 km^2) in the southeastern portion of Curlew Lake. It is massive and associated with numerous potassic dikes of 1 m to 3 m in width which, in the Curlew Lake area were observed crosscutting the two main trondhjemitic phases. This fine to medium grained unit has a pinkish white to pink weathered surface and commonly imposes a blastic texture upon the trondhjemite where it contacts the latter.

In thin section it exhibits a holocrystalline, hypidiomorphic granular texture. It is very leucocratic in that mafics occupy less than 2% of the samples.

Subhedral potassium feldspar dominates. It occurs in two forms, in roughly equal quantities. Polysynthetically twinned microcline occurs as subrounded to rectangular grains of up to 0.5 mm in diameter. It forms irregular boundaries with the plagioclase that it is replacing as well as containing inclusions of it. String and flame perthite occur in irregular forms, generally elongated and up to 0.7 mm in length (Figures 19, 20 and 21). These perthitic intergrowths are generally arranged in a parallel manner, suggesting formation along preferred crystallographic planes. Growth occurs along the grain boundaries and tapers towards the centre. It is also common to find randomly orientated inclusions of plagioclase and quartz within these perthites.

Plagioclase occurs as subhedral to anhedral, highly sericitized, subrounded grains with an average diameter of 0.5 mm. It is being extensively replaced by potassium feldspar.

Recrystallized subhedral quartz is generally finer grained and interstitial to the feldspars. Grain size is variable, the maximum size being 0.3 mm. These irregular shaped grains exhibit undulose extinction and a minor amount are fractured.

Biotite is a minor constituent and occurs as minute randomly orientated anhedral flakes interstitial to the feldspars. Epidote occurs in trace amounts.

vii) Quartz Diorite to Diorite

This medium to coarse grained unit was observed as small rounded plugs intruding the main trondhjemitic phase in the east and central parts of the stock. Its intrusive nature was best observed in the east

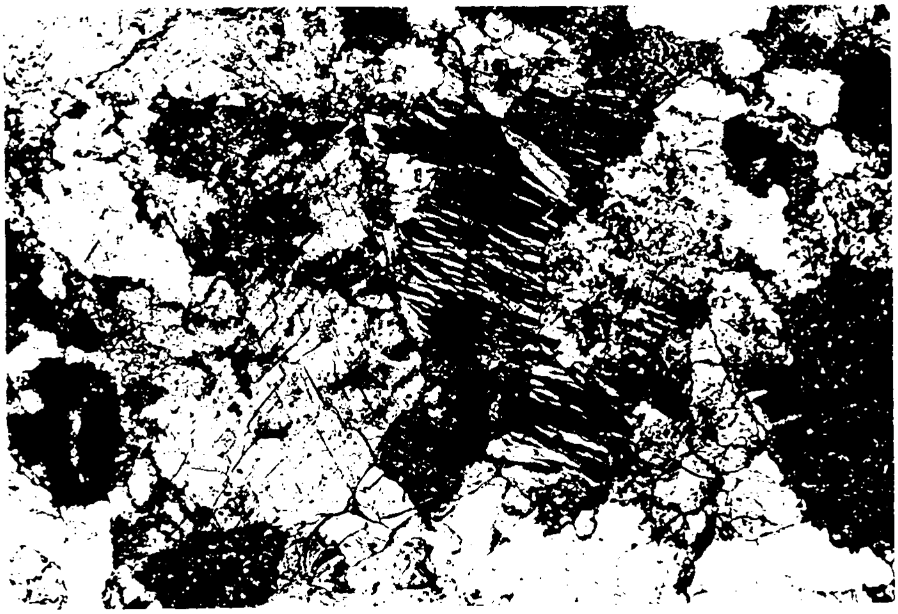


Figure 19: Well developed string perthite in quartz monzonite (Sample RK-7-40, XNICOLS). Magnification is 63x.

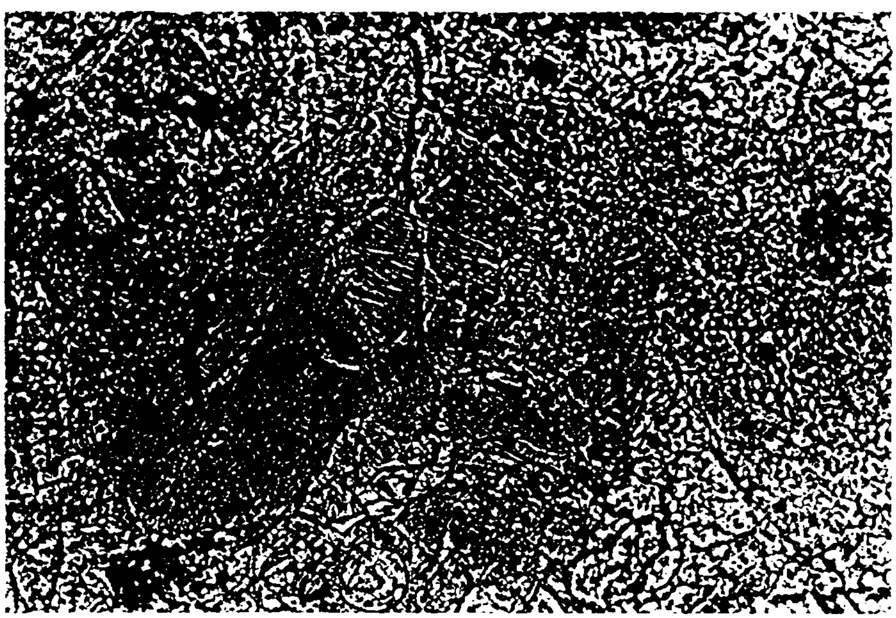


Figure 20: Same photomicrograph as above, but in plain light.

(RK-2-10) where apophyses of the larger plug were seen intruding several of the surrounding outcrops. It is massive, homogeneous and has a yellowish-green weathered surface. In the field the white feldspars are easily distinguished from the mafics.

This unit has a holocrystalline, hypidiomorphic granular texture. Its major minerals are plagioclase, hornblende, quartz and biotite with accessory sphene, chlorite and epidote.

Subhedral to anhedral andesine is the dominant mineral present. It occurs in a variety of forms ranging from subrounded crystals with a diameter of 1 mm, to lath-like with a maximum length of 2 mm. Albite twinning is common but has been largely masked by saussuritization. Some of the feldspars also contain inclusions of sphene, opaques, hornblende and biotite.

Subhedral hornblende is the most dominant ferromagnesian mineral present. It occurs as highly pleochroic green to greenish-brown irregular plates, some of which reach a length of 1.3 mm. It also occurs in aggregates as minute prisms.

Quartz exhibits undulatory extinction and is commonly fractured Individual grains are subrounded and form anhedral aggregates interstitial to the plagioclase and hornblende.

Anhedral biotite occurs as flakes and laths interstitial to plagioclase and hornblende. Occasionally it forms irregular shaped aggregates of 1 mm in diameter. Generally it appears to be forming at the expense of hornblende and has minor chlorite and epidote associated with it.

Euhedral sphene crystals exhibiting an angular rhombic form are

Figure 21: String perthite enclosed by anhedral mass of quartz and feldspar (Sample RK-7-40), XNICOLS). Magnification is 63x.

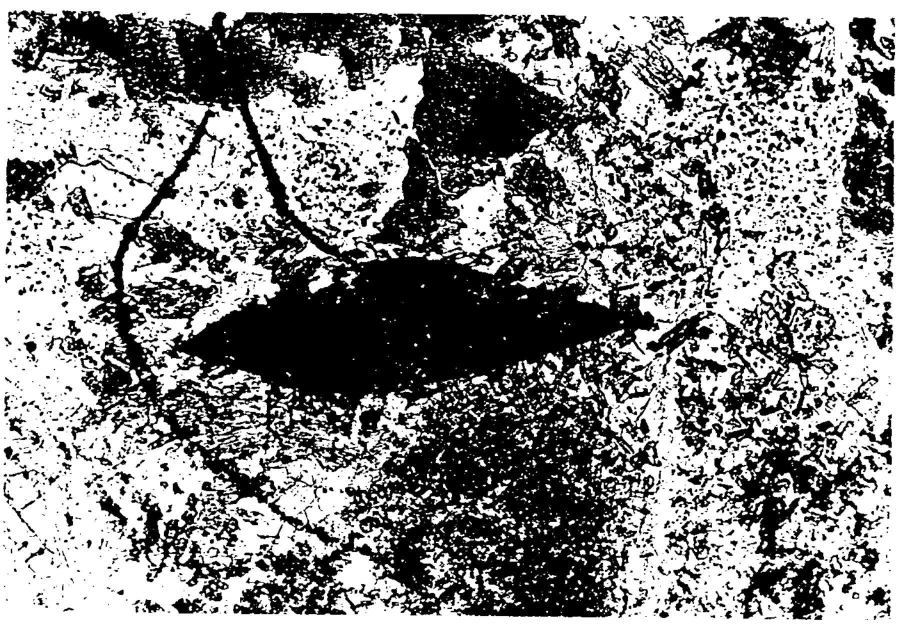


Figure 22: Euhedral sphene exhibiting a well developed angular rhombic form (Sample RK-4-4, Plain Light). Magnification is 63x.

elongated euhedral epidote, which occurs in rather high abundances and accessory hornblende.

Reddish to yellowish-brown opaques, probably pyrite, occur in minor amounts

3. Summary

The following mineralogical and textural characteristics were observed:

1. The granitoid clast in the conglomerate contains more quartz modally than any of the plutonic phases.

2. The fine grained trondhjemite is a chilled margin, characterized by its hypidiomorphic granular texture. Shearing along its southern contact has resulted in localized cataclastic textures. Mineralogically it is similar to the main trondhjemitic phase.

3. In the main trondhjemitic phase quartz commonly occurs in recrystallized aggregates, forming lenticular zones up to 7 mm in length.

4. The plutonic rocks have been severely sericitized and saussuritized.

5. The leucocratic trondhjemite is characterized by its very fine grain size and a total mafic content of less than 3%.

6. In the trondhjemites and granodiorites: (i) most of the potassium feldspar appears to be secondary; (ii) biotite and retrograde chlorite are the major mafic minerals; (iii) twinning and zoning has been either masked or destroyed by metamorphism and alteration.

7. Leucocratic quartz monzonite is characterized by its

perthitic insets and a total mafic content not exceeding 2%.

8. The quartz diorite to diorite is a minor intrusive phase.

9. The quartz andesite is characterized by its high amount of epidote.

CHAPTER IV

GEOCHEMISTRY

1. Analytical Methods

Whole rock and trace element analyses for twenty samples were obtained using a Philips Model 1450 AHP automatic sequential X-ray fluorescence spectrometer housed in the Geology Department, McMaster University. A Cr X-ray tube was used for the major elements; Si, Al, total Fe, Mg, Ca, Na, K, Ti, Mn and P, and a Mo X-ray tube for the trace elements; Rb, Sr, Y, Zr, Nb and Ni. Eight whole rock analyses were obtained from the Ontario Division of Mines. Chemical analyses (Tables V and VIII), as well as a discussion of errors, can be found in the appendix.

To prepare samples for analysis the weathered surfaces were removed. The samples were then crushed to -200 mesh using a Spex Industries shatter box with tungsten carbide rings. Pressed powder discs backed by crystalline boric acid were used for trace element analysis. They were made following a procedure outlined by Marchand (1973). Pressed fused discs were used for whole rock analysis. They were made by fusing 2 gms of rock powder with 4 gms of lithium tetraborate at 1100^{o}C for 30 minutes. The result was a fused glass bead which was then crushed using a Spex Industries #8000-II Mixer/Mill. Pressed discs were then made using Marchand's (1973) procedure.

