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PETROLOGY AND GEOCHEMISTRY
OF THE HERON BAY
AREA GRANITES
SUPERIOR PROVINCE, NORTHWESTERN ONTARIO

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OF THE HERON BAY AREA GRANITES
SUPERIOR PROVINCE, NORTHWESTERN ONTARIO

By

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SCOPE AND CONTENTS:

The Heron Bay area, located in the Wawa Belt of the Superior Province in northwestern Ontario, contains portions of three granitoid batholiths. Petrographic and chemical analysis revealed that nine different phases existed among the three batholiths:

- | | |
|----------------------------|---|
| PIC BATHOLITH | 1. Porphyritic quartz monzodiorite |
| (most northerly batholith) | 2. Biotite hornblende quartz monzodiorite |
| | 3. Biotite hornblende granodiorite |
| HERON BAY | 1. Porphyritic (K-feldspar) granodiorite |
| BATHOLITH | 2. Hornblende biotite granodiorite |

PUKASKWA GNEISS COMPLEX

- (most southerly batholith)
1. Porphyritic trondhjemite
 2. Granite
 3. Porphyritic granodiorite
 4. Hornblende biotite granodiorite

Each phase is distinctive through its mineralogy and texture.

Chemical variation diagrams suggest that the batholiths were formed from at least two different magmas though perhaps phases present within the individual batholiths are a result of magmatic differentiation from a single magma.

The high K/Rb ratios in the more mafic phases suggest that they were produced from a magma that was derived from partial melting of the upper mantle/lower crust rocks.

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CHAPTER I

INTRODUCTION

1. LOCATION AND ACCESSIBILITY

The Heron Bay Area is situated on the north shore of Lake Superior in the District of Thunder Bay and is part of the Wawa Belt of the Superior Province of the Canadian Precambrian Shield. It is bounded by longitudes $86^{\circ}07'30''\text{W}$ and $86^{\circ}22'30''\text{W}$ and by latitudes $48^{\circ}33'\text{N}$ and $48^{\circ}45'\text{N}$, giving it an area of about 310 km^2 . It can be located on maps 42D/9 of the National Topographic Series (Marathon Sheet) and the Ontario Division of Mines Compilation map 2220.

Most of the Pic Township and parts of Lecouer Township, Cotte Township and Mussy Lake area, are included in the Heron Bay Area. The town of Marathon, located just outside the north eastern boundary of the area, is about 301 km from Thunder Bay to the west, 405 km from Sault St. Marie to the east, and 98 km from Manitouwadge to the north-east (see Figure I-1).

Figure I-1 Location Map: Heron Bay Area (area enclosed by dots)
Scale: 1"=20 mi

Access to most of the area is provided by the Trans-Canada Highway (Highway 17), Highway 627, the Canadian Pacific Railway, the Pic River, the Black River and Lake Superior. More specifically, access to the sample area of the Pic Batholith was accomplished via the Black River and Sweede Creek, access to the sample area of the Heron Bay Batholith was possible by walking south from Highway 17 at Melgund Lake and finally, access to the Pukaskwa Gneiss complex was accomplished using a hydro access road than ran south off Highway 17 approximately 23 km east of Marathon.

2. PREVIOUS WORK

In 1872 Robert Bell (1872) reported small gold prospects in the vicinity of Heron Bay but it was not until 1930 that the Heron Bay Area was mapped. This was done by Thompson (1931) on a reconnaissance scale (1 in to 1.5 mi), at which time he determined the major geologic relationships and roughly defined the boundaries of the three major granitoid bodies studied in this report. They were all classified generally as hornblende biotite granite and gneiss. The Port Coldwell complex has been reported on by Pukas (1967).

During the field season of 1977 a detailed mapping project (1 in to 1/4 mi) of the Heron Bay Area was undertaken by the Ontario Geological Survey under the supervision of T.L. Muir. At this time the boundaries of the three granitoid bodies were more accurately determined and named as the Pic Batholith*, the Heron Bay Batholith and the Pukaskwa Gneiss Complex. Preliminary results of this study have been published (Muir, 1979).

3. STATEMENT OF PROBLEM

In August 1978, under the employment of the Ontario Geological Survey, the author investigated the three granitoid bodies of the Heron Bay Area.

The aim of the project was to sample the three granitoid bodies and to identify any chemical and petrographical variations to determine if they are in any way genetically related.

A generally north-south trending traverse of approximately 2 miles in length was run into each batholith beginning at its contact with the country rock. Some

*Note: the Pic Batholith is referred to as the Gowan Lake Pluton in Muir (1979).

sixty samples were collected. Of these, eighteen representative samples were selected for thin section and chemical analysis.

CHAPTER II

GENERAL GEOLOGY

Detailed geology (1 in = 1/4 mi) of the Heron Bay Area is reported by T.L. Muir (1979) and is shown on Preliminary Maps P1981 and P1982 of the Ontario Geological Survey Geological Series (see Appendix C).

The area consists chiefly of three granitoid bodies separated by metavolcanics and metasediments, all of which are considered to be of Archean age (no absolute dates are available). Massive intrusive rocks of the Port Coldwell Complex are found in the north west part of the area and have an estimated age of $\pm 1,050$ m.y. (i.e. Proterozoic) based on K/Ar dating of the syenites (Pukas, 1967). This complex is composed mainly of hornblende syenite and is intruded by a variety of alkalic dikes of syenitic gabbroic and ultramafic composition.

Large deposits of Pleistocene cover are found bordering the Pic River and Highway 17 east of the Pic River. A large area of glacial outwash is also found south of Pen Lake.

Diabase dikes are observed cutting all Archean rocks and generally have a northwest, north, or northeast trend. They are not found in the Port Coldwell Complex.

The Pic Batholith is situated in the most northerly part of the map area. Its northern and eastern perimeter extends outside the map boundary. The exposed portion within the map area has dimensions of approximately 5.6 x 4.4 km. It is composed mostly of porphyritic biotite hornblende quartz-monzodiorite, but phases of nonporphyritic quartz monzodiorite and biotite hornblende granodiorite were also found in the sample area. A weak foliation trending northwest to east-west was present.

The Pic Batholith is separated by approximately 4 km from the Heron Bay Batholith which lies in the east central region of the map area. The intervening area is comprised mainly of intermediate to felsic lapilli tuffs and mafic flows. The north-south dimension of the Heron Bay Batholith is approximately 5.6 km, while the east-west dimension included in the map area is approximately 9.0 km. The petrology of the sampled area showed little variation having only two phases present: a hornblende granodiorite phase and a porphyritic granodiorite phase. No distinctive structures were evident within the batholith.

A generally east-west trending belt of metasediments and metavolcanics lies south of the Heron Bay Batholith separating it from the Pukaskwa Gneiss complex by a minimum distance of 3.2 km. The metavolcanics in this belt consist mainly of massive mafic flows and pillowed flows in the southern portion, while in the northern portion they are represented mostly by intermediate to felsic pyroclastic breccia, lapilli tuff and crystal tuff. Narrow units of metasediment, commonly light brown or grey arkoses or wackes, and zones of ultramafics are found interbedded with the metavolcanics.

The Pukaskwa Gneiss Complex extends across the entire southern portion of the map area from Lake Superior to the eastern boundary, a distance of nearly 11.5 km. It is composed mainly of granodiorite and trondhjemite. A distinct foliation is generally present with some areas showing a gneissic texture.

The overall metamorphic grade in the area is middle to upper greenschist, except near the Port Coldwell Complex, where grades as high as the amphibolite facies are present.

Structurally, the most complex region of the Heron Bay River is found in the rocks which extend north between the Port Coldwell Complex and the Pic Batholith since they

show strong deformation and distortion. The volcanic and sedimentary rocks generally trend east-west and tend to follow the boundaries of the granitic intrusion as a result of regional deformation. The units between the Heron Bay Batholith and Pukaskwa Gneiss Complex dip north, while the units between the Heron Bay and Pic Batholiths appear to be inclined upwards as a result of the intrusion of these two bodies (Muir and Barnett, 1978).

South of the Heron Bay Batholith faults and lineations show a predominant east-west trend while north of this area they vary in orientation from northwest to northeast.

CHAPTER III

PETROGRAPHY

1. INTRODUCTION

Petrographic studies of samples representative of the different phases found in each granitic body were made. Sample locations can be found plotted on the map in Appendix C and petrographic descriptions of representative samples appear in Appendix A.

Table III-1 illustrates the average modal composition of the different phases found. Since the granite phase and hornblende granodiorite phase of the Pukaskwa Gneiss Complex are only represented by one sample, their modal analysis are found in Appendix A. Sample D42 and D39 correspond to the hornblende granodiorite and the granite phase, respectively.

(i) Modal Analyses

Thin sections were stained with sodium cobaltnitrate for plagioclase feldspar to facilitate point counting.

Table III-1 Modal Variations (average %)

	PIC BATHOLITH			HERON BAY BATHOLITH		PUKASKWA GNEISS COMPLEX	
	Porphyritic Quartz Monzodiorite	Biotite Quartz Monzodiorite	Biotite Hornblende Granodiorite	Hornblende Biotite Granodiorite	Porphyritic Grano- diorite	Porphyritic Trondj- hemite	Porphyritic Grano- diorite
Quartz	16.2	10.5	25.5	21.4	20.0	37.9	25.0
Plagioclase	45.1	45.25	37.4	49.0	50.3	46.7	48.2
K-feldspar	17.6	17.35	25.6	13.3	14.6	2.6	9.6
Hornblende	7.45	9.5	4.4	5.7	3.5	-	4.2
Biotite	8.4	11.65	5.2	4.4	5.4	7.3	7.2
Epidote	1.4	1.45	0.6	2.5	1.9	3.9	3.8
Chlorite	1.2	3.5	0.7	2.1	1.9	0.8	0.7
Sphene	1.7	-	-	0.5	0.3	-	1.7
Apatite	0.9	0.3	0.8	1.0	0.9	0.1	-
Allanite	0.8	0.4	0.4	0.2	tr.	0.5	-
Opques	0.3	-	tr.	tr.	tr.	0.4	0.1

Approximately 500 points were counted on each thin section with the point distance being approximately equal to the largest grain size. For these conditions an error of approximately 4% for the content would be expected. Increasing the counts to 1000 would only decrease the error by 1% (Van der Plas and Tobi, 1965). Modal analyses of the representative samples are summarized in Table A-1 in Appendix A.

From the modal analyses plagioclase K-feldspar and quartz were plotted on Figure III-1. This diagram supplemented with textural evidence the colour index diagram, Figure III-2, helped classify the phases found in the three batholiths.

2. PIC BATHOLITH PETROGRAPHY

In the Pic Batholith, the most northerly and generally the most basic granitic body, three different phases were found: porphyritic quartz monzodiorite, biotite hornblende quartz monzodiorite and biotite hornblende granodiorite.

i. Porphyritic Quartz Monzodiorite

This unit plots on Figure III-1 in the quartz monzodiorite field. It is characterized by poikilitic insets of

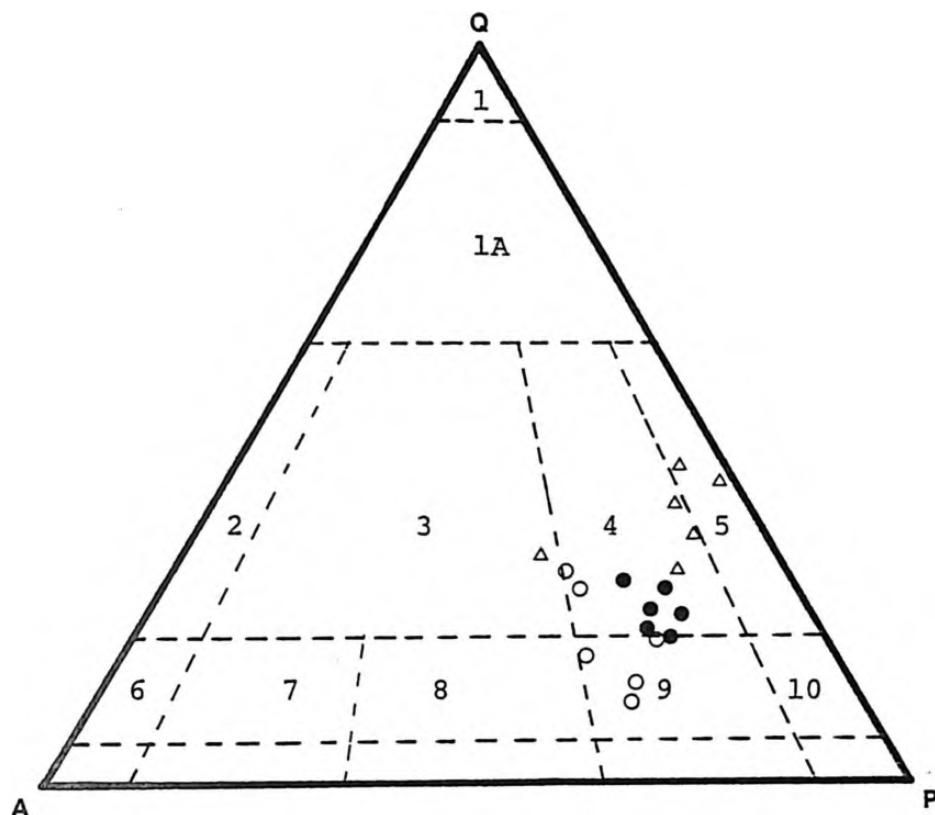


Figure III-1 Quartz-Alkali Feldspar-Plagioclase Diagram
(IUGS, 1973)

- | | | | |
|----|-------------------------|----|------------------------------|
| 1 | Quartz | 6 | Alkali-feldspar quartz syeni |
| 1A | Quartz rich granitoids | 7 | Quartz-syenite |
| 2 | Alkali-feldspar granite | 8 | Quartz-monzonite |
| 3 | Granite | 9 | Quartz-monzodiorite |
| 4 | Granodiorite | 10 | Quartz diorite |
| 5 | Tonalite | | |
| ○ | Pic Batholith | | |
| ● | Heron Bay Batholith | | |
| △ | Pukaskwa Gneiss Complex | | |

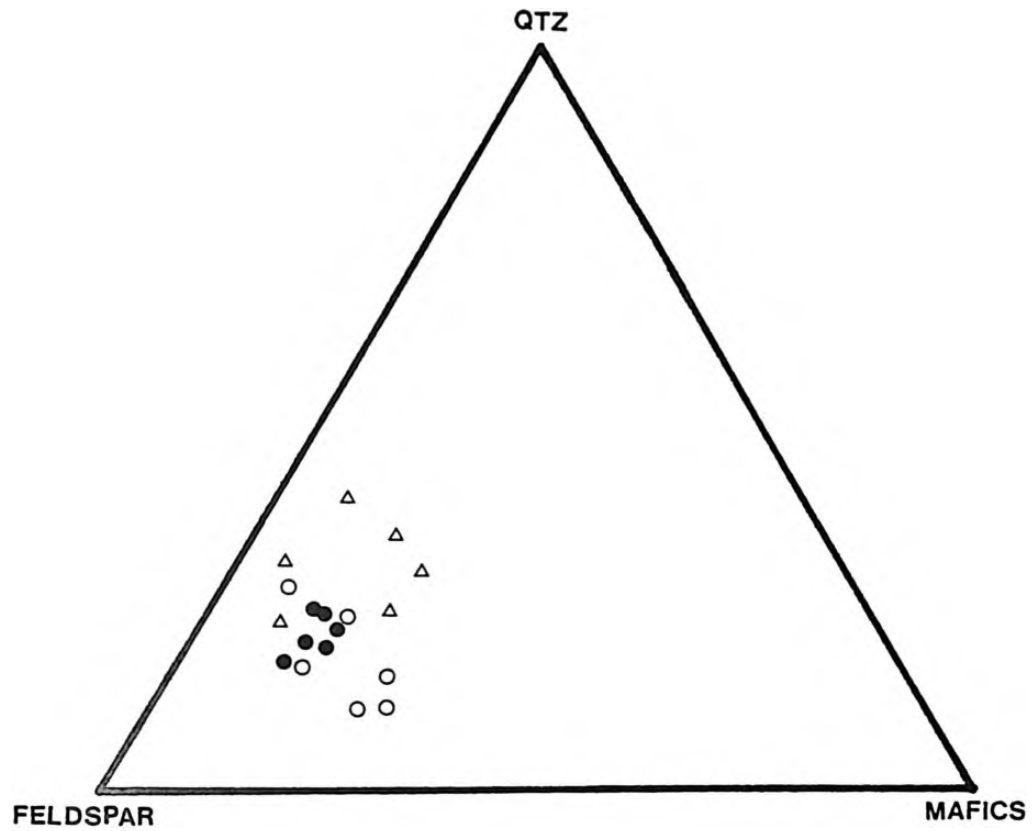


Figure III-2 Quartz-Totals Feldspar-Totals Mafic Diagram

- Pic Batholith
- Heron Bay Batholith
- △ Puskaskwa Gneiss Complex

microcline (see Figure III-3), varying in size up to 1 cm, in a medium grained, holocrystalline hypidiomorphic matrix composed predominantly of plagioclase and quartz. The inclusions in the microcline consist of quartz, plagioclase and biotite. Microcline is also found interstitially. Trace amounts of myrmekite were found associated with the k-feldspar in sample D-19 (see Appendix A).