TABLE II

CHEMICAL VARIATIONS (WT %) OF MAJOR ROCK UNITS

	Trondhjemite Range	Fine Grained Trondhjemite Range	Granodiorite Range	Leucocratic Quartz Monzonite Range	Amphibolite Range
SiO_2	61.66-71.57	60.60-70.41	71.96-72.07	74.43-75.65	49.75-50.56
TiO_2	0.33-0.66	0.28-0.80	0.27-0.33	0.09-0.10	0.71-0.95
AL_2O_3	14.80-19.60	15.00-19.09	15.00-15.10	13.82-14.80	14.64-15.65
Fe_2O_3	0.81-2.10	0.65-2.30	1.77-1.83	0.58-0.65	2.21-2.45
FeO	0.90-2.87	0.57-2.24	0.30-0.55	-	9.15-10.28
MnO	0.04-0.10	0.03-0.10	0.07	0.06-0.07	0.18-0.20
MgO	0.78-1.94	0.67-2.06	0.57-0.61	0.08-0.15	7.34-8.45
CaO	2.39-4.88	2.32-6.09	2.11-2.30	0.96-0.99	11.01-12.80
Na_2O	4.00-4.72	3.85-4.96	3.51-4.41	3.00-4.24	1.80-2.18
K_2O	1.50-2.73	1.56-2.42	2.78-4.25	4.71-5.67	0.17-0.35
P_2O_5	0.06-0.25	0.07-0.21	0.07-0.08	0.01	0.05-0.70

CIPW norms were calculated using a computer program devised by Mattison (1973). The total Fe content was separated into Fe_2O_3 and FeO components according to Irving and Baragar (1971). The results are in the appendix (Table VII).

2. Results

The range in major elements has been listed in Table II for the trondhjemite, fine-grained trondhjemite, granodiorite, leucocratic quartz monzonite and amphibolite. The leucocratic trondhjemite (Rk-7-11A), quartz diorite (RK-4-4), quartz andesite (RK-13-32B) and granitoid clast (RK-2-37A), are each represented by only one sample and as such their chemical analyses can be found in the appendix. Trace element variations for all of the phases are listed in Table III.

The main trondhjemitic unit has a wide range in SiO_2 (61.66-71.57 wt %) and CaO (2.39-4.88 wt %). The range in SiO_2 reflects the modal quartz content. This unit has the highest Sr value (633) for the plutonic rocks and a Na/K ratio which varies from 1.44 to 2.68. The K/Rb ratios range from 197-405 with an average of 272.

The fine grained trondhjemite is chemically similar to the main trondhjemitic phase, except for a wider CaO range (2.32-6.09). It also has slightly lower Rb and Sr values and a K/Rb ratio range of 266-294.

The leucocratic trondhjemite has the highest Na_2O value (6.65 wt %). Its highly leucocratic nature is demonstrated by very low values for total Fe, TiO_2 and MgO. It has a K/Rb ratio of 366, reflecting a low Rb value (34), and the highest Na/K ratio (3.95).

TABLE III

TRACE ELEMENT VARIATIONS (PPM)

	Trondhjemite Range	Fine Grained Trondhjemite Range	Leucocratic Trondhjemite	Granodiorite Range	Leucocratic Quartz Monzonite Range	Quartz Diorite	Quartz Andesite	Amphibolite Range
Rb	51-95	44-53	34	86-99	94-115	59	78	1-4
Sr	251-633	295-484	377	259-275	114-129	376	1321	96-136
Y	7-17	6-18	8	10-11	13-91	33	18	18-26
Zr	161-222	171-243	202	177-249	29-201	133	180	45-74
Nb	13-107	60-97	73	56-63	9-12	27	17	2-14
Ni	18.4-33.3	15.1-35.6	10.9	17.2-17.5	17.2-19.2	46.5	24.1	129.2-178.6
K/Rb	197-405	266-294	266	268-356	409-416	243	269	259-1411
Rb/Sr	0.088-0.378	0.096-0.180	0.090	0.313-0.382	0.825-0.891	0.157	0.059	0.010-0.058
Na/K	1.444-2.681	1.553-2.386	3.953	0.736-1.414	0.472-0.803	1.824	5.300	2.298-9.440

Chemically, the granodiorites do not exhibit any large variations. In relation to the two main trondhjemitic phases they are more K_2O and SiO_2 rich, and contain less Na_2O and CaO. They also have higher Rb (86-99) and lower Sr values (259-275). The Na/K ratios are lower (0.74-1.41) and the average K/Rb ratio is 312, which is slightly higher than that for the main trondhjemitic phases.

Chemical variations within the leucocratic quartz monzonites are minor. Compared to the other rocks they have the highest SiO_2 and K_2O values, and the lowest total Fe, TiO_2, Al_2O_3, MgO, CaO and P_2O_5 values. The leucocratic and potassic nature of these rocks is reflected by the low modal mafic content and the high modal K-feldspar. This phase also has the highest Rb and lowest Sr values, as well as the lowest Na/K ratios (0.47-0.80) and the highest K/Rb ratios (409-416).

The quartz diorite has the lowest SiO_2 values and the highest total Fe, TiO_2, MnO, MgO, CaO and P_2O_5 values of all the plutonic rocks. It has the highest Ni value (465) and K/Rb and Na/K ratios which are comparable to the two main trondhjemites.

The amphibolites have low Rb values (1-4) and the highest Na/K and K/Rb ratios. The quartz andesite has the highest Sr value (1321) and a K/Rb ratio of 269.

3. Summary

By considering the plutonic phases in order of increasing SiO_2, the following chemical trends are observed:

1. General decrease in total Fe, MgO and MnO.
2. Pronounced decrease in CaO.

3. Slight decrease in P_2O_5 and MnO.

4. Steady increase in K_2O and total alkali content.

5. There is a decrease in Sr and an increase in Rb concentration.

6. There is a decrease in Ni concentration and an overall decrease in Na/K.

7. There are definite increases in the average Rb/Sr and K/Rb ratios.

CHAPTER V

PETROGENESIS

1. Introduction

Recent work regarding the origin of trondhjemitic magmas has stressed their genetic relationship to basaltic source regions. Hanson and Goldich (1972) and Arth and Hanson (1975) suggest that the high -Al_2O_3 (>15 wt %) 2.7 b.y. old trondhjemite of northeastern Minnesota was formed by partial melting of a tholeiitic basalt at sufficient depth in the mantle to leave a residue of garnet and clinopyroxene. Arth et al. (1974) explain the high Al_2O_3 gabbro-diorite-tonalite-trondhjemite suite of southwestern Finland by fractional crystallization of hornblende, biotite, and plagioclase in varying proportions from a mildly-alkaline olivine tholeiite magma. Barker and Arth (1976) feel that the high -Al_2O_3 trondhjemitic-tonalitic liquids are generated in both old and recent convergent and tensional tectonic environments; either by hornblende-controlled fractionation of hydrous basaltic liquid or by partial melting of metabasaltic rocks. Recent work by Barker and others (1976) on the 1.7-1.8 b.y. old trondhjemitic bodies of Rio Brazos, New Mexico is consistent with magma generation from basaltic parent rocks. That is, these rocks were probably formed by partial melting or possibly by fractional crystallization of basaltic magma.

The trondhjemites of The Heron Lake Stock are of the high Al_2O_3 variety, and in major elements and Rb and Sr concentrations they are similar to the trondhjemites and granodiorites of Barker and others (1976). It should be pointed out that none of the models discussed above, involve a potassic rich phase such as quartz monzonite. This must be considered for the Heron Lake area. It will therefore be the purpose of this chapter to discuss the chemical and petrological trends in an attempt to discern the origin of The Heron Lake Stock.

2. Chemical Trends

Variation diagrams are used to compare trends within an igneous rock suite, to help decide whether or not the rocks are genetically related. The alkali-lime index (Peacock, 1931) was established using a Harker variation diagram. The index is used to distinguish four chemical classes of igneous rocks (Figure 23). For the rocks of The Heron Lake Stock the index was found to be approximately 60, classifying these rocks as calc-alkalic but very nearly calcic in nature.

Another method makes use of the differentiation index (DI) of Thornton and Tuttle (1960), who define it as the number that represents the sum of the weight percentages of normative quartz, orthoclase, albite, nepheline, leucite and kalsilite. This method involves plotting the major elements of the inferred cogenetic rock types against the DI (figure 24, a to f). The usefulness of the DI has been contested by Chayes (1964), who favours using the crystallization index (CI), which is calculated from the system anorthite-diopside-forsterite and represents the sum (in weight percent) of normative anorthite, normative magnesian diopside, normative forsterite, normative enstatite converted to forsterite, and magnesian spinel calculated from normative