Plagioclase is the major mineral component. It occurs in subhedral to euhedral grains having a typical length of 4 mm and is generally strongly altered to the degree where twinning is unrecognizable and the plagioclase composition cannot be determined.

The predominant mafic mineral is biotite though amphibole is also abundant. Much of the biotite occurs as an alteration of the amphibole, rimming the amphibole in small euhedral to subhedral crystals. Epidote and chlorite are also present as alteration products of the biotite.

Quartz is found interstitially in anhedral grains up to 3 mm in diameter. Accessory minerals include idiomorphic grains of sphene and skeletal apatite.

ii. Biotite Hornblende Quartz Monzodiorite

Mineralogically this phase is very similar to the porphyritic quartz monzodiorite plotting in the quartz monzo-

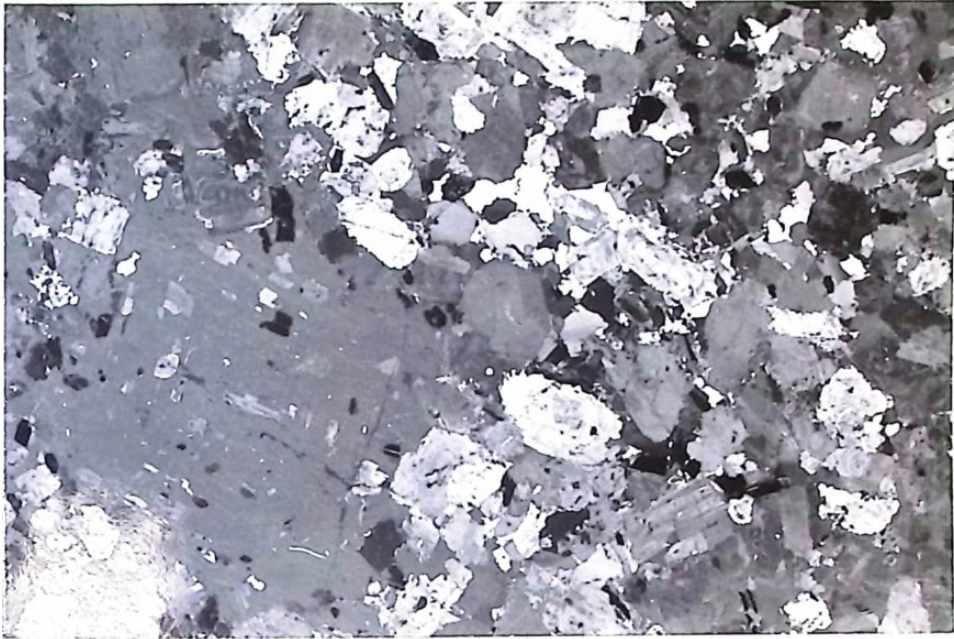


Figure III-3 Poikilitic microcline with inclusions of quartz, plagioclase and biotite (sample D-25, x nicols, 10x)

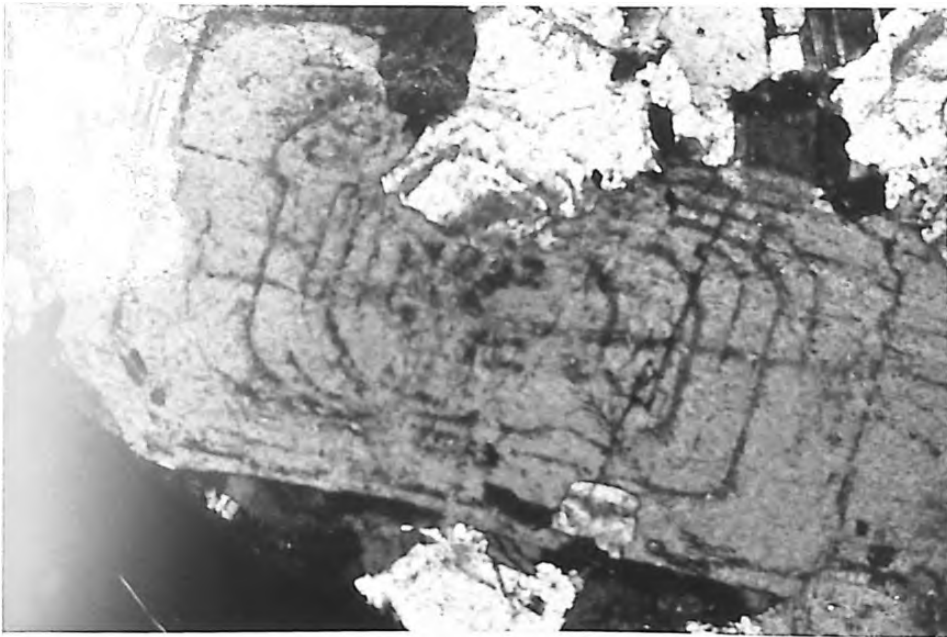


Figure III-4 Zoned plagioclase showing sericitization along zone boundaries (sample D-5, x nicols, 25x)

diorite field, but lacks the microcline insets.

It is characterized by a medium grained holocrystalline, hypidiomorphic granular texture with small (0.5 mm to 2 mm) xenomorphic crystals of microcline occurring interstitially. The microcline is commonly poikilitic containing inclusions of quartz biotite and plagioclase.

Again, plagioclase is the predominant mineral constituent occurring in anhedral to subhedral grains never exceeding 4 mm in length. Though some albite twinning is present the generally strong sericitization makes it difficult to determine its composition.

Biotite and hornblende are present in about equal abundances and generally occur in small clots. The biotite tends to form in subhedral laths less than 1 mm in length and is secondary. It commonly contains zircons and shows alteration to chlorite and minor amounts of opaques.

Accessory minerals, along with sphene, include skeletal apatite and allanite.

iii. Biotite Hornblende Granodiorite

This typical allotriomorphic, medium grained equigranular unit plots on Figure III-1 in the granodiorite field but close to the granite, granodiorite quartz monzodiorite and quartz monzonite junction.

The plagioclase occurs as subhedral to anhedral grains with lengths up to 3 mm. They are generally sericitized but commonly show albite twinning. Extinction angles for the albite twins average around 15° . This, combined with a negative optic sign, suggests that it has a composition of $An_{21}-An_{40}$. Some plagioclase grains are poikilitic with inclusions of biotite, quartz and K-feldspar.

Microcline is present as interstitial anhedral grains with a range in size from 0.1 mm to 3 mm. They commonly have inclusions of quartz and plagioclase.

Biotite and hornblende are the predominant mafic minerals with biotite being slightly more abundant. The biotite is anhedral to subhedral and generally occurs as an alteration of hornblende, though some primary biotite is present. It is commonly altered to chlorite and epidote.

Quartz typically occurs as subhedral interstitial grains with a maximum size of 2 mm.

3. HERON BAY BATHOLITH

The Heron Bay Batholith, situated between the more southerly Pukaskwa Gneiss Complex and the more northerly Pic Batholith, is petrographically very homogeneous having only a granodiorite and a porphyritic granodiorite phase

in the map area sampled.

i. Hornblende Biotite Granodiorite

Modally, this unit plots in the granodiorite field in Figure III-1. It is medium grained, holocrystalline, hypiomorphic granular in character and is characterized by distinctively zoned subhedral to euhedral plagioclase (see Figure III-4). The plagioclase grains vary in size from 0.5 mm to 5 mm in length and are generally sericitized along the zone boundaries. Carlsbad and weak albite twins were present allowing a composition estimate. Extinction angles for the albite twins averaged around 15° and most grains showed a positive optic sign. This suggests an An_0 - An_{15} composition.

Xenomorphic microcline, exhibiting good grid iron twinning, is found interstitially. It is commonly poikilitic with inclusions of biotite, amphibole, plagioclase and sphene. Biotite and plagioclase are often found at plagioclase-microcline boundaries possibly as reaction products.

Biotite and hornblende are the major mafic minerals present with hornblende being slightly more abundant, occurring in subhedral to euhedral grains generally less than 2 mm. Biotite is often replacing the amphibole while

it, in turn, is being replaced by chlorite. Many biotite grains contain zircons with a pleochroic halo.

Accessory minerals include subhedral to euhedral grains of skeletal apatite (see Figure III-5) and sphene.

In sample D5 a clot of mostly very fine grained mafic mineral, including biotite, epidote and amphibole, was observed. It was subhedral and had dimensions of 12 mm x 7 mm. It was interpreted as being a micro xenolith (see Figure III-6).

This xenolith along with skeletal apatite and strongly zoned plagioclase possibly indicates rapid cooling of an igneous magma.

ii. Porphyritic (K-feldspar) Granodiorite

This phase plots in the granodiorite field close to the quartz monzodiorite boundary in Figure III-1. This phase is distinguished from the granodiorite phase by the presence of megacrysts of poikilitic microcline in a medium grained granular matrix of quartz, plagioclase, hornblende and biotite. The microcline insets range in size up to 1 cm in width. They generally contain inclusions of somewhat idiomorphic biotite sphene and plagioclase often showing a reaction rim with the host feldspar. Sample D17 showed minor amounts of subhedral poikilitic insets of perthite.

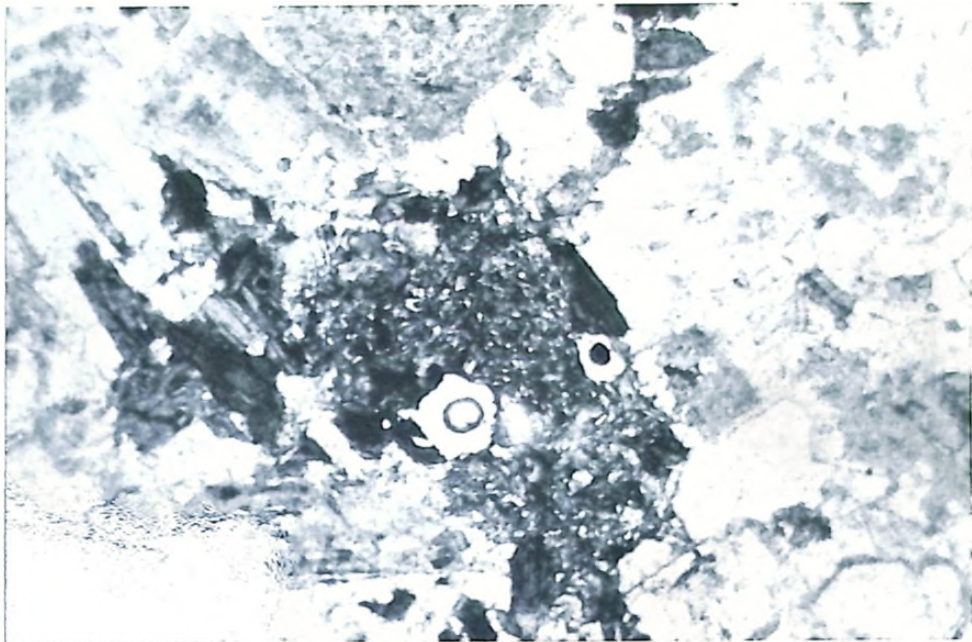


Figure III-5 Skeletal apatite surrounded by epidote and biotite
(sample D-5, Plain light, 25x)

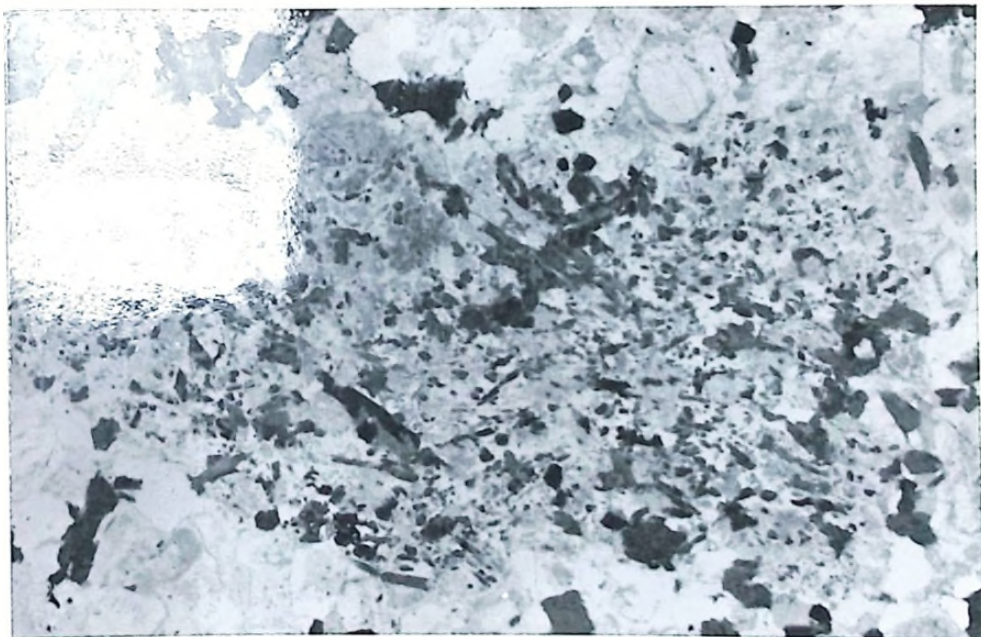


Figure III-6 Micro xenolith composed of fine grained biotite
epidote and amphibole
(sample D-5, x nicols, x10)

The plagioclase grains are subhedral in form with a range in size from 0.5 mm to 4 mm and commonly show zoning with a moderate degree of sericitization around zone boundaries. Extinction angles measured on albite twins had an average of 12° . This, combined with a negative optic sign, suggests a composition of An_0 - An_{30} . Carlsbad twins are also common.

Biotite is the predominant mafic mineral though hornblende is also ubiquitous.

Biotite occurs as subhedral laths 0.2 mm to 2 mm in length, either as primary grains or as alteration products of the amphibole. They commonly contain inclusions of zircon with their characteristic halos.

Accessory minerals include skeletal apatite, allanite and euhedral sphene.

4. PUKASKWA GNEISS COMPLEX

The Pukaskwa Gneiss Complex, which is situated in the most southerly part of the map area, exhibits the most diversity in terms of the petrology. It contains phases of true granite, granodiorite, trondhjemite and porphyritic granodiorite.

i. Porphyritic Trondhjemite

This phase plots in a tonalite field in Figure III-1. Streckeisen (1973) in his report on classification of igneous rocks recommended by the International Union of Geological Sciences suggests that the term trondhjemite may be used for light coloured tonalites ($m = 0-10$). Since most of the samples from this field are low in mafics, this term was used.

This unit is characterized by megacrysts of strongly altered plagioclases subhedral in form and varying in size from 4 mm by 3 mm to 1 mm by 2 mm. Some are poikilitic with inclusions of biotite and quartz.

The matrix is composed of xenomorphic granular quartz, plagioclase and biotite. The quartz forms in two distinct sizes: a fine grained mode with grains generally less than 0.5 mm, and a coarser grained mode with grains generally between 1 mm and 2 mm in size. Both sizes show a mosaic intergrowth texture and some recrystallization. They occur both as lensoidal aggregates and elongated quartz trains often separated by finer grained quartz and feldspar (see Figure III-7). Most grains exhibited undulatory extinction.

The two dominant mafic minerals are biotite and epidote with hornblende only occurring in trace amounts. Biotite is commonly found as stringers or as showing a

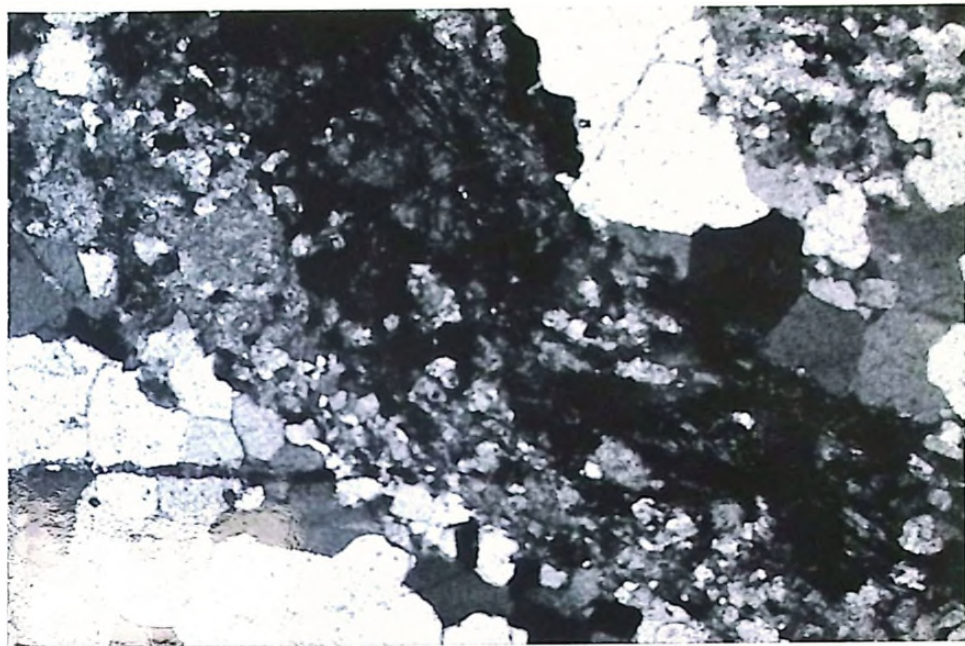


Figure III-7 Quartz trains separated by fine grained quartz and feldspar matrix (sample D-53, x nicols, 25x)

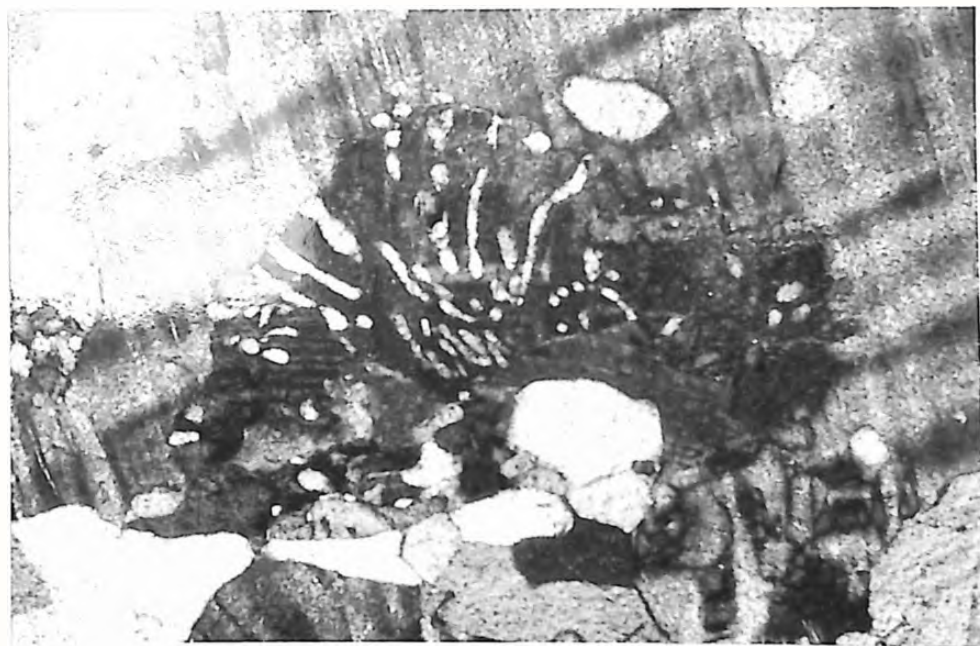


Figure III-8 Myrmekitic texture (sample D-39, x nicols, 63x)

lensoidal habit. The grains are subhedral to anhedral with an average length of 0.7 mm.

Epidote is generally found as discrete anhedral to subhedral crystals associated with biotite and interstitial to plagioclase.

Retrograde chlorite is also found associated with the biotite.

Potassium feldspar occurs only in minor amounts typically as minute anhedral grains of microcline (<0.2 mm) interstitial to plagioclase. Some grains show the characteristic polysynthetic twinning.

Sphene and opaques are subhedral to anhedral and occur in trace amounts.

ii. Granite

This unit plots in the "true" granite field in Figure III-1. This was the only granite phase found in the three sampled batholiths.

It is typically a medium grained allotriomorphic holocrystalline rock. Small amounts (<3%) of microcline perthite were observed sometimes with inclusions of biotite and plagioclase. The grains are interstitial, anhedral and vary in size from 0.2 mm to 2 mm. Interstitial grains of microcline, generally free of inclusions, are also present.

Plagioclase and quartz are the two most abundant minerals. The plagioclase occurs as subhedral rectangular crystals having an average grain size of 1.2 mm. Sericitization has masked or destroyed the twinning so that compositional measurements could not be done. Plagioclase associated with the K-feldspar often show myrmeketic texture (see Figure III-8).

Quartz occurs as anhedral interlocking grains and are commonly surrounded by smaller recrystallized grains. Most grains show a weak undulatory extinction.

Total mafics have a modal abundance of less than 5% with biotite, hornblende and epidote being the most common. Hornblende occurs as anhedral grains that are generally less than 1.5 mm. They almost always show some degree of alteration to biotite and epidote. The biotite, in turn, is often altered to chlorite.

Accessory minerals include euhedral sphene and minor opaques.

iii. Porphyritic Granodiorite

This unit plots in the granodiorite field in Figure III-1. Texturally, this unit is similar to the porphyritic granodiorite found in the Heron Bay Batholith, though some differences are noted. This phase exhibits a medium grained

holocrystalline, hypiomorphic, porphyritic texture. The insets are poikilitic, euhedral crystals of microcline containing inclusions of sphene, quartz, biotite and plagioclase. The phenocrysts have an average size of 0.6 cm which is slightly smaller than the Heron Bay microcline insets (average size 0.8 cm). Microcline also occurs interstitially as anhedral grains.

The plagioclase grains are subhedral to anhedral with a range in size from 0.5 mm to 9 mm, which is similar to the Heron Bay porphyritic granodiorite; however, these plagioclase grains are very strongly sericitized so that compositional measurements could not be made. They also lack the distinctive zoning typical of the Heron Bay plagioclases, though minor amounts are present. Plagioclase in contact with the K-feldspar is often corroded and myrmekitized. This was not seen in the Heron Bay phase. Perthite and antiperthite were also observed in minor amounts.

Quartz is present as anhedral crystals showing strain effects such as undulatory extinction, mosaic texture and recrystallization.

Though the two most abundant minerals are biotite and hornblende, as in the Heron Bay Batholith porphyritic granodiorite, the Pukaskwa porphyritic granodiorite is slightly more mafic. Biotite occurs both as primary crystals

and as an alteration of hornblende.

Sphene is the most common accessory mineral with minor amounts of opaques also present (see Figure III-9).

iv. Hornblende Biotite Granodiorite

This unit plots in the granodiorite field in Figure III-1. It shows a typical medium grained, holocrystalline, hypidiomorphic granular texture.

Plagioclases are generally subhedral with a size variation of 0.5 mm to 2 mm in length. Though some remnant albite and Carlsbad twins were present, sericitization prevented compositional measurements.

K-feldspar forms as interstitial, anhedral grains which generally do not exceed 1.5 mm in length.

Some evidence for deformation is indicated by the presence of undulatory extinction and minor recrystallization in the quartz grains. They typically form as subhedral grains averaging less than 1 mm in diameter.

The predominant mafic mineral is amphibole. Though the grain boundary is irregular it only shows minor alteration to biotite or opaques. Biotite generally forms as subhedral to idiomorphic crystals and appear to be primary.

Sphene and allanite are present as accessory minerals.



Figure III-9 Euhedral sphene
(sample D-46, x nicols, 60x)



Figure III-10 Twinned skeletal feldspar
(sample D-12, x nicols, 25x)

5. SUMMARY

i. Pic Batholith

- (1) Three phases were found in the sampled area:
 - (a) biotite quartz-monzodiorite;
 - (b) porphyritic quartz-monzodiorite;
 - (c) biotite hornblende granodiorite.
- (2) A roughly linear trend, showing an increase in quartz content and a decrease in mafics, is formed, going from the biotite quartz-monzodiorite to the biotite hornblende granodiorite.
- (3) The average mafic content of the Pic Batholith is the highest of the three batholiths sampled.
- (4) Plagioclase composition for the granodiorite phase was determined as $An_{21}-An_{40}$ using the Michel-Levy method. Plagioclase in the other phases was generally too altered to determine its composition.
- (5) Porphyritic quartz monzodiorite is characterized by poikilitic insets of microcline up to 1 cm in length, differentiating it from the non-porphyritic phase.

ii. Heron Bay Batholith

- (1) Petrographically, the sampled area shows little variation having only two phases:
 - (a) hornblende granodiorite;
 - (b) porphyritic granodiorite.
- (2) Both phases are characterized by distinctively zoned euhedral to subhedral plagioclase commonly exhibiting either albite or Carlsbad twins. Plagioclase composition was determined as An_0 - An_{30} .
- (3) The porphyritic phase is characterized by megacrysts of poikilitic microcline and a higher biotite content than amphibole content.
- (4) The non-porphyritic phase is characterized by a medium grained holocrystalline hypidiomorphic texture with the hornblende content exceeding the biotite content.
- (5) The average mafic content of the Heron Bay Batholith is intermediate between the Pic Batholith and Pukaskwa Gneiss Complex.

iii. Pukaskwa Gneiss Complex

- (1) Four phases were found in the sampled area:
 - (a) porphyritic trondhjemite;
 - (b) porphyritic granodiorite;
 - (c) hornblende granodiorite;
 - (d) granite.

(2) The porphyritic granodiorite, hornblende, granodiorite and porphyritic trondhjemite form a roughly linear series that show an increase in quartz and a decrease in K-feldspar and mafics.

(3) The porphyritic trondhjemite is characterized by megacrysts of strongly altered plagioclase in an xenomorphic matrix. Recrystallized quartz and strong foliation is common in these rocks. Biotite and epidote are the most abundant mafic mineral with hornblende only occurring in trace amounts

(4) The porphyritic granodiorite is characterized by hypidiomorphic medium grained porphyritic texture with insets of poikilitic microcline. The predominant mafic mineral is biotite which is generally secondary. It differs from the porphyritic granodiorite of the Heron Bay Batholith by the presence of myrmekite minor amounts of perthite and anti-perthite and generally stronger altered plagioclase.

(5) The hornblende biotite granodiorite shows a typical medium grained holocrystalline hypidiomorphic texture. It differs from the granodiorite phase in the Heron Bay Batholith in that it lacks zoned plagioclase and shows areas of recrystallized quartz.

(6) The average mafic content of the Pukaskwa is the lowest of the three sampled.

CHAPTER IV

GEOCHEMISTRY AND PETROGENESIS

1. INTRODUCTION

Whole rock and trace element analyses for eighteen samples were obtained using a Philips Model 1450 AHP automatic sequential X-ray fluorescence spectrometer, housed in the Geology Department, McMaster University. Details on experimental procedure and preparation are found in Appendix B.

CIPW norms were calculated using a computer program devised by Mattison (1973). The results are recorded in Appendix B.

2. GEOCHEMICAL RESULTS

The range in major elements and trace elements for the three batholiths have been listed in Tables IV-1 and IV-2. The analyses for individual samples are found in Appendix B (Tables B-1 and B-2).

In general the Pukaskwa Gneiss Complex shows the

Table IV-1 Chemical Variations

	Pukaskwa Gneiss Complex		Heron Bay Batholith		Pic Batholith	
	Range	Average	Range	Average	Range	Average
SiO ₂	73.58-65.08	69.32	68.29-66.97	67.50	58.02-67.61	62.40
Al ₂ O ₃	16.18-14.60	15.38	16.13-15.66	15.96	14.68-16.14	15.15
Fe ₂ O ₃	5.12-1.50	3.26	2.95-3.53	3.22	3.55-7.06	5.51
MgO	2.16-0.36	1.31	1.24-1.85	1.51	1.35-5.34	3.11
CaO	4.69-1.70	3.25	3.83-3.18	3.47	2.83-5.58	4.40
Na ₂ O	5.13-3.61	4.43	4.76-5.09	4.91	3.73-4.32	4.02
K ₂ O	3.33-1.95	2.10	2.21-2.65	2.39	2.56-4.74	3.53
TiO ₂	0.55-0.17	0.37	0.31-0.35	0.33	0.37-0.61	0.51
MnO	0.09-0.04	0.06	0.04-0.06	0.05	0.06-0.14	0.10
P ₂ O ₅	0.23-0.01	0.11	0.08-0.11	0.10	0.21-0.30	0.26

Table IV-2 Trace Element Variation*

Trace Element	Pukaskwa Gneiss Complex		Heron Bay Batholith		Pic Batholith	
	Range	Average	Range	Average	Range	Average
Rb	39-82	50	58-80	66	76-134	107
Sr	216-1349	772	986-1152	1068	719-1187	945
Y	1-11	4	-	-	5-20	111
Zr	90-167	139	51-73	60	116-149	130
Nb	2-16	7	4-8	6	7-18	13
Ni	3-13	6	1-22	7.8	5-45	19
S	36-106	47	44-111	66	36-106	90

*in parts per million

highest silica content, while the Pic Batholith shows the lowest. However, there is considerable variation within these two batholiths. In the Pic Batholith, the silica content varies from 58.02 to 67.01 weight percent, with the low values being represented by the quartz monzodiorites and the high values by the biotite granodiorites. In the Pukaskwa, the silica content varies from 73.58 weight percent found in the granites, to 65.08 weight percent found in the hornblende granodiorite. The Heron Bay Batholith shows very little variation in silica content throughout the sampled area. In all three batholiths the range in silica content tends to reflect the modal and normative quartz content.

The Al_2O_3 content is very consistent throughout the three batholiths with its weight percent varying by less than 2 percent.

Total iron, magnesium and calcium tend to be highest in the Pic Batholith, but it also has a notable variation. Generally the lower values are reflected in the biotite granodiorite and the higher values in the quartz monzodiorite. It is noted that this is opposite to the silica content. The Pukaskwa and Heron Bay Batholiths show similar average abundances with respect to Fe_2O_3 , MgO and CaO ; however, the Pukaskwa shows a much more distinctive variation. Again the more silica-rich rocks (i.e. granites and trondhjemites)

have the lowest values and the silica-poor rocks (i.e. hornblende granodiorite) show the highest values.

The average alkali content does not show large variations among the batholiths, though the Pic Batholith has a slightly higher overall K_2O content and the Heron Bay Batholith shows higher average Na_2O values. The high K_2O value (4.7 weight percent) of the Pic Batholith is found in the biotite granodiorites and is probably a reflection of the high modal percent of K-feldspar. The lowest K_2O value (1.6 weight percent) is found in the porphyritic trondhjemites of the Pukaskwa Gneiss Complex.

Though the average Na_2O values are highest in the Heron Bay Batholith, the highest Na_2O value (5.13 weight percent) is found in the hornblende granodiorite of the Pukaskwa Gneiss Complex.

The TiO_2 , MnO and P_2O_5 contents are less than 1 percent in all phases found in the three batholiths.

3. PETROGENESIS

i. Chemical and Normative Trends

A series of variation diagrams have been plotted to show chemical trends that exist between the studied batholiths and to help determine whether or not the rocks are

generally related.

Figure 4-1 shows the normative composition of the rocks from the three batholiths in the Heron Bay Area in relation to the Q-Ab-Or ternary diagram. Presnall and Bateman (1973) used this system when considering a chemical model for the granitic magmas of the Sierra Nevada Batholith whose rocks contained more than 79% of normative feldspars and quartz. Since all of the samples from the Heron Bay Area (except D22, D23 and D25 from the Pic Batholith) contain more than 80% of normative feldspars and quartz, the Or-Ab-An-Q-H₂O system seems appropriate to use. The dashed lines represent field boundaries for sections of various Ab/An ratios at 2 kb H₂O (Winkler, 1967, after Von Platen, 1965). The solid irregular lines represent the Winkler and Von Platen (1961) area of granitic rocks. Most of the Pukaskwa samples fall within this area. The Heron Bay samples lie just below this area in a small cluster but show a bit of overlap with the Pukaskwa samples. The Pic samples also lie below the Winkler and Von Platen area of granitic rocks forming a group roughly along the cotectic line for Ab/An = 5.2.