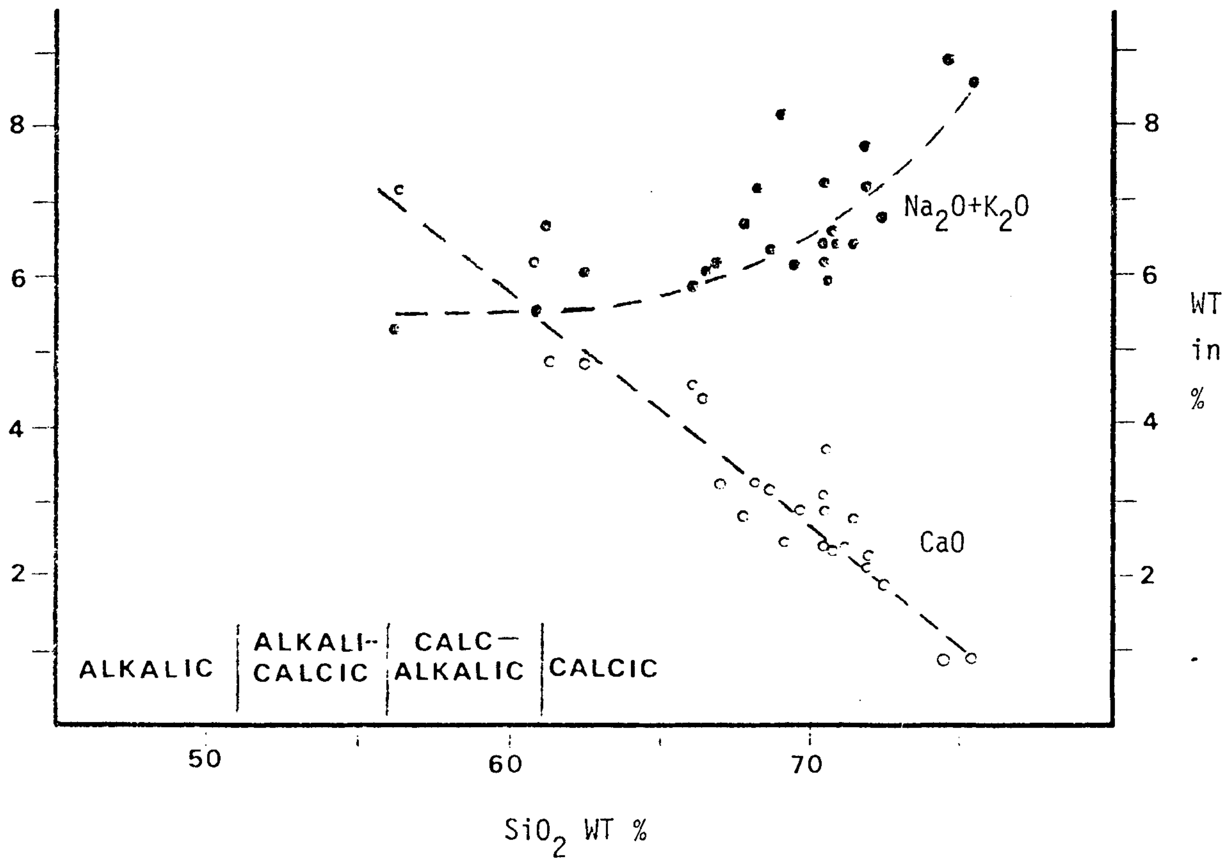


Figure 23: Plot of $Na_2O + K_2O$ and CaO versus SiO_2

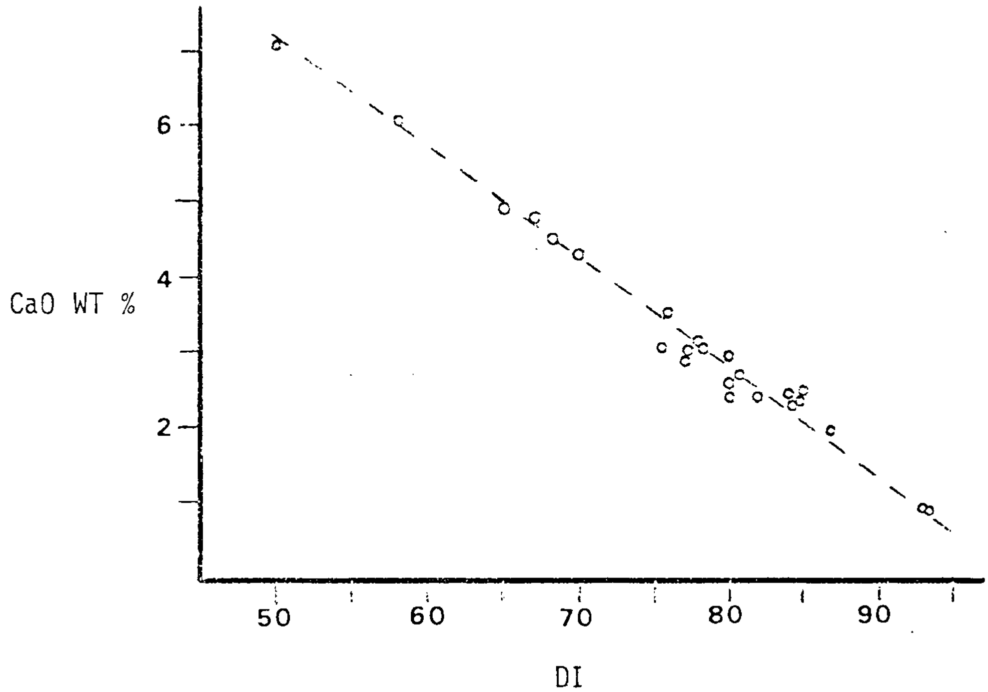


Figure 24(a): CaO vs DI

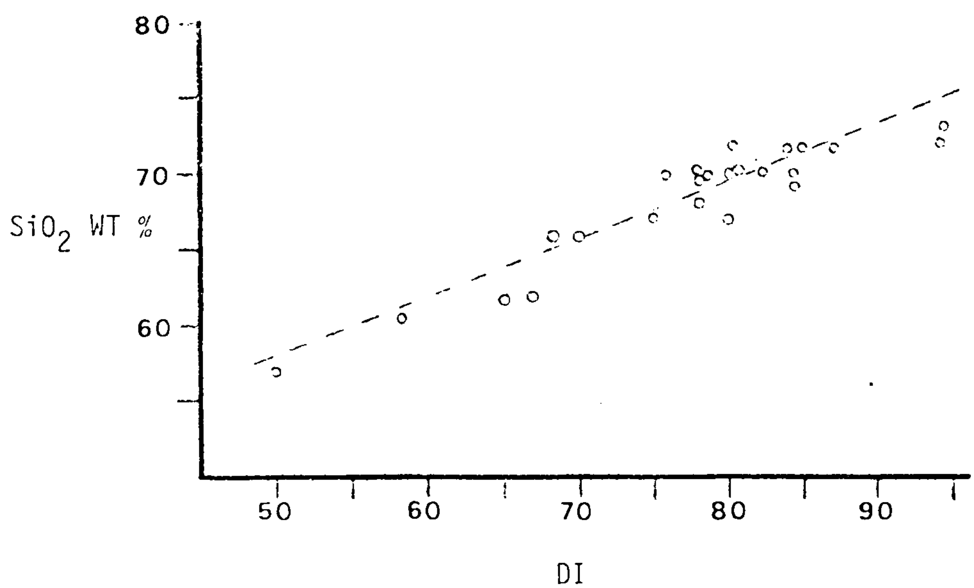


Figure 24(b): SiO_2 vs DI

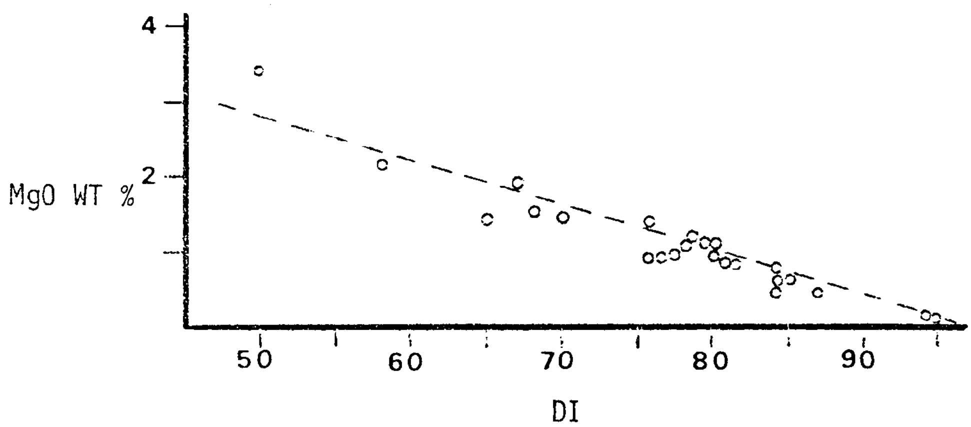


Figure 24(c): MgO vs DI

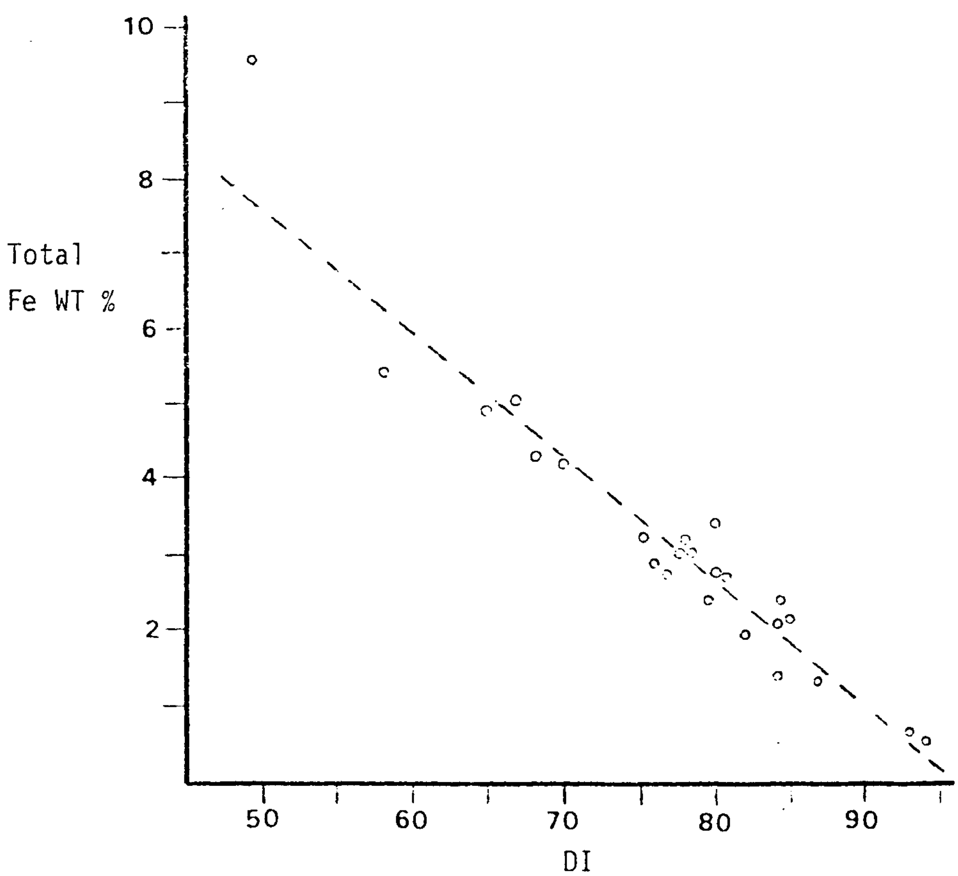


Figure 24(d): Total Fe vs DI

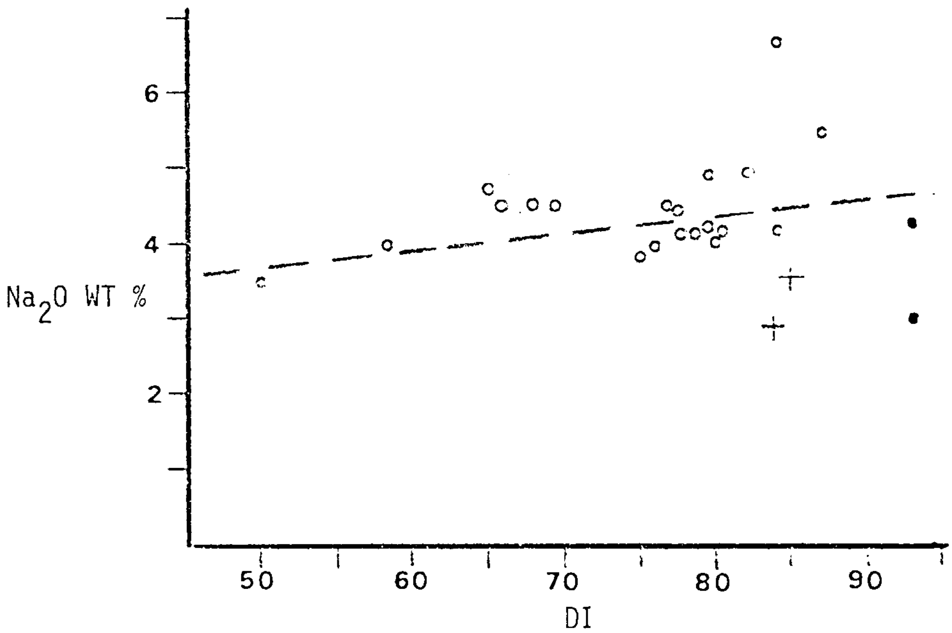


Figure 24(e): Na_2O vs DI

● QUARTZ MONZONITE
+ GRANODIORITE

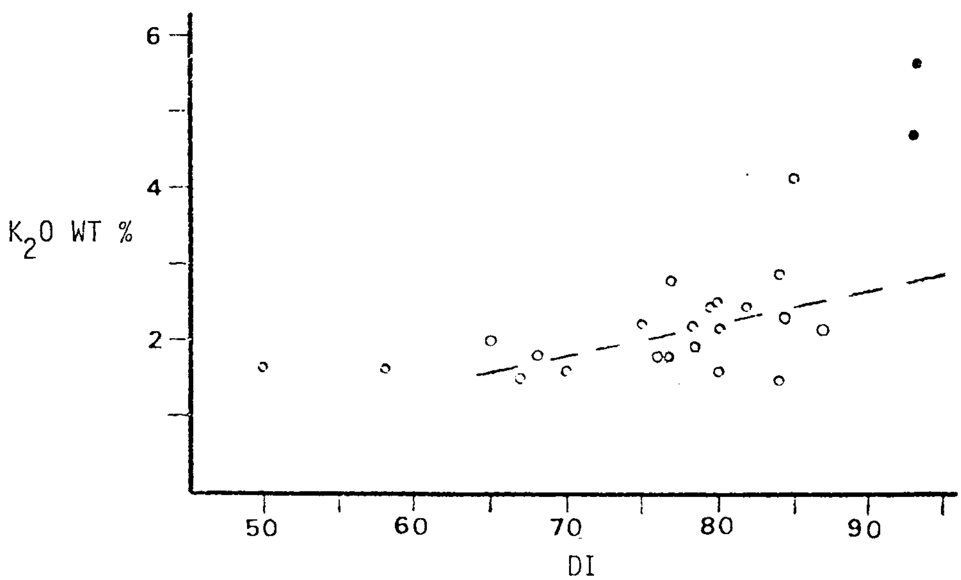


Figure 24(f): K_2O vs DI

corundum in ultramafic rocks (Poldervaart and Parker, 1964). Carmichael, et al. (1974) argue that the DI has a sound thermodynamic basis, because the normative components used correspond to minerals with low entropies of melting and as such demands their concentration in low-temperature liquids. The author used DI, because it is more applicable for felsic rocks such as those from Heron Lake.

The plots indicate distinct linear trends for all but the alkalies. Wiebe (1975) feels that such trends can be partly explained by fractional crystallization of plagioclase and biotite and that the scatter in the alkalies reflect either heterogeneity in a crustal melting source or assimilation during emplacement. The samples deviating the most from the linear trends for Na_2O are the quartz monzonites which are abundant in perthites and the granodiorites which are abundant in secondary K-feldspar. Such a texture is highly suggestive of metasomatic processes in the residual fluids. The largest deviation for K_2O was exhibited by the K-rich quartz monzonites.

These plots of oxides vs DI indicate that both the soda and potash content of the rocks is variable. However, there is an overall slight increase in Na_2O and a more noticeable one in K_2O. This occurs because soda is continually taken from magmatic liquids during crystallization as a component of plagioclase feldspars, while potash is generally held in the liquid until alkali feldspar crystallizes or until the water content is sufficiently high to precipitate biotite (Thornton and Tuttle, 1960).

The negative trend with increasing DI for CaO, MgO and total Fe, can be attributed to the removal of these oxides into the solid phase (plagioclase, mafics, etc.) during crystallization. The overall aspect of these plots reveals a mafic to felsic fractionation trend namely; trondhjemites grading into granodiorites and quartz monzonites.

Figure 25 is an AFM diagram. It suggests a gradational felsic to mafic variation, with the most felsic unit; leucocratic quartz monzonite and the most mafic unit; quartz diorite as end members.

Figure 26 is the K:Na:Ca plot of the rocks, compared with the calc-alkalic trend of Nockolds and Allen (1953). Although the trondhjemites exhibit a wide scatter they are generally consistent with the calc-alkali trend. This diagram is more suggestive of a calcic to sodic plus potassic trend.

Figure 27 illustrates the normative composition of the rocks relative to the Q-Ab-Or ternary system (Tuttle and Bowen, 1958). Since most of the rocks contained at least 80% normative Ab-Q-Or (Table VII), the usage of this diagram is justified. It is evident that most of the rocks fall within and on the plagioclase side of the irregular solid line which represents Winkler and Van Platen's (1961) area for granitic rocks. In fact the trondhjemites are generally clustered near the dashed circles which represent melts produced by the experimental melting of K_2O-poor plagioclase + quartz + biotite gneisses at 720^oC and PH_2O = 2000 bars. This is an important point, considering the close proximity of the stock to the English River Gneiss Belt (1/4 km). The relatively small range within which these rocks are found suggests that magmatic processes dominated over metasomatic ones and that they were derived from a single magma. According to Winkler (1976),if we increase the PH_2O to greater than 2 K bars, the compositions will be forced

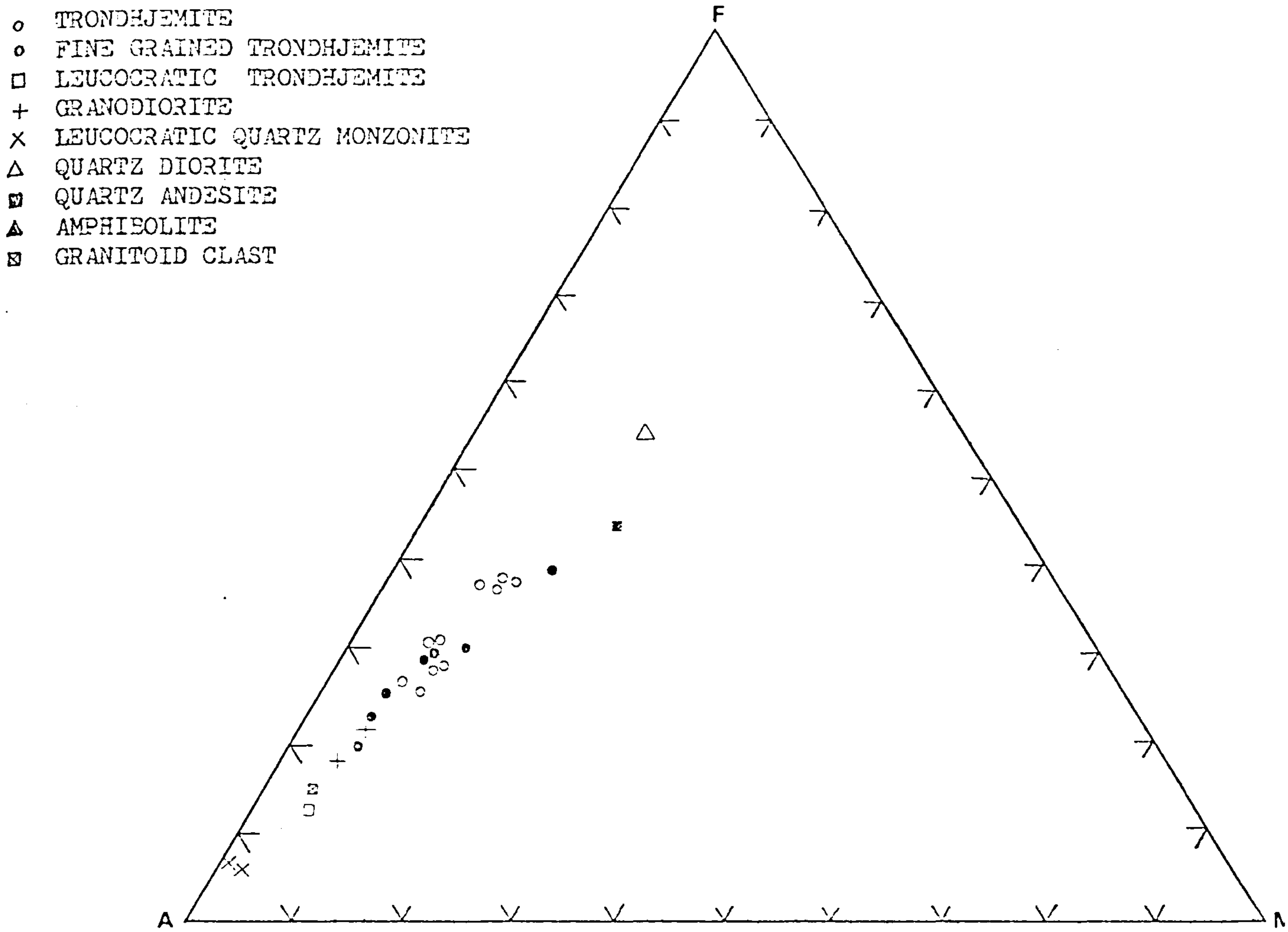


Figure 25: AFM

A: Total alkalies

F: Total Fe

M: Mg

in cation WT % summed to 100

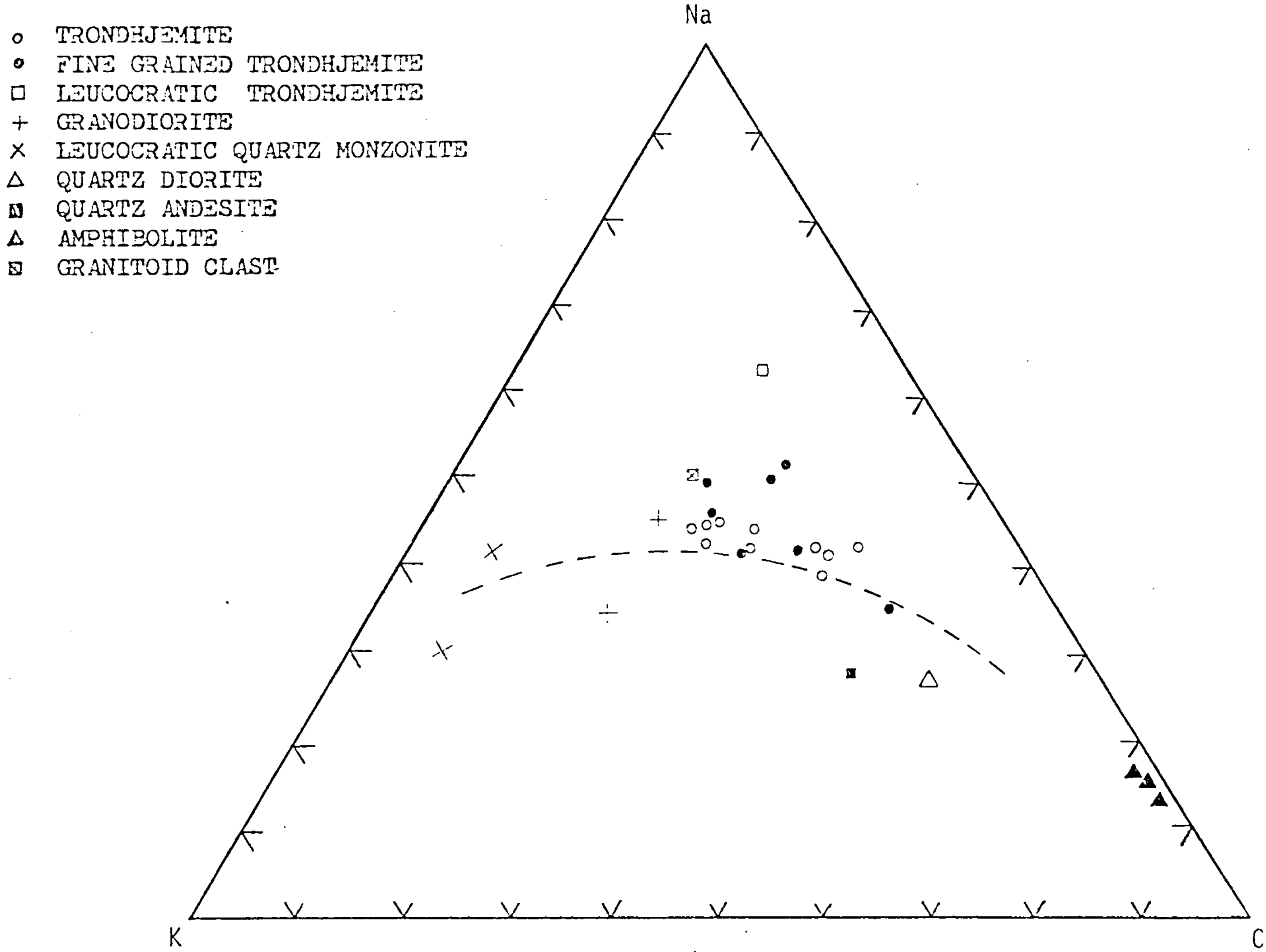


Figure 26: K:Na:Ca diagram
Dashed line is calc-alkalic trend of (Nockolds and Allen, 1953)