This pattern may be considered to represent a crude gradation from the more quartz poor - mafic rich rocks of the Pic Batholith to the more quartz rich - mafic poor

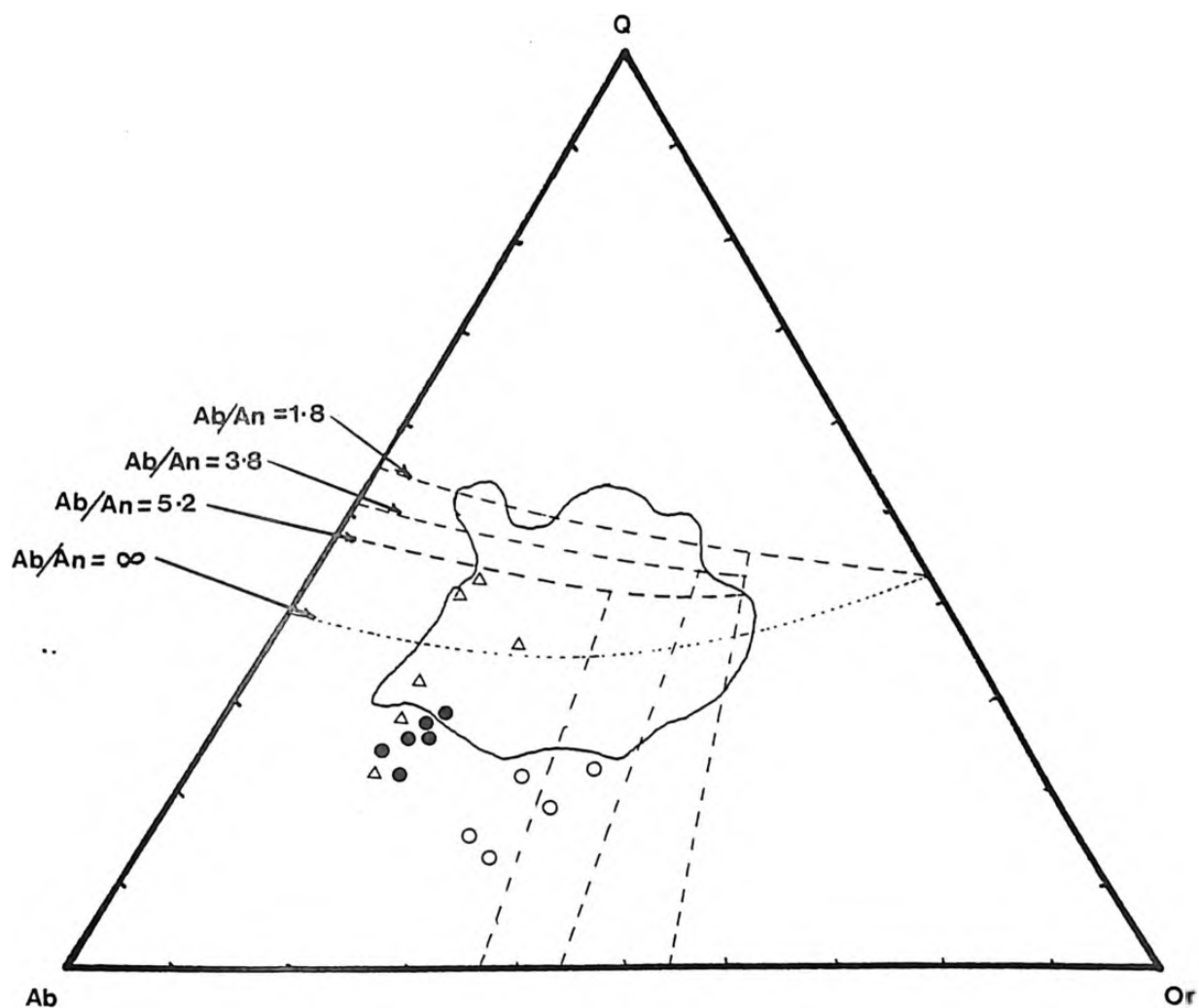


Figure IV-1 Normative Composition in Relation to the Q-Ab-Or Ternary Projection (from Winkler, 1967)

Solid irregular line is for Winkler and Von Platen's (1961) area for granitic rocks. Dashed lines represent field boundaries at indicated Ab/An ratios at 2 Kb P_{H_2O} .

- Pic Batholith
- Heron Bay Batholith
- △ Pukaskwa Gneiss Complex

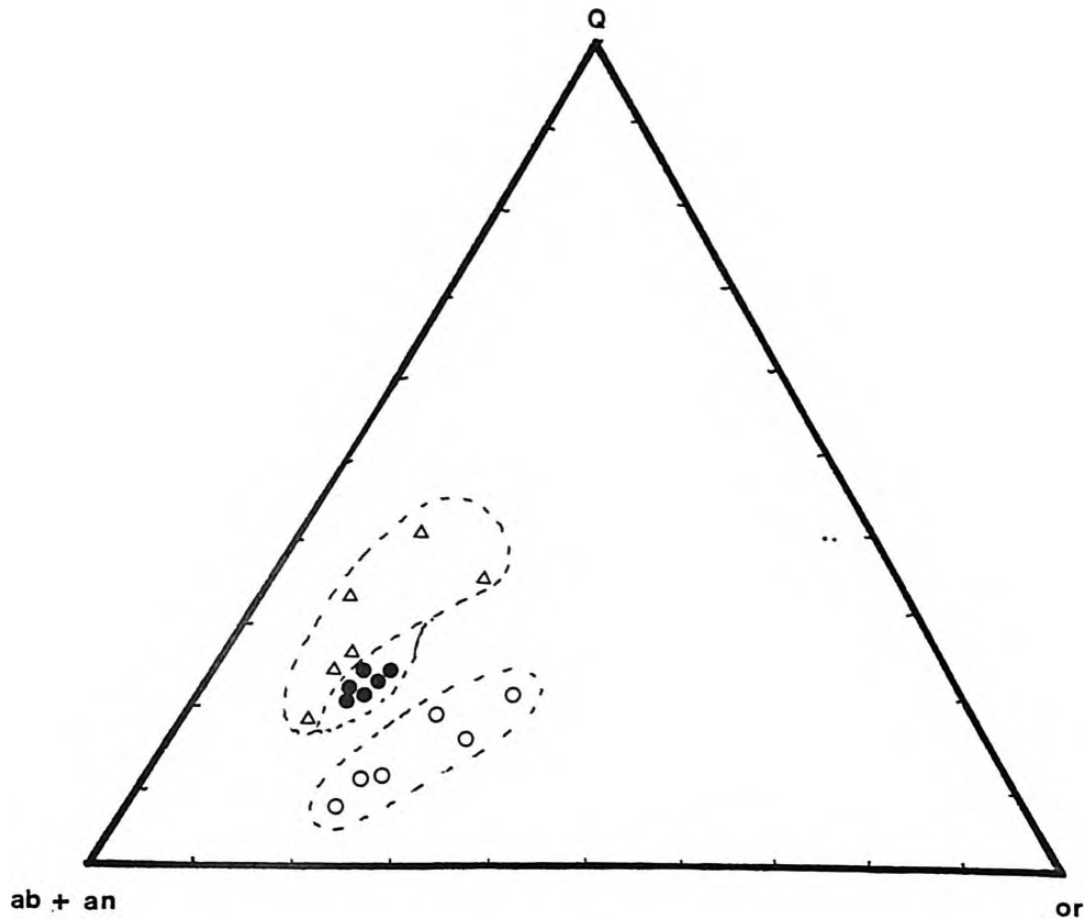


Figure IV-2 Normative Ab+An-Or-Q Plot for Heron Bay area Granitoid Rocks

- Pic Batholith
- Heron Bay Batholith
- △ Pukaskwa Gneiss Complex

rocks of the Pukaskwa Gneiss Complex, perhaps being caused by magmatic differentiation of a single magma. However, it should also be noted that the Pic samples form a separate group and show no overlap with rocks from either of the other two batholiths so that there is not a complete gradation of rocks. This possibly suggests that the Pic rocks were formed from a magma unassociated with the other two batholiths.

A similar trend is observed on the Ab+An-Or-Q plot in Figure IV-2.

Figure IV-3 shows the normative percentage of albite and orthoclase of the analysed samples on the H_2O -saturated and silica-saturated plane of the Or-Ab-An-Q tetrahedron and the low temperature trough of Kleeman (1965). It is seen that no samples fall into the thermal trough and only the biotite hornblende granodiorite of the Pic Batholith and the granite from the Pukaskwa Gneiss Complex lie within the 2% contour of Tuttle and Bowen (1958) for "normal granites".

Figure IV-4 represents the K:Ca:Na cation weight percent diagram illustrating the calc-alkali trend of Nockolds and Allen (1953) that was established from studies of calc-alkali rock series of the Southern California Batholith. The rocks from the Pic Batholith are consistent with the calc-alkali trend, while the Heron Bay and Pukaskwa rocks show a more sodic to sodic plus calcic trend.

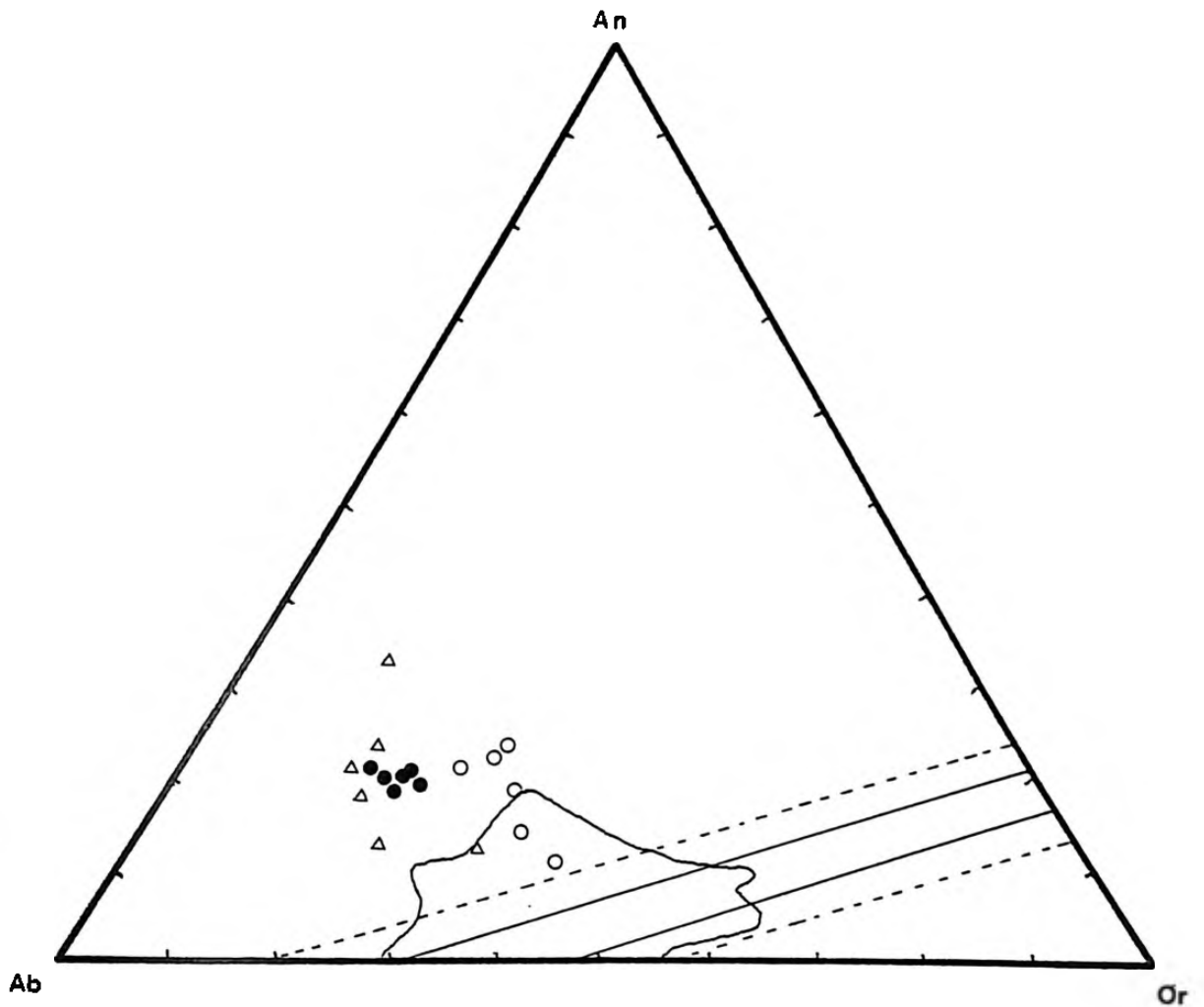


Figure IV-3 Normative Composition in Relation to An-Ab-Or Ternary System.

Solid straight lines show boundary of low temperature trough and dotted lines are uncertainty due to analytical error (Kleeman, 1965). Irregular solid line is the two percent contour of Tuttle and Bowen (1958).

- Pic Batholith
- Heron Bay Batholith
- △ Pukaskwa Gneiss Complex

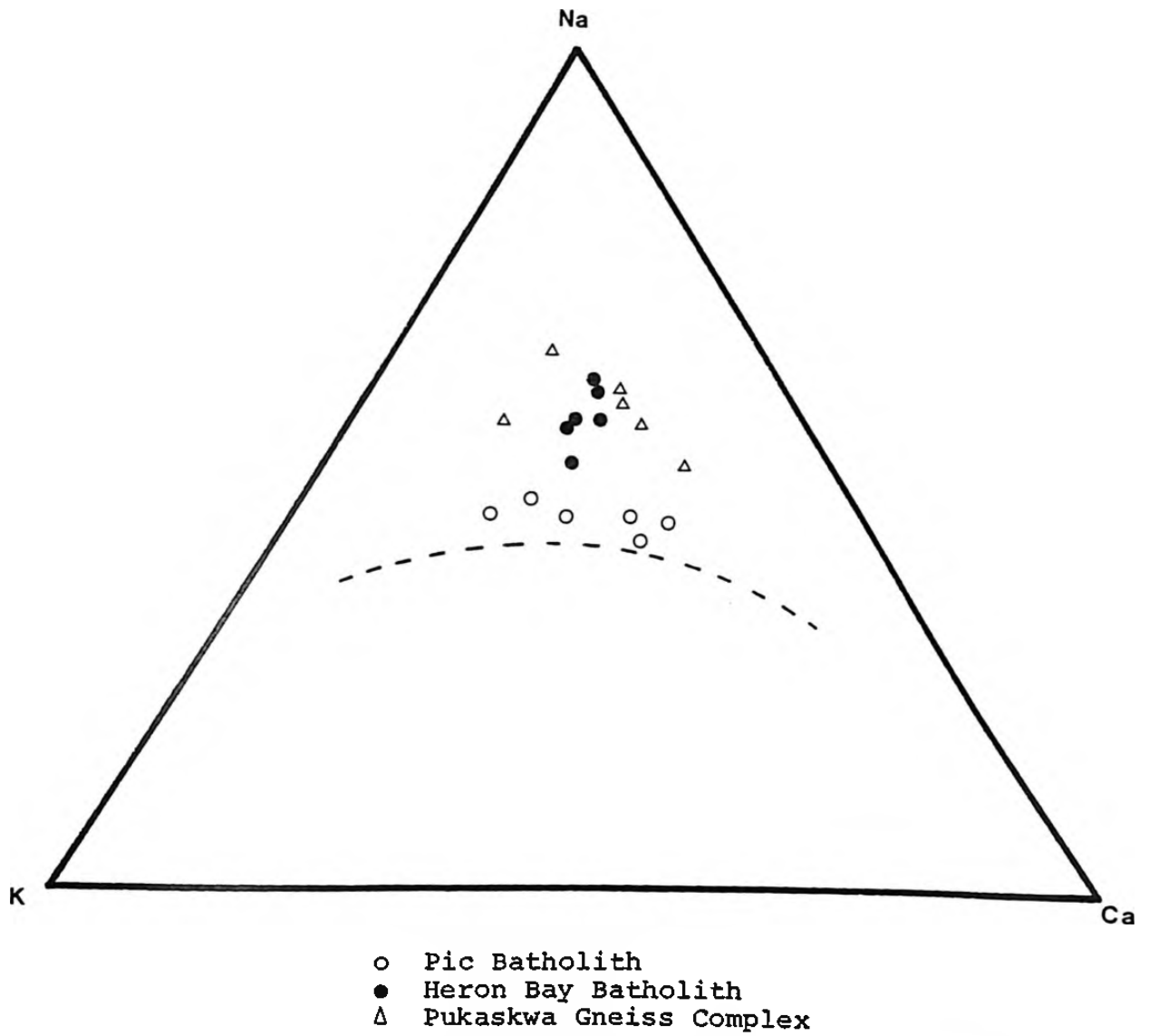


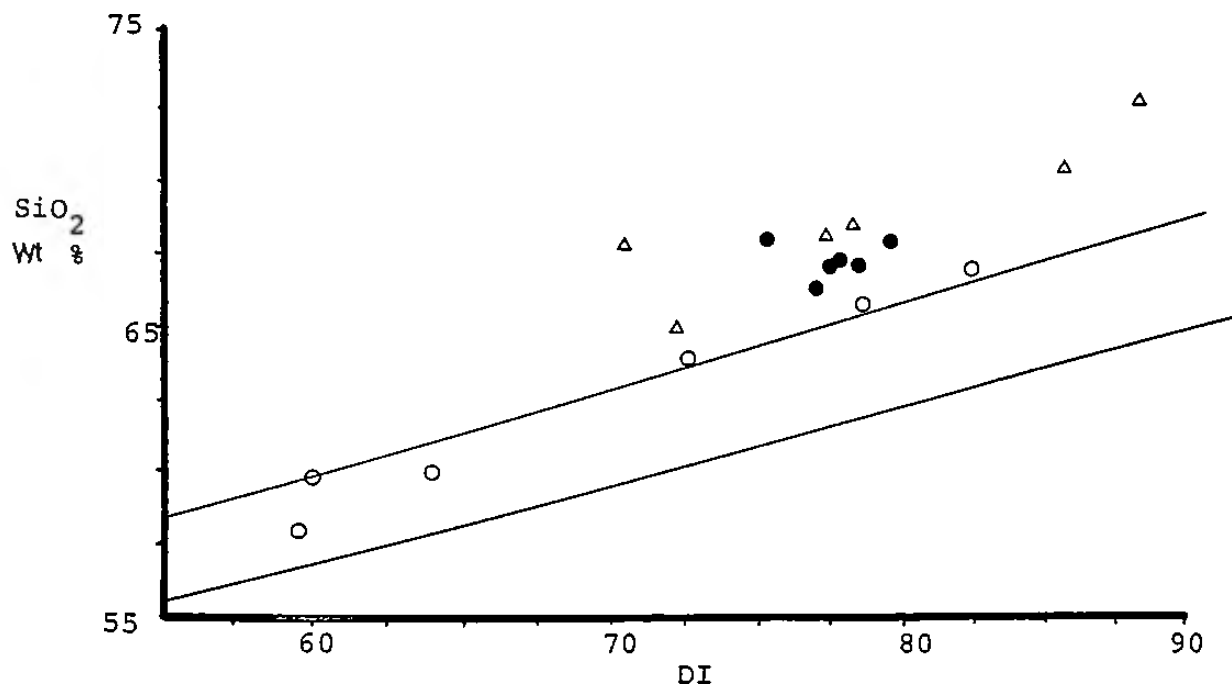
Figure IV-4 K:Na:Ca Plot. Dashed line is calc-alkalic of Nockolds and Allen (1953)

The major elements in the rocks from the three batholiths have been plotted on variation diagrams against the differentiation index (D.I.) of Thorton and Tuttle (1960) in Figures IV-5a to IV-5e.