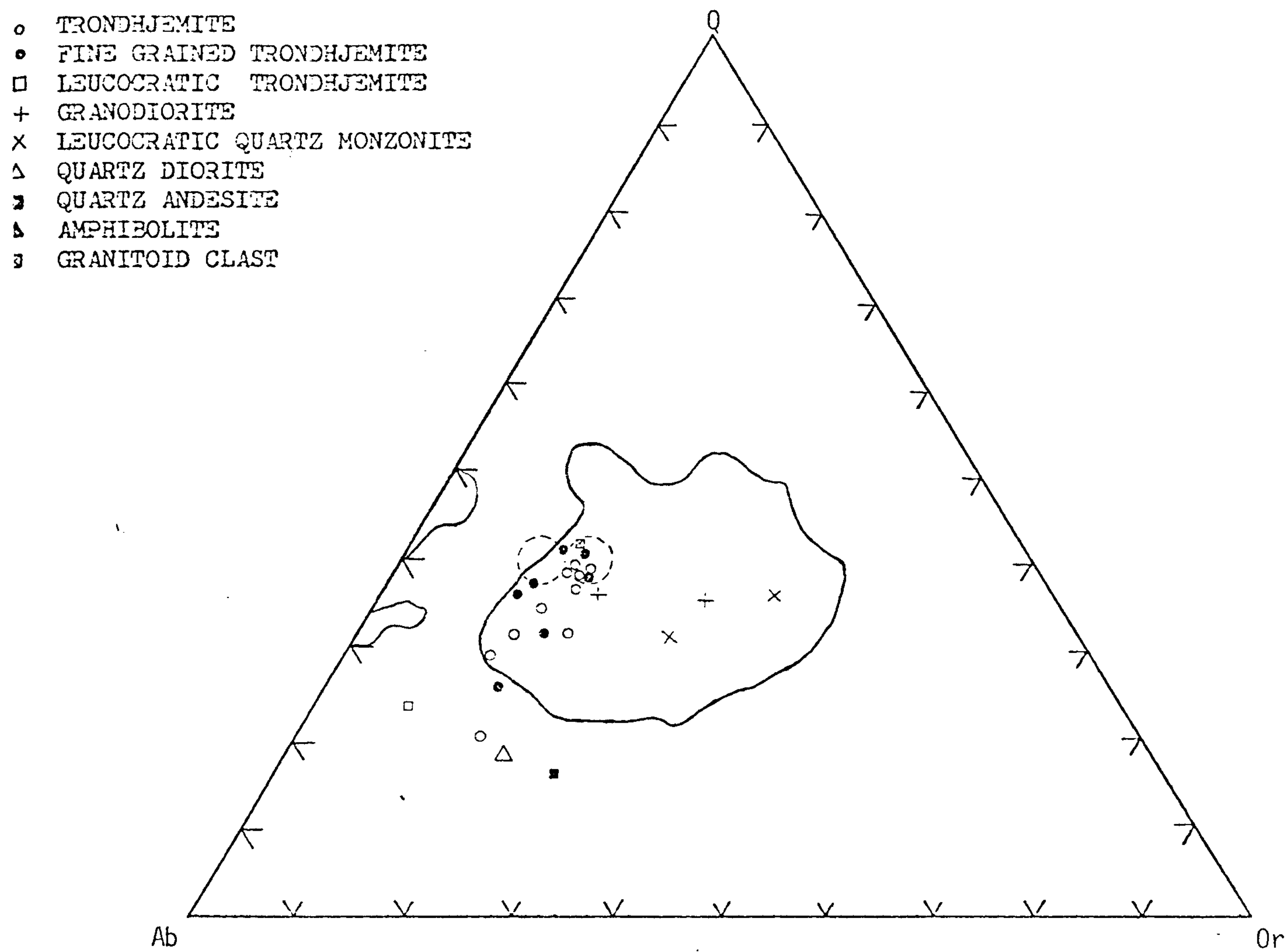


Figure 27: Normative Q-Ab-Or ternary plot. Solid irregular line is Winkler and Van Platen's (1961) area for granitic rocks. Dashed circles indicate the composition of anatectic melts produced experimentally at 720°C and PH_2O = 2000 bars.

towards the Ab end of the diagram.

Figure 28 is a plot of the normative percentage of Ab, An and Or in relation to An-Ab-Or-Q tetrahedron. The solid line is the low temperature trough of Kleeman (1965), into which the composition of granitic liquids should fall, irrespective of the pressure at which they are generated. Only one of the quartz monzonite samples lies within this thermal trough, while the other lies within Kleeman's (1965) uncertainty lines. All of the other samples plot outside of the 2% contour of Tuttle and Bowen (1958) for average granites, as expected since they are not true granites. These rocks lie on the plagioclase side of the thermal trough, and contain a significantly high amount of normative An, relative to Ab. Kleeman (1965) feels that liquids generated at high PH_2O would be richer in An for any given Or:Ab ratio, than those generated at low pressures. The overall aspect of this diagram suggests that magmatic rather than metasomatic processes prevailed.

3. Trace Element Trends

In considering the origin of trondhjemitic magmas previous authors (mentioned at beginning of chapter), have placed a good deal of emphasis on Rb and Sr concentrations, as well as K/Rb ratios.

The variation of Rb in the rocks as a function of DI is plotted on Figure 29. There appears to be a general increase towards the more acidic rocks as predicted by crystal-chemical principles (Dostal, 1975). Likewise, Sr vs DI (Figure 30) exhibits a general decline towards the more acidic rocks. This latter trend is characteristic of highly

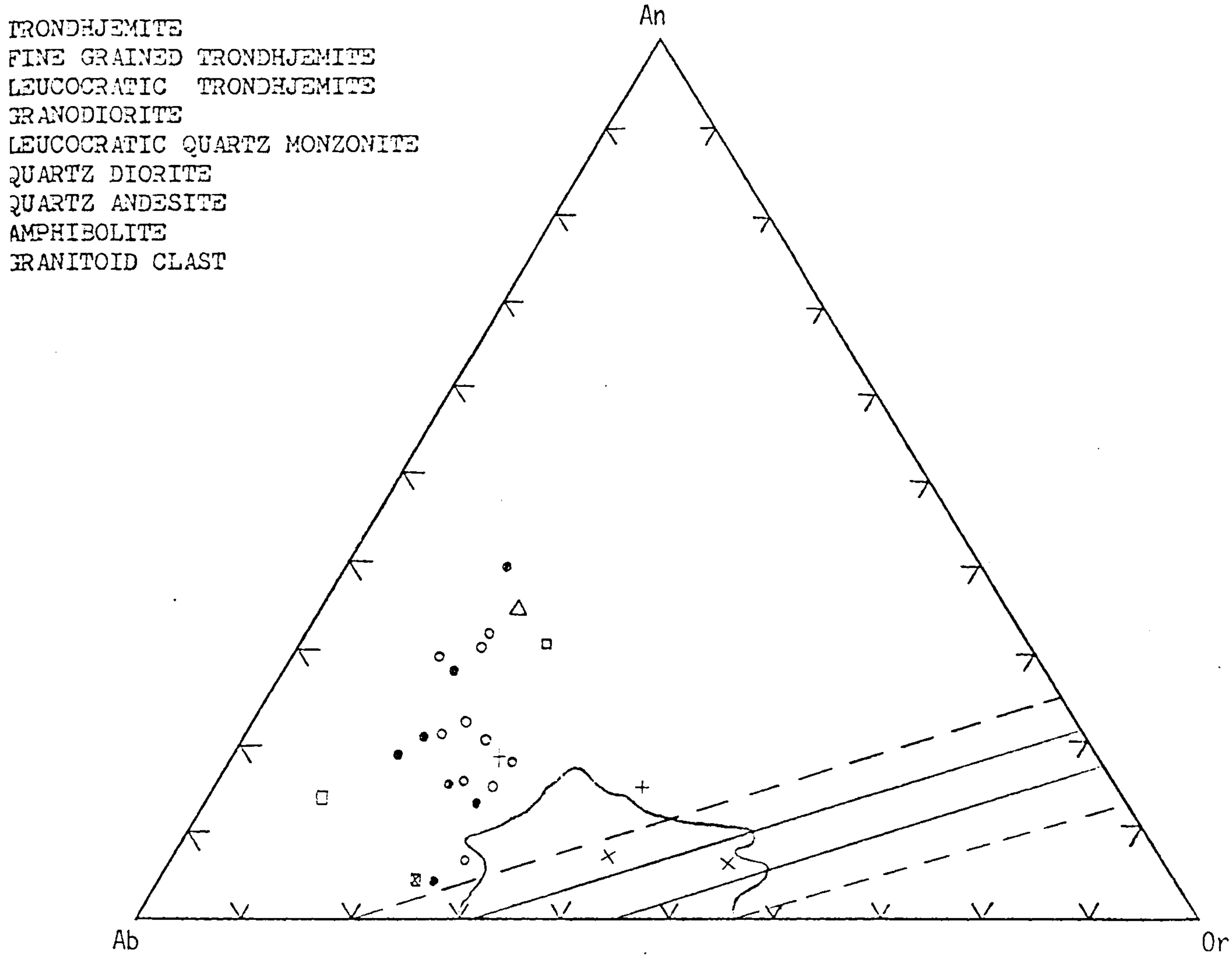


Figure 28: Normative An-Ab-Or ternary projection from the quartz apex.. Solid straight lines indicate the low temperature trough and dashed lines show the uncertainty due to analytical error (Kleeman, 1965). The irregular solid line represents the "Average Granites" of Tuttle and Bowen (1958). These rocks contain 80% or more normative Ab-An-Or.