The differentiation index is defined as the sum of the normative percentages of quartz, orthoclase albite nepheline, leucite and kalsilite and hence is a measure of the basicity of a rock.

Figure IV-5a shows that samples from all three batholiths lie within the oversaturated field of Thorton and Tuttle (1960), except for the quartz monzodiorites of the Pic Batholith, and indicate a distinct linear trend. The Pic rocks are generally much more mafic in composition grading from quartz monzodiorite (DI = 60) to granodiorite (DI = 85). The Pukaskwa rocks, though overlapping slightly with the Pic rocks, have generally higher silica content and D.I.'s ranging up to 87. The Heron Bay Batholith rocks cluster in a D.I. range of 75-81 and show little variation.

The magnesium (Figure IV-5b) and calcium (Figure IV-5e) content decrease toward the higher D.I. values in both the Pic and Pukaskwa Batholiths, while the Heron Bay Batholith rocks show little variation. It can also be seen that the Pic Batholith has a much higher calcium and magnesium content than the Pukaskwa Gneiss Complex and that

Figure IV-5a SiO_2 vs. DI

○ Pic Batholith
 ● Heron Bay Batholith
 △ Pukaskwa Gneiss Complex

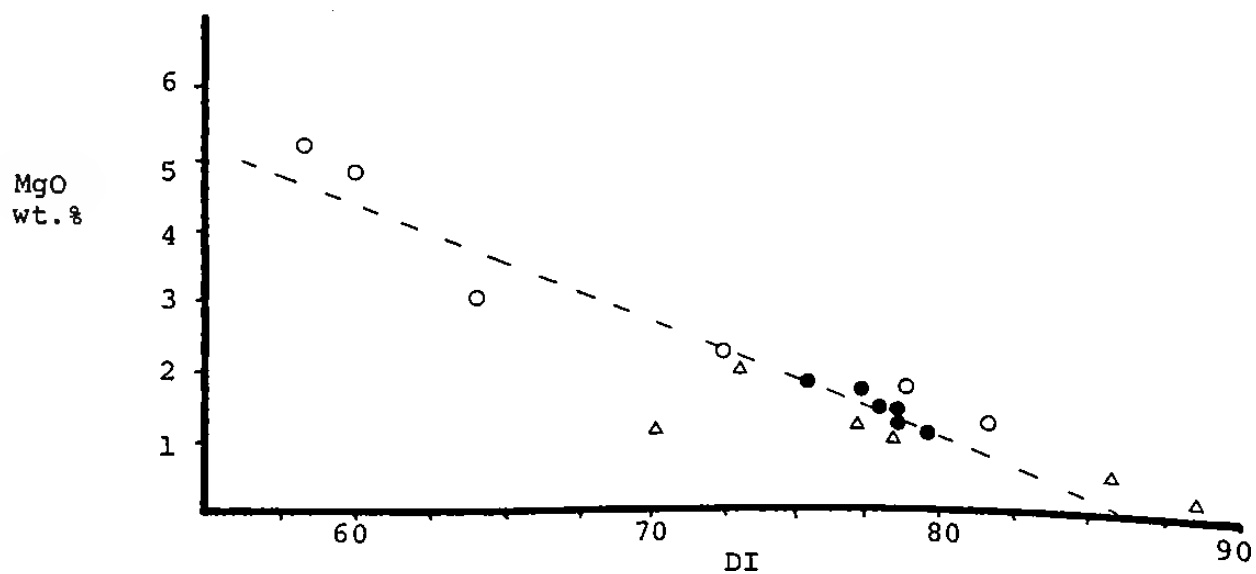


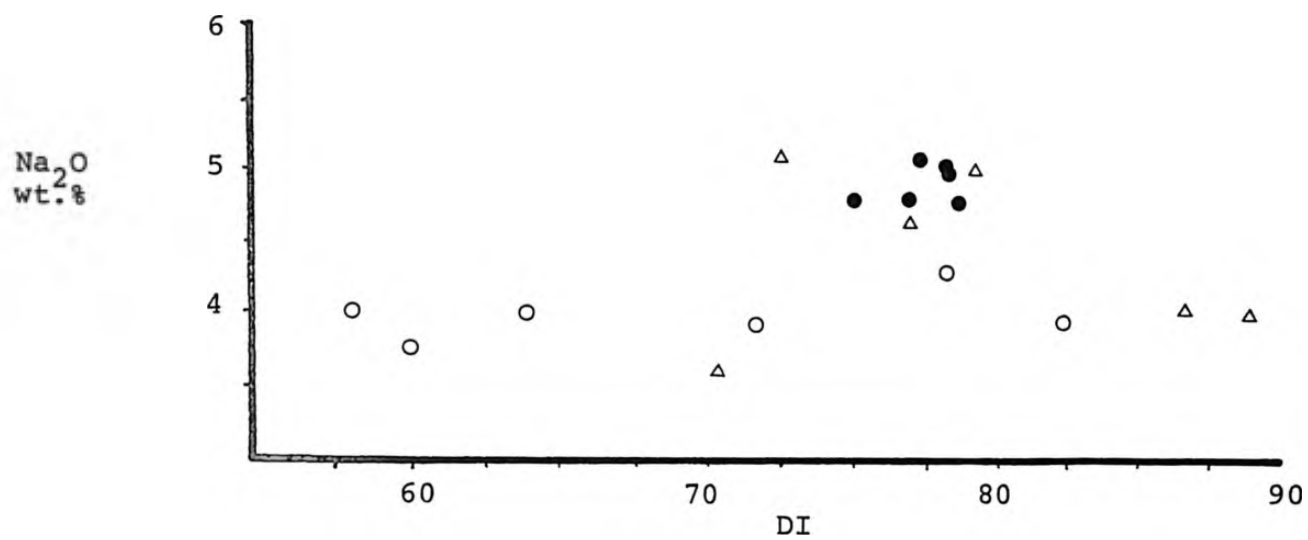
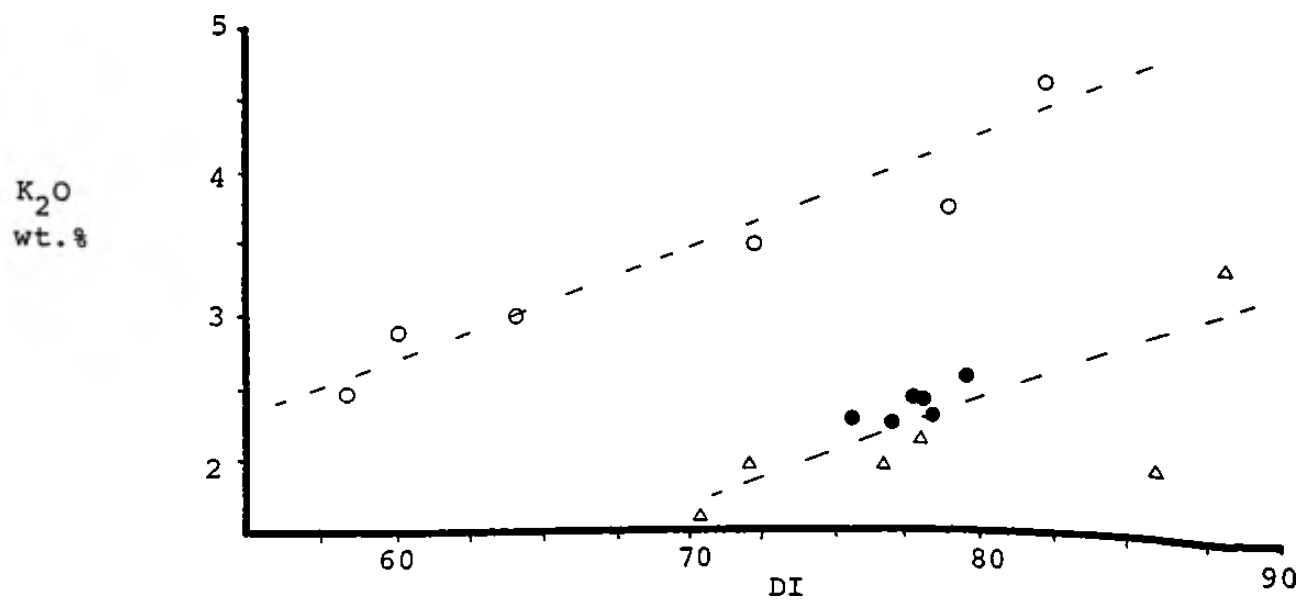
Figure IV-5b MgO vs. DI

the Heron Bay Batholith rocks are intermediate with respect to these two elements.

The alkali distribution is shown in Figures IV-5c and IV-5d. Sodium does not show any strong trend but remains fairly constant except for a slightly higher content in the Heron Bay rocks and the trondhjemitic rocks of the Pukaskwa. The potash content, on the other hand, shows a sharp increase with an increase in the D.I. This is expected in magmatic liquids undergoing crystallization since soda is continually being taken out as a component of plagioclase feldspar and amphiboles, while potash is generally held in the liquid until alkali feldspar or biotite crystallize (Thorton and Tuttle, 1960).

It is also noted that two distinct trends are evident in the potash plot: one for the Pic Batholith and one for the Heron Bay Batholith and Pukaskwa Gneiss Complex. The Pic Batholith shows potash percents ranging from 2.5-4.7%, while the Heron Bay Batholith and Pukaskwa Gneiss Complex rocks show generally lower potash values ranging from 1.5-3.3%.

Figure IV-6 is a plot of $(\text{Na}_2\text{O} + \text{K}_2\text{O}) - \text{FeO}_{\text{TOTAL}} - \text{MgO}$. Though no distinct trends are obvious it does indicate a slight mafic to felsic gradation in the Pic and Pukaskwa while the Heron Bay Batholith shows little variation.

Figure IV-5c Na_2O vs. DIFigure IV-5d K_2O vs. DI

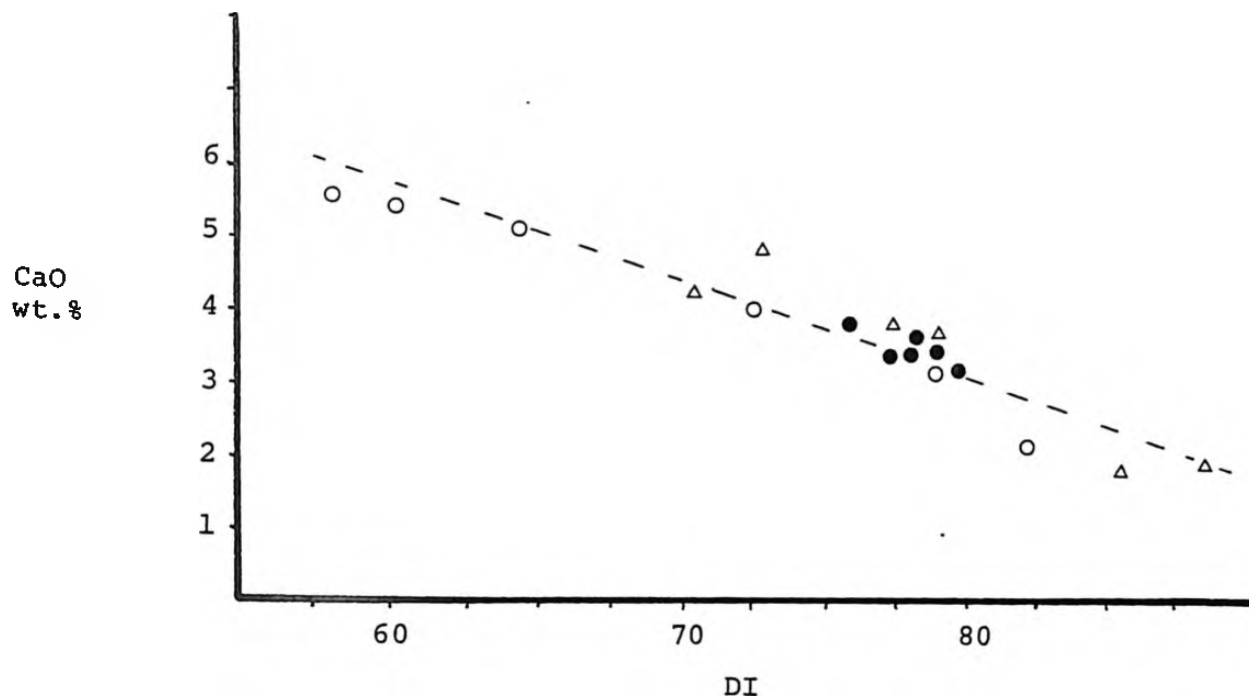


Figure IV-5e CaO vs. DI

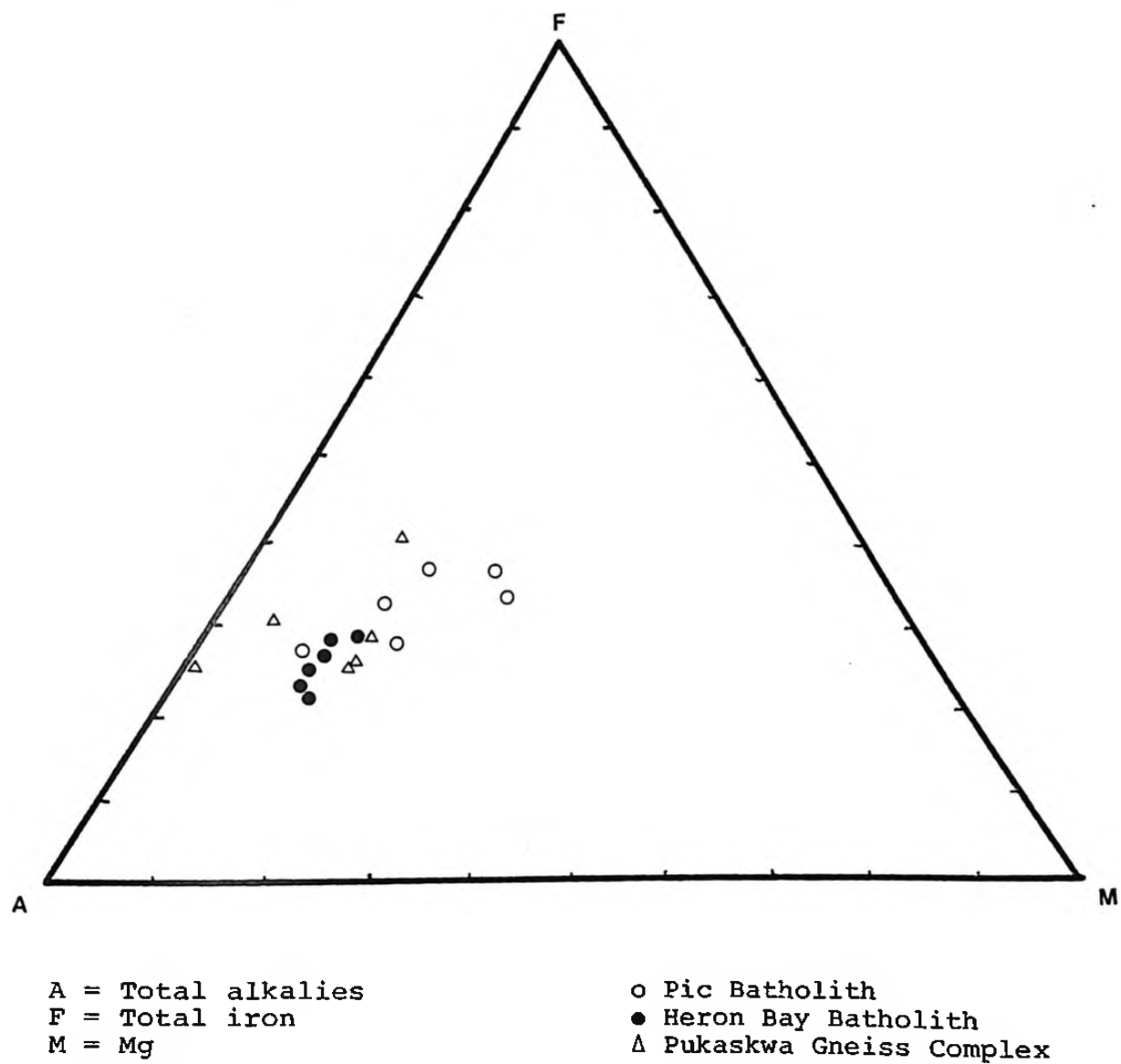


Figure IV-6 AFM Plot

ii. K/Rb Trends

The Rb content of the rocks from the three sampled batholiths are plotted against the differentiation index in Figure IV-7. If these batholiths represent a series of rocks formed as a result of fractional crystallization from a single parental magma, an increase in Rb content would be expected from the more basic rocks to the more felsic rocks (Dostal, 1973). However, in Figure IV-7 two distinct trends are observed. The more mafic rocks of the Pic Batholith have a range in Rb content from 76 ppm to 134 ppm with the lower values found in the quartz monzonites and the higher values found in the biotite granodiorite. The rocks of the Pukaskwa and Heron Bay Batholiths have a Rb content that ranges from 39 ppm to 82 ppm. The fact that two trends exist suggests that perhaps the Pic Batholith was formed from a different magma than either the Pukaskwa or Heron Bay Batholiths.

Figure IV-8 shows the variation of K with Rb and again two trends are seen. The Pukaskwa and Heron Bay Batholiths show a tendency to become enriched with Rb relative to K and have an average K/Rb ratio of 465 (K/Rb ratios were calculated following Shaw, 1968). The rocks of the Pic Batholith also show a tendency to become enriched in Rb relative to K, but a lower average K/Rb ratio (394). For

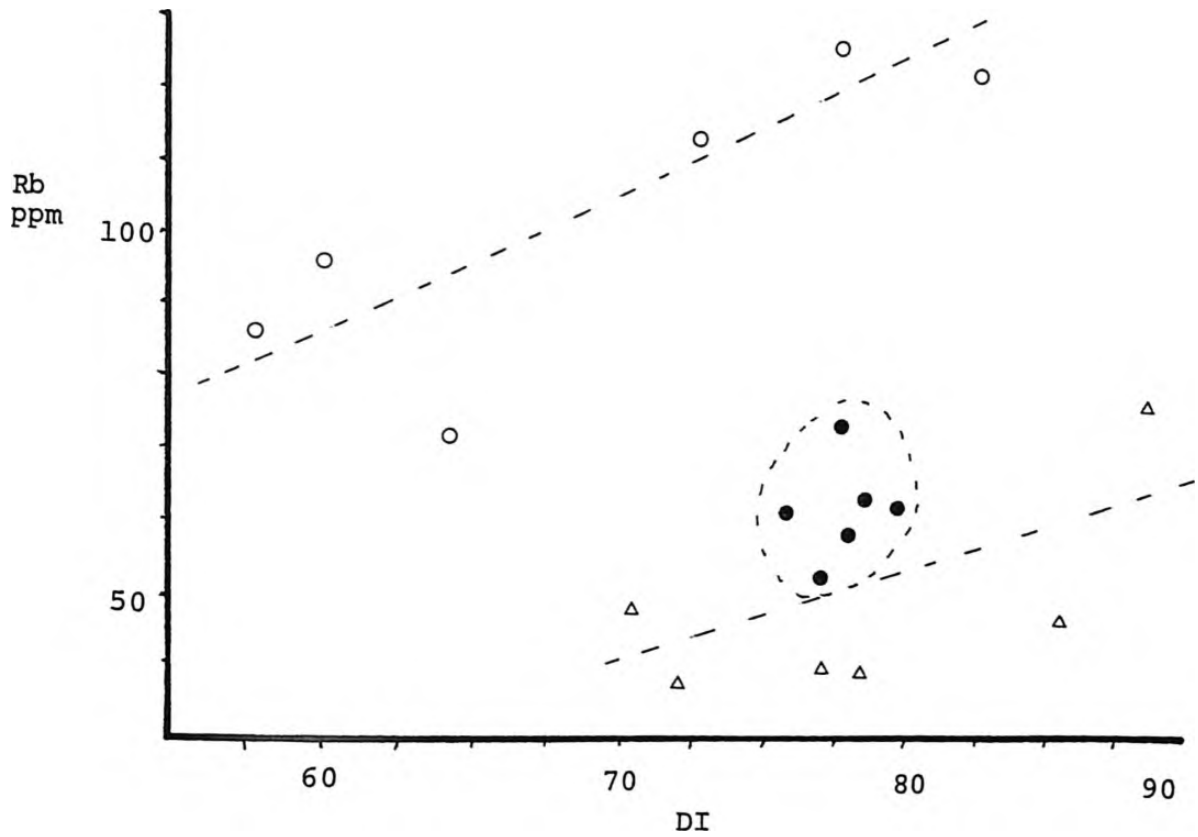


Figure IV-7 Rb vs. DI

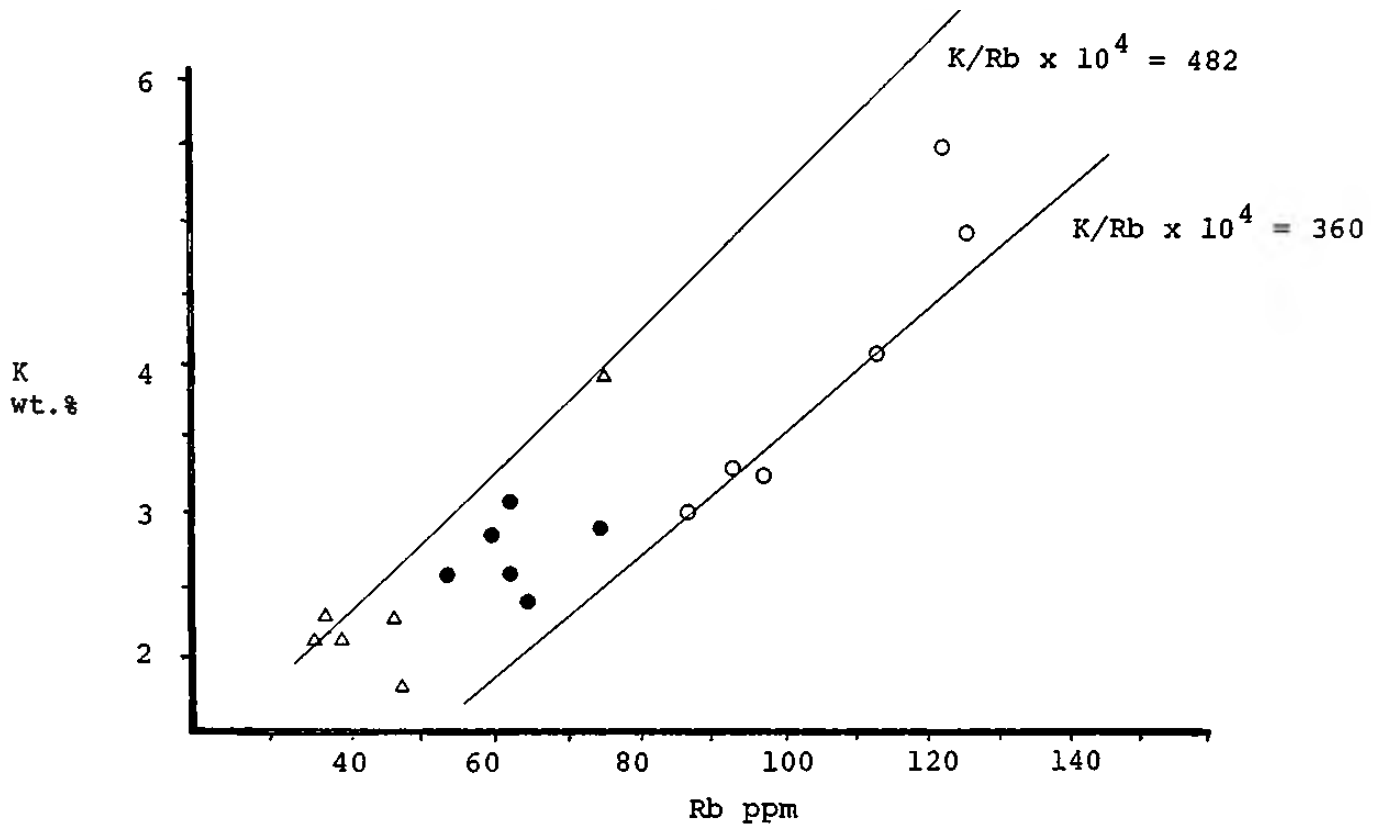


Figure IV-8 K vs. Rb

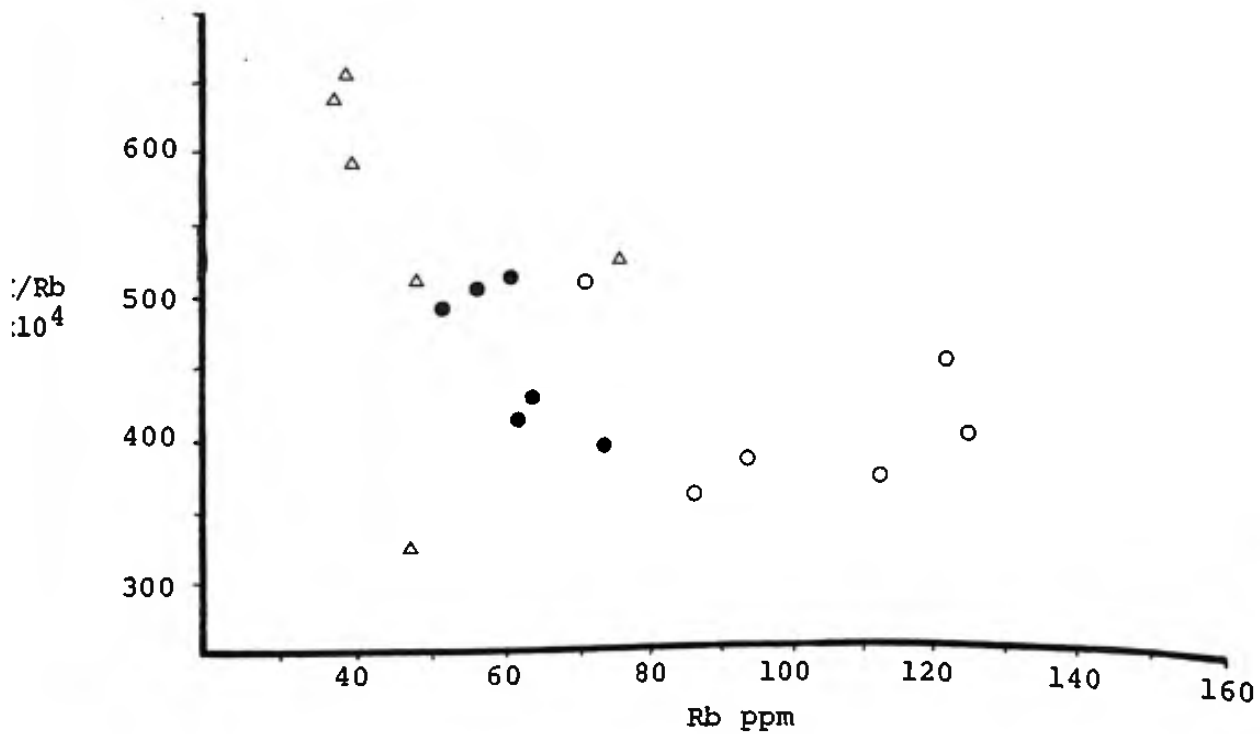


Figure IV-9 K/Rb vs. Rb

the rocks of the three batholiths to be related by the process of magmatic differentiation, the Pic Batholith rocks, which are generally more mafic, should have higher K/Rb ratios.

The variation of K/Rb with respect to Rb is plotted on Figure IV-9. Again it is seen that the more felsic rocks of the Pukaskwa have higher K/Rb ratios than those of the more mafic rocks of the Pic Batholith, which is not expected if the three batholiths are considered to be related by processes of magmatic differentiation from a single magma (Shaw, 1968). However, it is noted that if the Pukaskwa batholith is considered by itself there is a distinct trend of decreasing K/Rb from the more mafic hornblende granodiorite to the more felsic trondhjemites and granites. This suggests that there may have been processes of magmatic differentiation within the batholith itself. Clear trends are not seen in the rocks of the Pic and Heron Bay Batholiths.

The average K/Rb ratio for crustal rocks is approximately 230 (Heier and Adams, in Shaw, 1968). Reynolds et al. (1969) have found high K/Rb ratios for basaltic achondrites and some oceanic tholeiites which led them to suggest that values in excess of 500 may represent mantle or deep crustal material.

The most mafic phase of the Pic Batholith (biotite quartz monzodiorite) has an average K/Rb ratio of 358, while the most mafic phases of the Heron Bay Batholith and

Pukaskwa Gneiss Complex (both hornblende granodiorites) have average K/Rb ratios of 440 and 592, respectively. This possibly suggests that the more mafic rocks of the three batholiths were produced by partial melting of the lower crust/upper mantle.

3. SUMMARY

(1) The normative plots of Q-Ab-Or (Figure IV-1), Q-(Ab+An)-Or (Figure IV-2), and the oxide versus D.I. plots of SiO_2 (Figure IV-5a), MgO (Figure IV-5b) and CaO (Figure IV-5c) show a rough chemical gradation from the more mafic rocks of the Pic Batholith to the more felsic rocks of the Pukaskwa. This may have been caused by differentiation of a single parental magma.

(2) K/Rb ratios are consistently higher in the more felsic Pukaskwa rocks than in the more mafic rocks of the Pic and Heron Bay Batholiths. This is opposite to what is expected if all three batholiths were related to a single parental magma suggesting that the batholiths were derived from at least two different magmas of varying basicity.

It is also noted that the Pic Batholith rocks form a distinct cluster on the Or-Ab-Q and Or-(Ab+An)-Q plots showing no overlap with the Heron Bay or Pukaskwa batholiths

and the K_2O vs. DI plot shows two distinct trends; one for the Pic Batholith and one for the Heron Bay and Pukaskwa Batholiths. These facts tend to favour the idea that the batholiths were derived from more than one magma.

(3) The magma or magmas that formed these batholiths were formed by partial melting of the lower crust/upper mantle.

CHAPTER V

CONCLUSIONS

(1) Nine phases can be identified mineralogically and texturally within the sample area of the three batholiths studied:

PIC BATHOLITH	1. Biotite quartz monzodiorite
	2. Porphyritic quartz monzodiorite
	3. Biotite hornblende granodiorite
HERON BAY	1. Hornblende biotite granodiorite
BATHOLITH	2. Porphyritic granodiorite
PUKASKWA GNEISS COMPLEX	1. Hornblende granodiorite
	2. Porphyritic granodiorite
	3. Granite
	4. Porphyritic trondhjemite

(2) Textures and chemical trends suggest that all three batholiths are magmatic though the Pukaskwa Gneiss Complex shows textural evidence of deformation.

(3) Chemical trends suggest that the batholiths were formed from at least two magmas of varying basicity though the individual batholiths may be a result of magmatic differentiation from a single parental magma.

(4) The magmas that formed these batholiths were derived by partial melting of the lower crust/upper mantle material.

SUGGESTIONS FOR FURTHER WORK

(1) Rb/Sr whole rock geochronology to help determine age relationship between the batholiths.