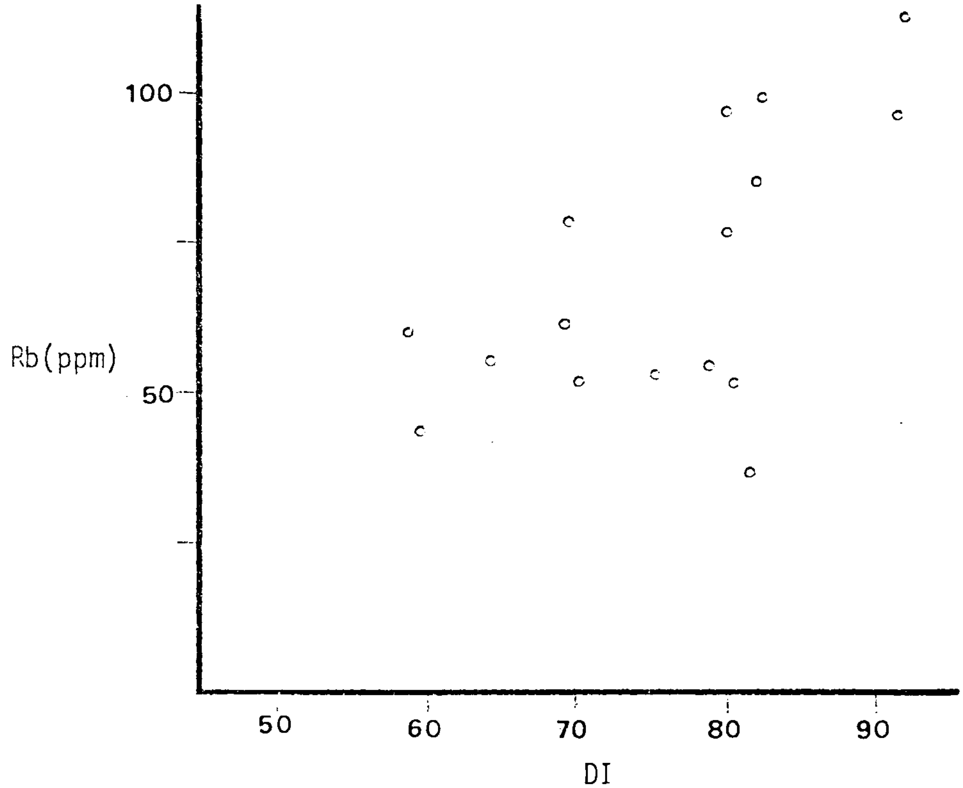


Figure 29: Variation of Rb as a function of DI

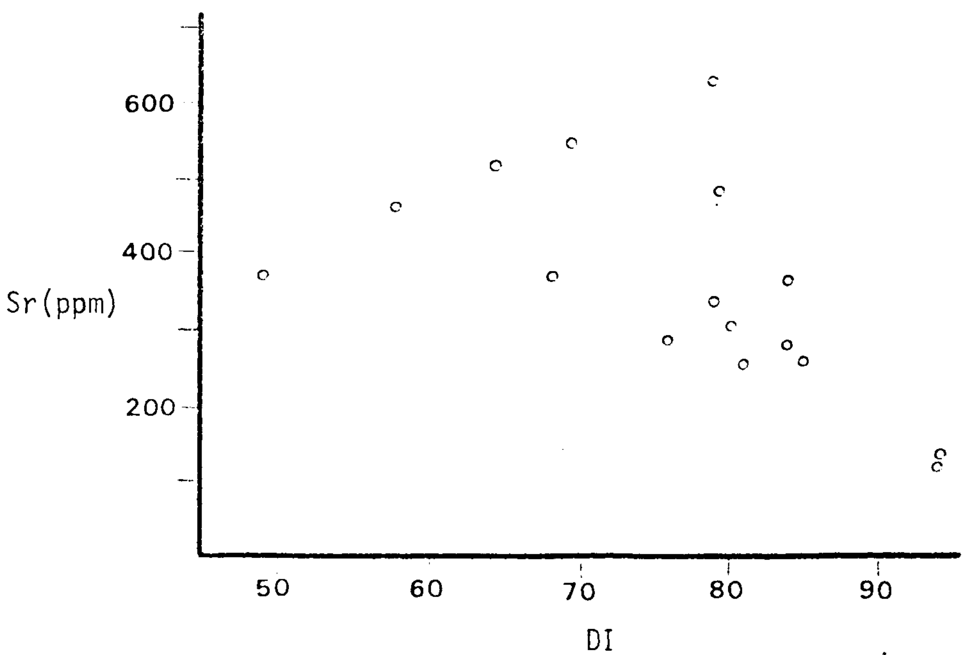


Figure 30: Variation of Sr as a function of DI

differentiated magmas in that during the crystallization of feldspars, Sr is taken up in the solid phase leaving late crystallizing phases Sr deficient (Dostal, 1975).

Figure 31 illustrates the variation of K with Rb and shows two trends. Most of the rocks (K/Rb = 200) exhibit a general tendancy for Rb enrichment relative to K, such as is expected if differentiation is from a single parental magma. A secondary trend (K/Rb = 400) occurs because of the high K/Rb values for the quartz monzonites. Figure 32 was plotted according to Dostal (1975) and once again we see that most of the rocks fall along a distinctive trend with the noticeable exception of the quartz monzonites. Unless the unusually high K/Rb values for thelatter can be explained, an argument against a comagmatic origin for these rocks could be put forth.

Table IV compares the average Rb, Sr, and K/Rb values of the Heron Lake trondhjemites against others. The most significant difference is the higher Rb values from Heron Lake which have resulted in lower K/Rb ratios. Heier and Adams (reported in Shaw, 1968) that the average K/Rb ratio for crustal rocks is 230 and from Table 8 we see that the average K/Rb values for trondhjemitic magmas thought to be derived from the mantle is generally greater than 450. This would insinuate that the Heron Lake trondhjemites formed as a result of the partial melting of lower crust/upper mantle material. However it is feasible that the ratios were originally higher and have since been reduced by one of three mechanisms discussed by Shaw (1968), namely; (a) Biotite accumulation (Rb is concentrated in biotite to a greater degree than in other rock forming minerals), (b) Metasomatism after separation of

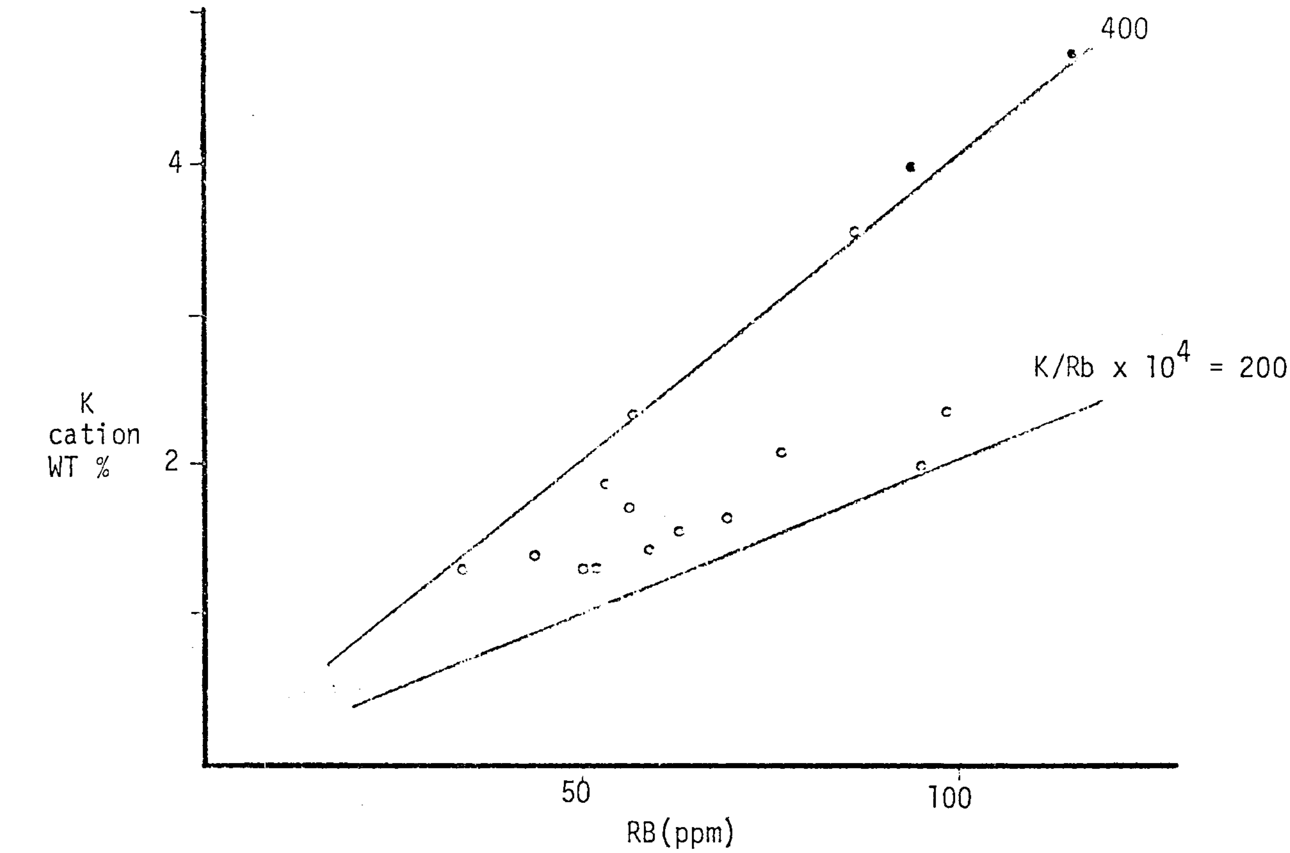


Figure 31: K vs Rb

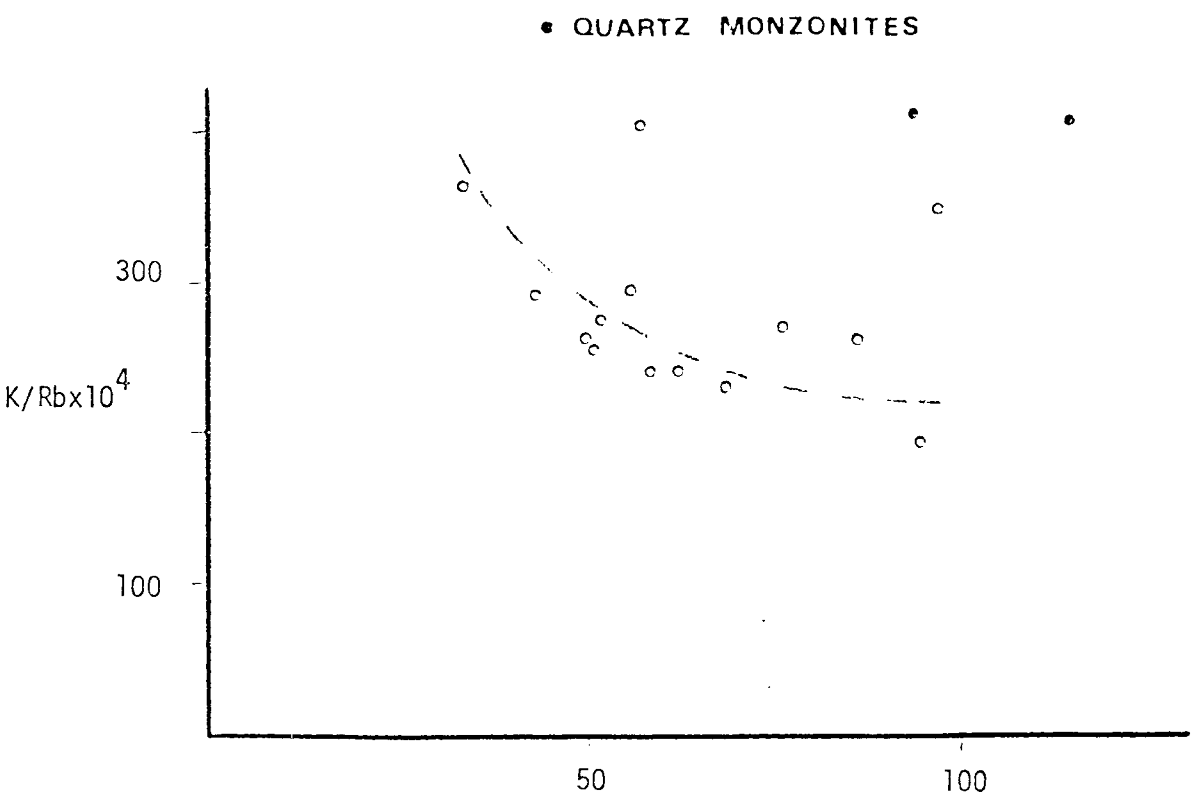


Figure 32: K/Rb vs Rb

TABLE IV

AVERAGE Rb, Sr and K/Rb VALUES

	(1)	(2)	(3)	(4)
Rb	66	28	27	14
Sr	432	101	730	1064
K/Rb	272	450	369	586

1. Heron Lake Stock Trondhjemites
2. Rio Brazos Trondhjemites (Barker, et al., 1976)
3. Trondhjemite-Tonalite, Northeastern Minnesota (Arth, 1975)
4. Saganga Tonalite (Hanson and Goldich, 1972)

aqueous fluids, (c) Crystallisation and removal of hornblende. In the case of the Heron Lake Stock, the first two possibilities must be seriously considered.

The quartz monzonite phase is also interesting because of its rather high K/Rb ratios (409-416). Slightly higher ratios were observed for the quartz monzonites of The Loon Lake Pluton (Dostal, 1975). He attributes these abnormally high ratios as being the result of the low Rb contents in the K-feldspars from monzonites, and states that the ratios are probably inherited from the original liquid from which they crystallized. The fact that the Heron Lake Stock quartz monzonites contain less than 2% modal biotite may also be a factor, since biotite concentrates Rb and tends to keep ratios low.

Overall, Ni is depleted as we go from the basic to the acidic phases of the stock, a trend that is consistent with a processes of fractionation (Dostal, 1975).

4. Summary

There is no doubt that the magma from which the Heron Lake Stock formed was water rich. Biotite and retrograde chlorite are the predominant mafic minerals and a high degree of sericitization and saussuritization has occurred. Secondary K-feldspar is a common occurrence in the granodiorites.

The leucocratic trondhjemite which occurs as minute veinlets intruding the trondhjemite probably represents a residual accumulation of quartz and Na-feldspar and is a minor local occurrence.

The leucocratic quartz monzónite is probably the product of an accumulation of residual alkaline rich fluids and was injected in the form of a small pod and numerous dikes. The perthites, characteristic of this unit, are probably the result of K-autometasomation rather than unmixing as suggested by Tuttle and Bowen (1958).

The relationship of the quartz diorite to the other phases is unclear. It occurs in minor amounts and appears intrusive in the eastern part of the stock. It may represent a distinct intrusive event. The quartz andesite is a late extrusive phase.

Three theories can now be postulated as to the origin of the Heron Lake Stock:

1. Complete or partial melting of lower crustal material, producing a trondhjemitic magma and a residual alkaline fluid in which K-autometasomatism occurs.

2. Partial melting of lower crust/upper mantle material producing a magma of trondhjemitic composition. The other phases were produced as a result of magmatic differentiation, fractional crystallization and residual alkaline fluids in which K-autometasomatism occurs.

3. Complete melting of the mantle producing a trondhjemitic magma. Fractional crystallization resulted in residual alkaline fluids producing the other phases.

The author favours the second model. It is most consistent with chemical trends. Models 1 and 3 cannot explain the K/Rb ratios and if we are to believe model 3 we might expect to find inclusions of ultramafics and eclogites rather than just amphibolites.

CHAPTER VI

CONCLUSIONS

1. The Heron Lake Stock is a magmatic pre-tectonic intrusion formed by partial melting of lower crust/upper mantle material.

2. The stock has been greatly affected by the metamorphic and tectonic events since its emplacement.

3. The fine grained trondhjemite is basically a chilled margin and slightly pre-dates the main trondhjemitic body.

4. The bulk composition of the stock is essentially trondhjemite.

5. Chemical trends are consistentwith and suggest derivation from a single parental magma accompanied by processes of magmatic differentiation and fractional crystallization.

6. K-autometasomatism predominantly occurs in the accumulated, residual, late stage alkali-rich fluids which are responsible for the occurrence of quartz monzonite.

1. Suggestions for Further Work

1. More whole rock and trace element data to try and establish trends across the stock.

2. More detailed mapping of the contact along the north and northwestern boundaries.

3. A petrographic and chemical analysis of the gneisses to the immediate northwest to examine the feasibility of the magma being formed by their complete or partial melting.

4. XRD analysis of the plagioclase to determine its composition.

5. REE studies to further clarify possible magmatic sources.

6. Determine the relationship of the quartz diorite by mapping and more chemical work.

7. Geochronology of the stock and the granitoid clasts to the south as well as chemical analysis of the latter, in an attempt to discern the relationship between the two.

APPENDIX

GEOCHEMICAL WHOLE ROCK AND TRACE ELEMENT DATA

ACCURACY OF XRF DETERMINATIONS

1. Powder Method

The powder method was used for trace element analysis. The accuracy of the XRF chemical analysis was checked by running standards as unknowns and comparing them to recommended values (Abbey, 1972). The standards used in constructing the calibration curve for Rb, Sr, Y, Zr and Nb were W-1, BR, GSP-1, NIM-G, GA, G-2, AGV-1 and BCR-1. The standards used in constructing the calibration curve for Ni were GSP-1, JG-1, BR, AGV-1, BCR-1, NIM-G, JB-1 and NIM-N.

The following is the result of running standards BR and BCR-1 as unknowns.

	BR (Recommended)	BR (Unknown)	BCR-1 (Recommended)	BCR-1 (Unknown)
Nb	90	86	17	21
Ni	270	260.2	13	16.1
Rb	45	39	50	42
Sr	1350	1286	330	341
Y	27	24	46	39
Zr	240	242	185	184

Errors are negligible

2. Fusion Method

Fusion was used for major oxide analysis. In this method the unknown was compared to one standard rather than a calibration curve composed of several standards. Counting rates for standard/unknown were computed using the following fusion standards: B-1, W-1, BCR-1, SY2, GSP-1, B3. These rates were calculated as a ratio (S/U).

A combination of the following criteria was used to determine the proper standard for the unknowns.

(1) The unknown that revealed the best S/U ratios (closest to 1) for each oxide.

(2) The unknown whose percent total was closest to 100, before normalization.

Based upon the above criteria W-1 and BCR-1 were used for low Si rocks (48-58 WT %) and GSP-1 was used for high Si rocks (>58 WT %).

TABLE V

WHOLE ROCK ANALYSES (NORMALIZED TO 100%) IN WEIGHT PERCENT OXIDES

SAMPLE	SiO_2	AL_2O_3	Fe_2O_3 (1)	FeO (2)	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O-	CO_2	TiO_2	P_2O_5	S	Mn(
K-3-16B	61.66	19.60	2.10	2.81	1.44	4.88	4.72	2.02	-	-	-	0.66	0.14	-	0.
K-2-12B*	62.50	16.30	1.68	2.87	1.94	4.78	4.51	1.50	1.13	0.22	1.22	0.66	0.19	0.01	0.0
K-10-3	66.21	16.94	2.04	2.23	1.50	4.52	4.02	1.82	-	-	-	0.54	0.13	-	0.0
K-10-17	66.31	16.92	2.02	2.17	1.47	4.34	4.53	1.56	-	-	-	0.52	0.11	-	0.0
K-2-5*	67.80	15.50	0.81	1.96	1.16	2.56	4.19	2.43	0.95	0.24	1.22	0.40	0.13	0.05	0.0
K-13-6B	68.08	16.06	2.08	1.40	1.21	3.16	4.42	2.73	-	-	-	0.58	0.25	-	0.0
K-2-19*	68.80	14.80	1.18	1.89	1.14	3.07	4.07	2.24	0.75	0.28	1.02	0.43	0.13	0.01	0.0
K-4-9	70.52	15.71	1.90	1.30	0.90	3.08	4.15	1.93	-	-	-	0.40	0.08	-	0.0
K-2-22	70.86	15.19	1.93	1.49	1.08	2.39	4.00	2.47	-	-	-	0.43	0.11	-	0.0
K-7-26	71.57	15.35	1.83	0.90	0.78	2.70	4.18	2.26	-	-	-	0.33	0.66	-	0.0
K-13-6A	60.69	19.09	2.30	2.23	2.06	6.09	3.97	1.56	-	-	-	0.80	0.21	-	0.1
-7-5A*	67.00	15.70	0.95	2.24	1.35	3.02	3.85	2.21	1.11	0.25	1.10	0.43	0.16	0.01	0.0
-9-8*	69.70	15.80	0.81	1.89	0.92	2.87	4.47	1.67	0.62	0.29	0.08	0.40	0.14	0.01	0.0
-9-10B*	70.20	16.00	0.65	1.26	0.74	2.44	4.96	2.42	0.26	0.31	0.08	0.28	0.11	0.01	0.0
-7-4*	70.40	15.00	0.76	1.33	0.70	2.32	4.22	2.32	0.83	0.31	1.50	0.31	0.14	0.01	0.0

Cont'd...

able V Cont'd...

SAMPLE	SiO_2	AL_2O_3	Fe_2O_3 (1)	FeO (2)	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	CO_2	TiO_2	P_2O_5	S	MnO
K-11-2	70.40	16.09	1.90	0.94	0.81	3.62	3.95	1.78	-	-	-	0.40	0.07	-	0.07
K-2-12A	70.41	16.62	1.85	0.57	0.67	2.95	4.88	1.60	-	-	-	0.35	0.07	-	0.07
K-7-11A	68.89	18.49	1.38	-	0.41	2.45	6.65	1.50	-	-	-	0.15	0.05	-	0.07
K-7-12	71.96	15.10	1.77	0.34	0.57	2.11	3.51	4.25	-	-	-	0.27	0.08	-	0.07
K-2-9	72.07	15.00	1.83	0.55	0.61	2.30	4.41	2.78	-	-	-	0.33	0.07	-	0.07
K-4-1C	74.43	14.80	0.58	-	0.15	0.96	4.24	4.71	-	-	-	0.10	0.01	-	0.06
K-7-40	75.65	13.82	0.65	-	0.08	0.99	3.00	5.67	-	-	-	0.09	0.01	-	0.07
K-4-4	56.51	15.84	3.11	6.52	3.45	7.09	3.54	1.73	-	-	-	0.61	0.46	-	0.14
K-13-32B	58.69	16.55	2.26	5.03	3.63	6.33	3.69	2.53	-	-	-	0.76	0.39	-	0.14
K-5-27	49.75	14.64	2.34	10.28	8.45	11.01	2.08	0.35	-	-	-	0.84	0.06	-	0.19
K-10-13	49.98	15.65	2.21	9.15	7.41	12.68	1.80	0.17	-	-	-	0.71	0.05	-	0.18
K-7-35	50.56	14.70	2.45	10.22	7.34	11.09	2.18	0.25	-	-	-	0.95	0.07	-	0.20
K-2-37A*	72.4	14.40	1.32	-	0.46	1.89	4.45	2.27	0.54	0.30	1.12	0.18	0.09	0.01	0.03

; Fe_2O_3 = 1.5 + % TiO_2 Irvine and Baragar (1971).

eO = $FeO_{TOTAL} - Fe_2O_3$.

nalyses by the Ontario Division of Mines.

TABLE VI

MODAL ANALYSES

SAMPLE	RK-3-16B	RK-2-12B	RK-10-3	RK-10-17	RK-2-5	RK-13-6B	RK-2-19	RK-4-9	RK-2-22	RK-7-26
Quartz	20.8	25.9	30.6	31.2	34.0	30.6	37.8	27.2	41.4	37.0
Plagioclase	66.4	65.0	48.4	51.6	56.2	46.8	56.0	62.2	55.4	56.6
K-feldspar	-	-	-	-	-	4.8	-	0.4	-	0.8
Biotite	0.4	3.0	17.4	15.6	-	10.4	4.0	9.6	0.8	3.4
Chlorite	11.6	5.0	-	-	7.0	-	1.6	-	1.6	0.2
Epidote	-	-	2.4	1.4	-	5.2	0.4	0.2	-	0.2
Carbonate	0.8	1.6	0.8	-	1.6	0.4	-	0.2	0.2	1.6
Sphene	-	-	-	0.2	0.2	0.4	-	0.2	-	0.2
Muscovite	-	-	-	-	-	1.2	-	-	-	-
Amphiboles	-	-	-	-	-	-	-	-	-	-
Opaques	-	-	-	-	1.0	-	-	-	0.2	-
Allanite	--	-	-	-	-	-	0.2	-	0.4	-
Points Counted	500	500	500	500	500	500	500	500	500	500

Cont'd...

Table VI Cont'd...