(2) Electron probe analysis of plagioclase to determine its compositional range.

(3) A more extensive sampling of each batholith to help determine their petrogenesis and establish phase boundaries.

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APPENDIX A

PETROGRAPHIC DESCRIPTIONS

AND

SKETCHES

SAMPLE: D-1

CLASSIFICATION: Granodiorite

MODAL ABUNDANCES:	Quartz	19.0%
	Plagioclase	48.6%
	K-feldspar	14.4%
	Biotite	4.6%
	Hornblende	7.2%
	Epidote	1.8%
	Chlorite	2.4%
	Sphene	0.6%
	Apatite	1.4%
	Opagues	trace

TEXTURES:

This is a medium grained, holocrystalline hypiomorphic granular rock.

The plagioclase occurs in subhedral to euhedral zoned grains varying in size from 0.5 mm to 5 mm in length and are generally sericitized along zone boundaries. Carlsbad and poor albite twins are present. Extinction angles averaging 15° and a +ve optic figure suggest that it has an An_0 - An_{15} composition.

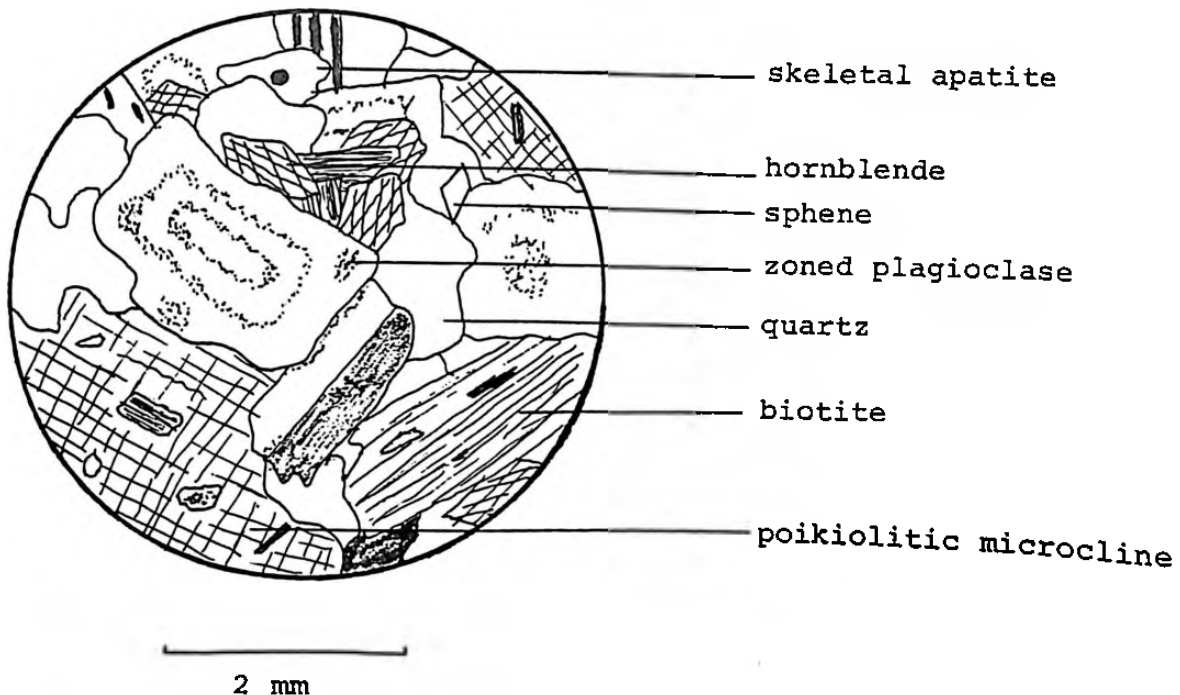
Xenomorphic microcline, characterized by grid iron twinning is found interstitially. It is commonly poikilolitic with inclusions of biotite, amphibole, plagioclase, apatite and sphene. The plagioclase microcline grain boundaries often

show signs of reaction resulting in the formation of biotite and epidote.

The major mafic minerals are biotite, amphibole and epidote with amphibole being the most abundant. The biotite is often found replacing the amphibole while it, in turn, is being replaced by chlorite and epidote. Some biotite grains contain zircons with pleochroic halos. Both biotite and amphibole grains are subhedral to euhedral and are less than 2 mm.

Other minor minerals include skeletal apatite, which along with zones plagioclase indicate rapid cooling, and subhedral to euhedral grains of sphene.

Quartz is typically interstitial.



SAMPLE: D-17

CLASSIFICATION: Porphyritic (K-feldspar) biotite granodiorite

MODAL ABUNDANCE:	Quartz	20.6%
	Plagioclase	46.2%
	K-feldspar	18.4%
	Biotite	6.0%
	Hornblende	4.0%
	Epidote	2.4%
	Chlorite	1.2%
	Apatite	1.0%
	Allanite	0.2%

TEXTURES:

This rock shows a medium grained, holocrystalline porphyritic texture.

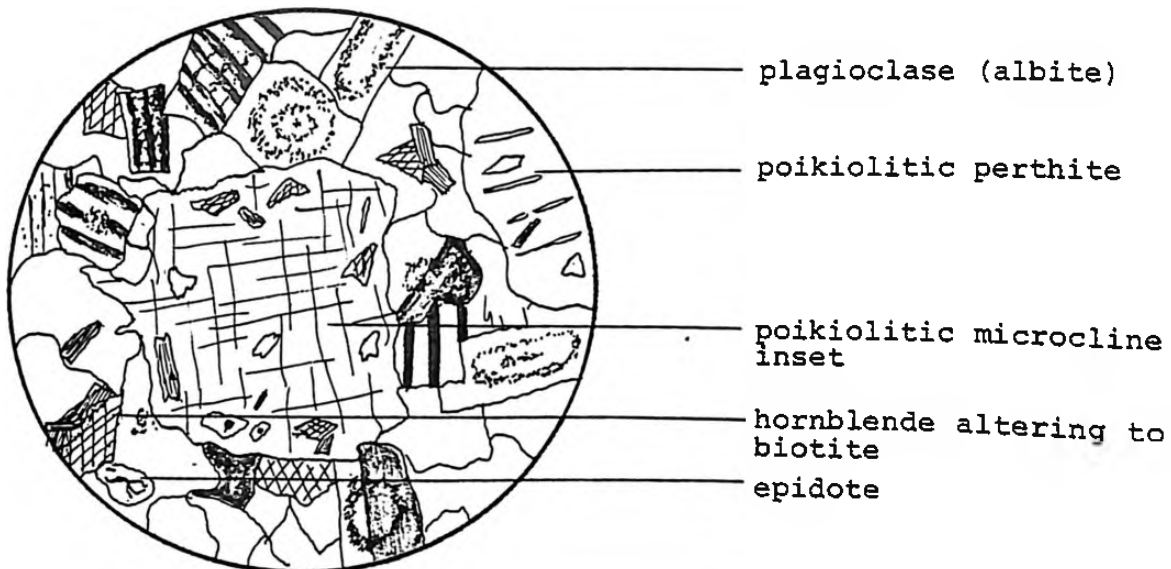
Megacrysts of poikilitic microcline occur in a granular matrix of quartz, plagioclase, hornblende and biotite. They are generally up to 1 cm in width and contain inclusions of somewhat idiomorphic biotite, sphene and plagioclase. The inclusions are randomly orientated and show some alteration around grain boundaries. Some subhedral, poikilitic insets of perthite are also present.

The plagioclase grains are subhedral in form with a size variation of 0.5 mm to 4 mm. They are commonly zoned with a moderate degree of sericitization especially around zone boundaries. Carlsbad and albite twins are present. Extinction angles average around 12° with -ve optic signs suggesting a composition of An_0 - An_{30} .

The mafic minerals are biotite, hornblende, chlorite and epidote with biotite the most abundant. Biotite occurs in subhedral crystals 0.2-2 mm in length and commonly contain inclusions of sphene and zircons. It is also found being replaced by chlorite.

Quartz is typically interstitial with anhedral grains varying in size from 0.5-2 mm.

Other minor minerals include skeletal apatite allanite and euhedral sphene.



Sample D-17 Porphyritic (K-feldspar) biotite granodiorite

SAMPLE: D-19

CLASSIFICATION: Porphyritic quartz monzodiorite

MODAL ABUNDANCE:	Quartz	16.8%
	Plagioclase	45.0%
	K-feldspar	22.6%
	Biotite	5.8%
	Hornblende	4.4%
	Epidote	1.8%
	Chlorite	0.8%
	Sphene	1.8%
	Apatite	1.0%
	Opagues	trace

TEXTURES:

This is a porphyritic, holocrystalline, hypidiormorphic rock characterized by large (up to 1 cm) phenocrysts of microcline.

The microcline phenocrysts are poikilitic with inclusions of quartz plagioclase and biotite. They are subhedral to euhedral and are surrounded by a granular matrix of plagioclase quartz and mafics. Microcline also occurs interstitially.

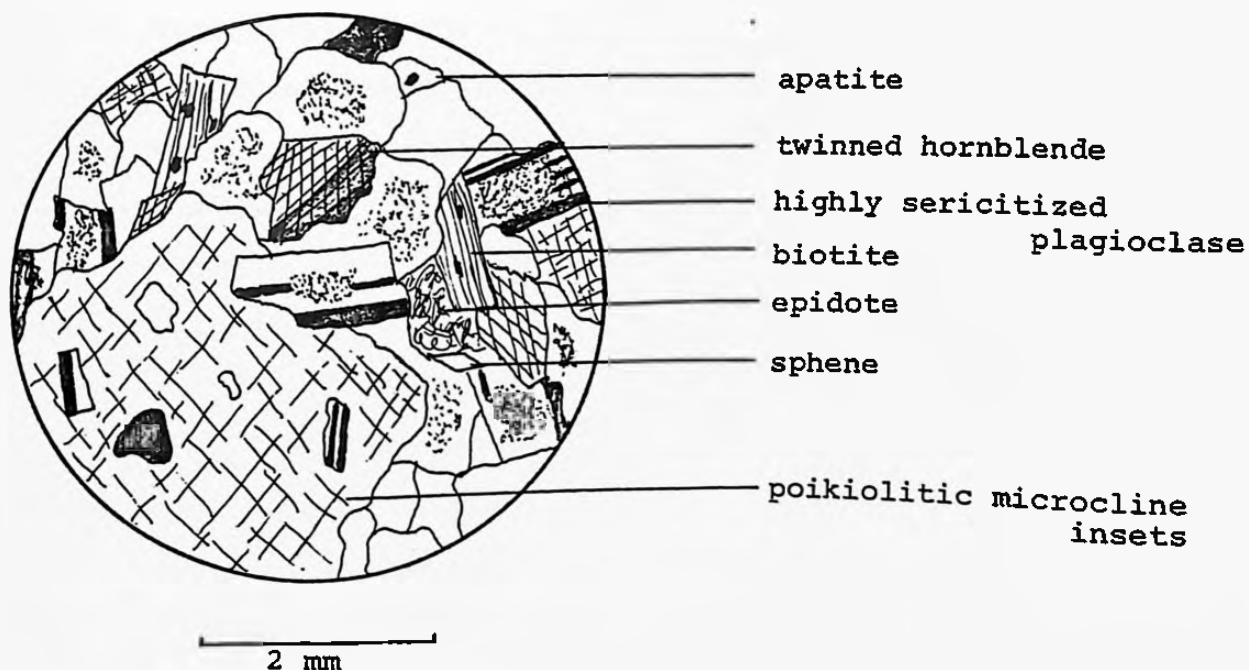
The plagioclase occurs in subhedral to euhedral grains ranging in size from 0.5-3 mm. They are strongly sericitized so that almost no twinning can be seen. Some grains show signs of being replaced by K-feldspar as small patches occur within the grains.

Amphibole and biotite are the major mafic minerals.

Amphibole generally occurs as subhedral grains though some excellent basal sections are present. They are commonly rimmed by biotite and small grains of epidote. Chlorite is also found replacing the biotite.

Trace amounts of myrmekite were found. Quartz is found interstitially in anhedral grains up to 2 mm in diameter.

Other minor constituents include idiomorphic grains of sphene and skeletal apatite.



Sample D-19 Porphyritic quartz monzodiorite

SAMPLE: D-23

CLASSIFICATION: Biotite hornblende quartz monzodiorite

MODAL ABUNDANCE:	Quartz	10.4%
	Plagioclase	44.4%
	K-feldspar	16.2%
	Biotite	13.2%
	Hornblende	10.0%
	Epidote	0.8%
	Chlorite	4.4%
	Apatite	0.6%
	Allanite	0.4%

TEXTURES:

This is a hypiomorphic granular, holocrystalline medium grained rocks.

Microcline occurs as interstitial xenomorphic crystals ranging in size from 0.5-2 mm and often shows typical grid iron twinning. Many commonly contain inclusions of plagioclase, quartz and biotite giving it a poikilolitic texture.

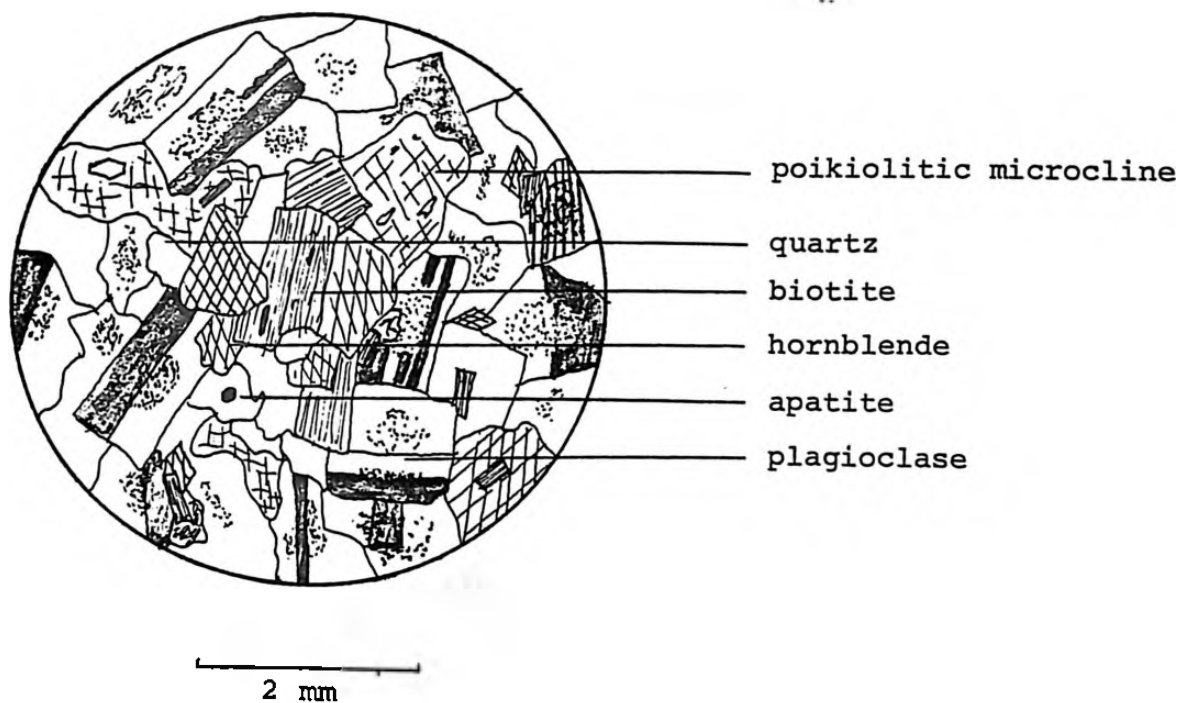
Plagioclase occurs in anhedral to subhedral grains never exceeding 4 mm in length. They are relatively strongly altered to sericite and show some poor Carlsbad and albite twinning. Extinction angles and optic signs were not able to be obtained because of the alteration.

The mafics generally occur in highly altered clots or along feldspar grain boundaries. Biotite is the most abundant mafic mineral occurring almost always as an alteration of hornblende. It occurs in subhedral laths often containing

inclusions of micas or may be altered to an opaque.

Interstitial quartz occurs in anhedral grains generally less than 1 mm in diameter.

This sample lacks sphene but has some skeletal apatite.



Sample D-23 Biotite hornblende quartz monzodiorite

SAMPLE: D-34

CLASSIFICATION: Biotite hornblende granodiorite

MODAL ABUNDANCE:	Quartz	23.2%
	Plagioclase	41.6%
	K-feldspar	20.4%
	Biotite	6.6%
	Hornblende	6.0%
	Epidote	0.8%
	Chlorite	1.0%
	Allanite	0.4%
	Opaques	trace

TEXTURES:

This rock generally shows a medium grained allotriomorphic, holocrystalline, equigranular texture. The plagioclase grains vary from subhedral to anhedral and commonly show albite twinning. Extinction angles averaging around 15° and a -ve optic sign suggest that it has an $An_{21}-An_{40}$ composition. They obtain widths up to 3 mm. A few are poikilitic with inclusions of biotite and quartz. K-feldspar occurs as small patches within the plagioclase though this is probably not a true antiperthite. Minor sericitization also occurs masking the twinning.