SAMPLE	RK-13-6A	RK-7-5A	RK-9-8	RK-9-10B	RK-7-4	RK-11-2	RK-2-12A	RK-2-23	RK-7-11C
Quartz	23.2	33.2	37.6	39.8	35.0	32.6	34.3	31.4	29.6
Plagioclase	53.2	60.0	45.6	47.2	57.8	45.4	61.0	65.2	64.6
K-feldspar	-	-	-	2.2	-	3.8	0.7	-	-
Biotite	17.8	-	6.0	6.6	2.0	13.8	1.9	2.4	5.4
Chlorite	2.6	5.4	5.4	-	2.0	-	1.5	1.0	-
Epidote	3.0	0.4	4.2	4.2	1.0	3.8	0.2	-	-
Carbonate	-	0.8	-	-	1.4	-	0.4	-	-
Sphene	0.2	0.2	-	-	-	0.4	-	-	0.2
Muscovite	-	-	0.8	-	-	0.2	-	-	0.2
Amphiboles	-	-	-	-	-	-	-	-	-
Opaques	-	-	0.4	-	0.8	-	-	-	-
Allanite	-	-	-	-	-	-	-	-	-
Points Counted	500	500	500	500	500	500	1000	500	500

Cont'd...

Table VI Cont'd...

SAMPLE	RK-7-12	RK-2-9	RK-2-29	RK-2-30	RK-4-1C	RK-7-40	RK-4-4	RK-13-32B	RK-2-37A
Quartz	31.3	36.4	38.0	34.0	22.6	30.2	12.4	15.2	42.2
Plagioclase	40.1	47.0	51.0	53.0	31.0	25.6	54.4	47.4	50.8
K-feldspar	20.4	9.8	6.8	9.2	43.6	43.2	-	3.0	-
Biotite	5.6	6.0	1.8	3.4	2.0	0.6	9.8	18.6	0.6
Chlorite	-	0.3	-	-	-	-	0.6	-	1.6
Epidote	2.4	0.4	1.4	-	0.8	0.4	0.8	12.2	2.6
Carbonate	-	0.1	1.0	0.4	-	-	-	-	1.6
Sphene	0.2	-	-	-	-	-	1.8	-	-
Muscovite	-	-	-	-	-	-	-	-	-
Amphiboles	-	-	-	-	-	-	19.8	1.6	-
Opaques	-	-	-	-	-	-	0.4	1.2	0.6
Allanite	-	-	-	-	-	-	-	-	-
Points Counted	500	1000	500	500	500	500	500	500	500

Cont'd...

Table VI Cont'd...

SAMPLE	RK-5-27	RK-7-35	RK-10-13
Quartz	2.5	4.2	-
Plagioclase	30.8	36.4	32.2
K-feldspar	-	-	-
Biotite	-	-	-
Chlorite	-	-	-
Epidote	1.0	0.4	13.4
Carbonate	-	-	0.2
Sphene	-	-	-
Muscovite	-	-	-
Amphiboles	65.3	58.4	54.0
Opaques	0.4	0.6	0.2
Allanite	-	-	-
Points Counted	500	500	500

TABLE VII

CIPW NORMS

SAMPLES	Q	or	ab	an	di	hy	ol	ct	il	ap	sp	he	mte	cor	DI
RK-3-16B	13.07	11.94	39.94	23.30	-	6.21	-	-	1.14	0.32	-	-	3.05	1.11	64.95
RK-2-12B	19.94	8.87	38.16	14.76	-	7.74	-	2.76	1.25	0.44	-	-	2.44	1.85	66.96
RK-10-3	23.55	10.76	34.02	21.58	-	5.40	-	-	1.03	0.31	-	-	2.96	0.45	68.32
RK-10-17	22.07	9.22	38.33	20.81	-	5.29	-	-	0.99	0.26	-	-	2.93	0.15	69.62
RK-2-5	29.54	14.36	35.46	4.14	-	5.23	-	2.78	0.76	0.30	-	-	1.17	4.46	79.36
RK-13-68	24.02	16.13	37.40	14.05	-	3.08	-	-	1.10	0.58	-	-	3.02	0.69	77.56
RK-2-19	30.57	13.24	34.44	7.93	-	4.72	-	2.32	0.82	0.30	-	-	1.71	2.77	78.25
RK-4-9	31.15	11.41	35.12	14.76	-	2.53	-	-	0.76	0.19	-	-	2.76	1.39	77.67
RK-2-22	31.45	14.60	33.85	11.14	-	3.27	-	-	0.82	0.26	-	-	2.80	1.85	78.90
RK-7-26	31.83	13.36	35.37	13.00	-	1.94	-	-	0.63	0.14	-	0.31	2.21	1.26	80.55
RK-13-6A	15.62	9.22	33.59	28.84	-	6.19	-	-	1.52	0.49	-	-	3.34	0.30	58.43
RK-7-5A	29.88	13.06	32.58	6.99	-	6.07	-	2.50	0.82	0.37	-	-	1.38	4.41	75.52
RK-9-8	29.38	9.87	37.82	12.82	-	4.53	-	0.18	0.76	0.32	-	-	1.17	1.94	77.08
RK-9-10B	25.66	14.30	41.97	10.88	-	3.21	-	0.18	0.53	0.26	-	-	0.94	1.23	81.93
RK-7-4	34.82	13.71	35.71	1.11	-	3.12	-	3.41	0.59	0.32	-	-	1.10	5.14	84.24
RK-11-2	31.84	10.52	33.42	17.50	-	2.02	-	-	0.76	0.16	-	0.45	2.10	1.25	75.79

Cont'd...

Table VII Cont'd...

SAMPLES	Q	or	ab	an	di	hy	ol	ct	il	ap	sp	he	mte	cor	DI
RK-2-12A	28.78	9.46	41.29	14.18	-	1.67	-	-	0.67	0.16		1.13	1.05	1.67	79.53
RK-7-11A	18.80	8.87	56.27	11.58	-	1.02	-	-	0.15	0.12	0.18	1.14	-	1.68	83.94
RK-7-12	30.13	25.12	29.70	9.95	-	1.42	-	-	0.51	0.19	-	0.40	0.54	1.08	84.95
RK-2-9	30.14	16.43	37.32	10.95	-	1.52	-	-	0.63	0.16	-	1.11	1.05	0.72	83.88
RK-4-1C	29.51	27.84	35.88	4.59	-	0.37	-	-	0.13	0.02	0.08	0.58	-	1.05	93.23
RK-7-40	34.29	33.51	25.39	4.81	-	0.20	-	-	0.15	0.02	0.03	0.65	-	0.99	93.19
RK-4-4	9.22	10.22	29.96	22.22	8.81	11.58	-	-	3.06	1.07	-	-	4.51	-	49.40
RK-13-32B	8.43	14.95	31.22	21.13	6.33	12.32	-	-	1.44	0.90	-	-	3.28	-	54.61
RK-5-27	-	2.07	17.60	29.58	20.21	20.97	4.44	-	1.60	0.14	-	-	3.39	-	19.67
RK-10-13	0.49	1.01	15.23	34.12	23.34	21.13	-	-	1.35	0.12	-	-	3.55	-	20.65
RK-7-35	0.73	1.48	18.45	29.59	20.55	23.70	-	2.55	0.34	0.21	-	-	0.90	4.00	87.23

TABLE VIII

TRACE ELEMENT ANALYSES IN PPM

SAMPLE	Rb	Sr	Y	Zr	Nb	Ni
Trondhjemite						
RK-3-16B	56	518	12	222	107	18.4
RK-10-3	62	379	11	199	77	33.3
RK-10-17	51	549	9	192	103	32.9
RK-13-6B	56	633	8	161	13	19.7
RK-4-9	69	344	7	195	70	33.0
RK-2-22	76	350	17	182	71	28.5
RK-7-26	95	251	11	164	53	26.1
Fine Grained Trondhjemite						
RK-13-6A	44	460	18	243	97	35.6
RK-11-2	53	295	6	171	60	15.1
RK-2-12A	50	484	9	194	93	16.2
Leucocratic Trondhjemite						
RK-7-11A	34	377	8	202	73	10.9
Granodiorite						
RK-7-12	99	259	10	249	63	17.5
RK-2-9	86	275	11	177	56	17.2
Leucocratic Quartz Monzonite						
RK-4-1C	94	114	91	201	9	11.6
RK-7-40	115	129	13	69	12	19.2
Quartz Diorite						
RK-4-4	59	376	33	133	27	46.5
Quartz Andesite						
RK-13-32B	78	1321	18	180	17	24.1

Cont'd...

Table VIII Cont'd...

SAMPLE	Rb	Sr	Y	Zr	Nb	Ni
Amphibolite						
RK-5-27	4	109	18	45	2	141.5
RK-7-35	8	136	26	74	14	129.2
RK-10-13	1	96	20	51	2	178.6

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HERON LAKE STOCK
1KM
0 SCALE 1MILE
1A MAFIC METAVOLCANICS, DERIVED AMPHIBOLITES
1B LAPILLI TUFF, TUFF BRECCIA
2A FELSIC METAVOLCANICS
3A QUARTZ ANDESITE, OCCURS AS DIKES ONLY
4A POLYMICTIC METACONGLOMERATE (GRANITOID CLASTS)
5A TRONDHJEMITE
5B FINE GRAINED TRONDHJEMITE
5C LEUCOCRATIC TRONDHJEMITE, OCCURS AS VEINS ONLY
6A GRANODIORITE
7A QUARTZ DIORITE TO DIORITE
8A LEUCOCRATIC QUARTZ MONZONITE
SYMBOLS
SMALL BEDROCK OUTCROP
AREA OF BEDROCK OUTCROP
FOLIATION, (INCLINED, VERTICAL, DIP UNKNOWN)
LINEATION, (HORIZONTAL, INCLINED)
FAULT
SHEARING AND DIP
GEOLOGICAL BOUNDARY
IF IRON FORMATION
INTERMITTENT STREAM
SECONDARY ROADS
TRAILS
GEOLOGY BY R. T. KUSMIRSKI, 1976.
0 200 MILES
MANITOBA
MAP AREA
KENORA
U.S.A.
N
90°45'
90°40'
50°28'
50°27'
50°26'
WINSOME LAKE
CURLEW LAKE
HERON LAKE
KASHAWEOGAMA LAKE
HIGHWAY #599


WINSOME LAKE
RK-13-6A,WR,MA
-6B
RK-13-32B,WR,MA
RK-9-10B,WR,MA
RK-9-8,,WR,MA
RK-5-27,WR,MA
RK-11-2,WR,MA
RK-10-13,WR,MA
RK-10-3,WR,MA
RK-10-17,WR,MA
RK-4-9,WR,MA
RK-4-4,WR,MA
RK-4-1C,WR,MA
RK-7-26,WR,MA
CURLEW LAKE
RK-7-12,
WR,MA
RK-7-40,WR,MA
35,WR,MA
RK-7-11A,WR
-11C,MA
RK-7-5A,WR,MA
RK-7-4,WR,MA
RK-3-16B,WR,
MA
HERON
LAKE
RK-2-31,WR,MA
RK-2-30,MA
RK-2-29,MA
RK-2-19,
WR,MA
RK-2-
22,WR,MA
RK-2-12A,WR,MA
-12B
RK-2-5,WR,MA
RK-2-9,WR,MA
RK-2-34,MA
RK-2-37A,WR,MA
KASHAWEOGAMA LAKE
SAMPLE LOCALITY MAP
SMALL BEDROCK OUTCROP
AREA OF BEDROCK OUTCROP
MA LOCATION OF MODAL ANALYSIS
WR LOCATION OF CHEMICAL ANALYSIS
GEOLOGICAL BOUNDARY
INTERMITTENT STREAM
TRAILS
SECONDARY ROADS
N
1KM
0
SCALE
1
MILE