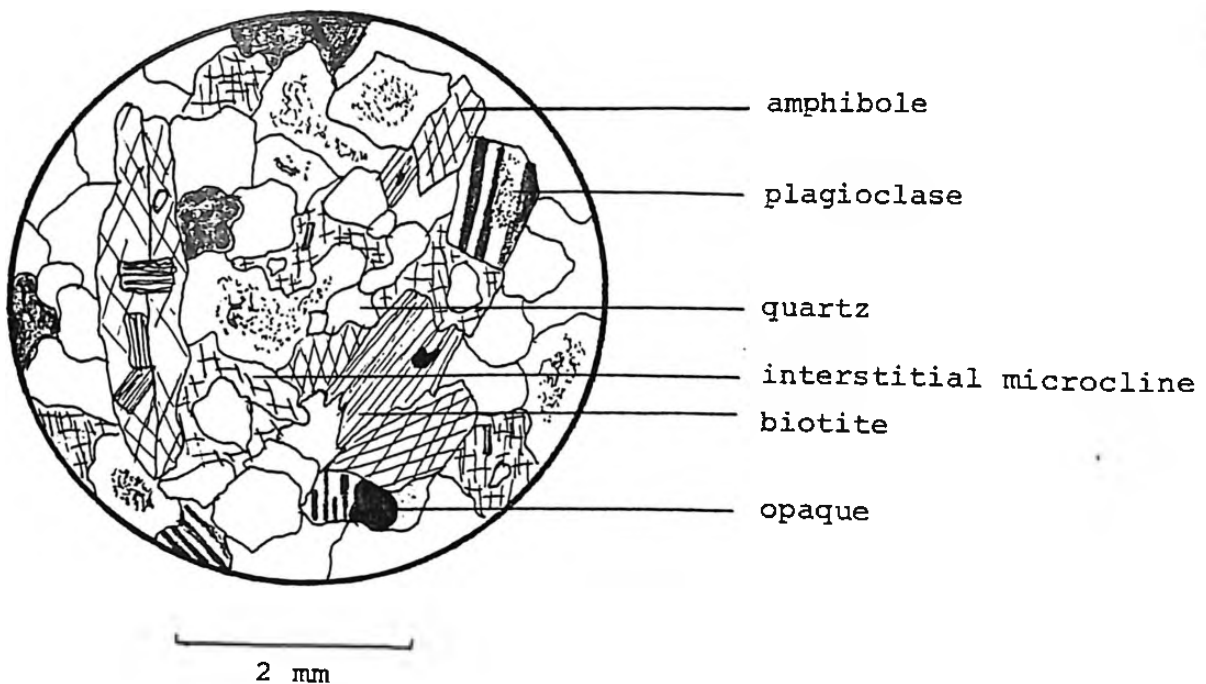
Microcline is present as interstitial anhedral grains. They range in size from 0.1-3 mm and some have inclusions of quartz and plagioclase.

Biotite and hornblende are the predominant mafic minerals with an average size of 0.5 mm in length. They are

anhedral to subhedral. The hornblende is commonly altered to biotite chlorite and epidote. Opaques are also associated with many biotite and amphibole grains.

Quartz typically occurs as subhedral interstitial grains with a maximum size of 2 mm.

Some allanite is also present as anhedral grains interstitial to microcline.



Sample D-34 Biotite hornblende granodiorite

SAMPLE: D-39

CLASSIFICATION: Granite

MODAL ABUNDANCE:	Quartz	32.4%
	Plagioclase	40.1%
	K-feldspar	21.8%
	Biotite	1.9%
	Hornblende	0.3%
	Epidote	1.2%
	Chlorite	0.7%
	Sphene	0.5%
	Allanite	0.1%
	Opaques	0.4%

TEXTURES:

This is a medium grained, allotriomorphic holocrystalline rock. A small amount of microcline perthite was observed having a poikilitic fabric with inclusions of quartz and biotite. Interstitial grains of microcline, generally free of inclusions, are also present. The anhedral grains vary in size from 0.2-2 mm.

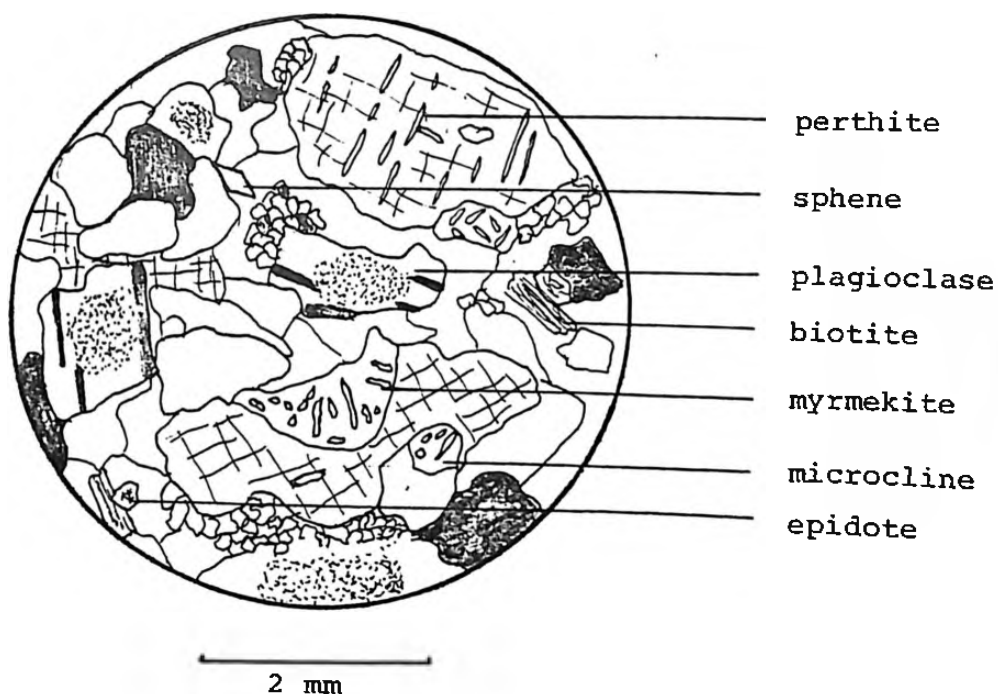
The plagioclase is generally strongly sericitized and occurs as subhedral to anhedral grains having an average size of 1.2 mm. Plagioclase associated with the K-feldspar often show myrmekitic texture.

Mafic minerals are minor with biotite hornblende and epidote being the most abundant. Hornblende is xenomorphic with an average grain size of less than 1 mm. It is always altered to biotite and epidote. Much of the biotite

in turn is altered to chlorite.

Quartz occurs as anhedral interlocking grains and are commonly bounded by small recrystallized grains. Some show weak undulatory extinction.

Accessory minerals include euhedral sphene and minor opaques.



Sample D-39 Granite

SAMPLE: D-42

CLASSIFICATION: Hornblende biotite granodiorite

MODAL ABUNDANCE:	Quartz	29.8%
	Plagioclase	35.6%
	K-feldspar	10.4%
	Biotite	7.6%
	Hornblende	11.6%
	Epidote	0.8%
	Chlorite	2.0%
	Sphene	2.0%
	Allanite	0.2%

TEXTURES:

This is a medium grained, holocrystalline hypiomorphic rock.

The plagioclase is generally hypiomorphic with a size variation of 0.5-2 mm. Some albite and Carlsbad twins are present but sericitization makes it difficult to determine extinction angles.

K-feldspar is interstitial forming small anhedral crystals having an average grain size of less than 1.5 mm. Some crystals exhibit microcline twinning. A few plagioclase crystals appear to be being replaced by K-feldspar.

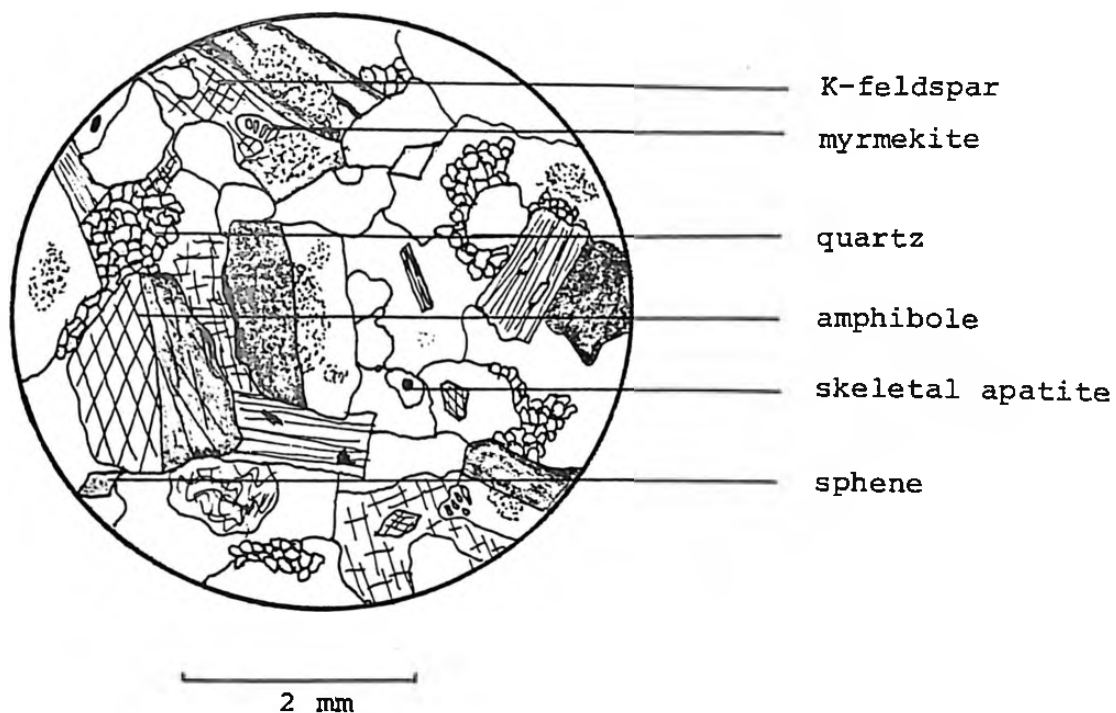
Quartz occurs interstitially as subhedral to anhedral grains averaging about 1 mm in diameter. Undulatory extinction and some recrystallization is present.

The predominant mafic mineral is hornblende which occurs as subhedral grains varying in size from 0.5-2.5 mm.

Amphibole is slightly altered to biotite.

Biotite generally occurs as idiomorphic grains and appear to be primary with minor alteration to chlorite.

Sphene and allanite are present as accessory minerals.



Sample D-42 Hornblende biotite granodiorite

SAMPLE: D-46

CLASSIFICATION: Porphyritic biotite hornblende granodiorite

MODAL ABUNDANCE:	Quartz	23.6%
	Plagioclase	50.8%
	K-feldspar	12.6%
	Biotite	5.2%
	Hornblende	3.0%
	Epidote	2.0%
	Chlorite	1.0%
	Sphene	1.8%
	Opagues	trace

TEXTURES:

This rock exhibits a medium grained holocrystalline hypidiomorphic porphyritic texture characterized by insets of euhedral microcline and strong alteration. The insets are poikilolitic with inclusions of sphene, quartz, biotite and plagioclase. The phenocrysts have an average size of 0.5 cm. Interstitial microcline is also found in minor amounts.

The plagioclase is generally subhedral to anhedral and range in size from 0.5-4 mm. They are commonly sericitized and lack good twinning making it difficult to determine its composition.

Plagioclase in contact with the K-feldspar are often corroded and myrmekitized.

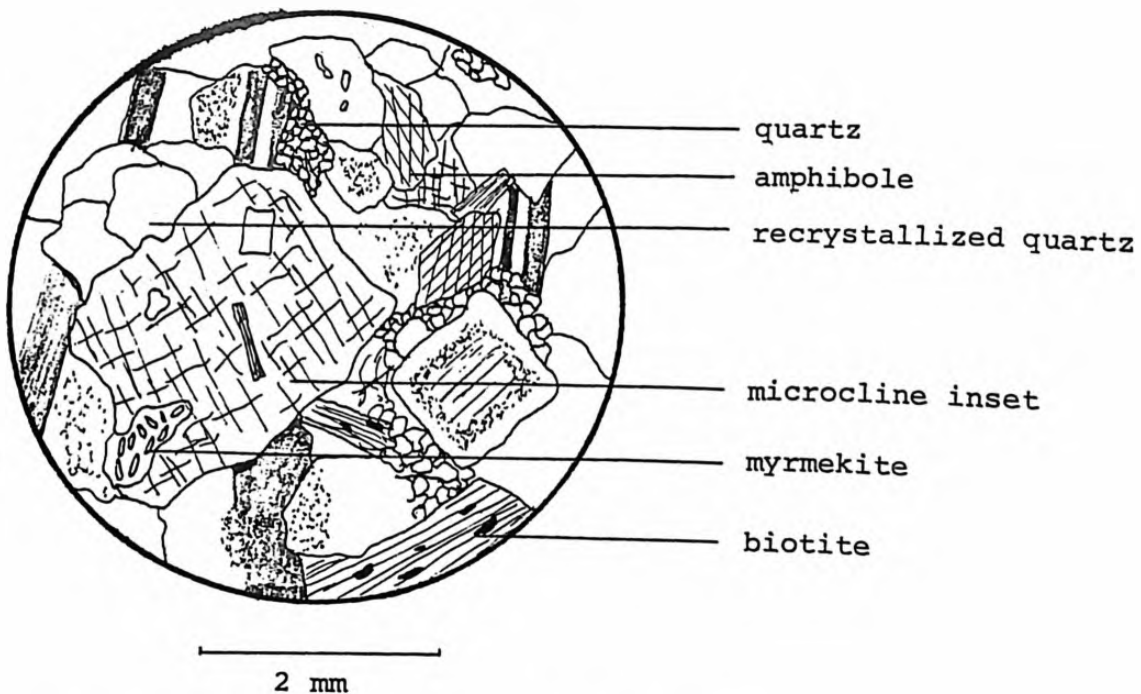
Perthite and antiperthite were observed in minor amounts.

Quartz is present as anhedral crystals showing strain

effects such as undulatory extinction and mosaic grain growths. The smaller crystals (0.1 mm) tend to flow around larger plagioclase grains.

The most abundant mafic mineral is biotite. It commonly occurs as an alteration of amphibole and is itself being replaced by chlorite and epidote.

Sphene occurs frequently, generally euhedral and some with inclusions of quartz.



Sample D-46 Porphyritic granodiorite

SAMPLE: D-49

CLASSIFICATION: Porphyritic trondhjemite

MODAL ABUNDANCES:	Quartz	35.3%
	Plagioclase	47.3%
	K-feldspar	0.7%
	Biotite	9.3%
	Hornblende	trace
	Epidote	5.5%
	Chlorite	0.8%
	Sphene	0.2%
	Opagues	0.5%

TEXTURES:

This is a medium grained, holocrystalline porphyritic rock with megacrysts of strongly altered plagioclase in a xenomorphic granular matrix of quartz, plagioclase and biotite.

The plagioclase insets are subhedral to euhedral and vary in size from 4x3 mm to 1x2 mm. They are generally sericitized and show remnant albite twinning. Some are poikilolitic with inclusions of biotite and quartz.

Quartz is present in the matrix as anhedral crystals often showing a mosaic intergrowth texture and some recrystallization.

The major mafic mineral is biotite which occurs as subhedral to anhedral crystals with an average length of 0.5 mm. They are commonly altered to chlorite and epidote. Opagues are also associated with the biotite.

Table A-1 Modal Analyses

Sample	D-1	D-5	D-6	D-12	D-15	D-17	D-19	D-22	D-23
Quartz	19.0	20.8	16.9	24.2	24.4	20.6	16.7	10.7	10.4
Plagioclase	48.6	51.8	51.9	50.6	46.6	46.2	44.8	46.1	44.4
K-feldspar	14.4	10.2	17.5	12.0	15.4	18.4	22.5	18.5	16.2
Hornblende	7.2	5.4	2.5	4.0	4.6	4.0	4.3	9.1	10.0
Biotite	4.6	4.8	5.7	4.6	3.8	6.0	5.7	10.1	13.2
Epidote	1.8	3.8	2.1	2.0	2.0	2.4	1.7	2.1	0.8
Chlorite	2.4	2.0	1.5	1.8	2.0	1.2	0.79	2.7	4.4
Sphene	0.6	0.4	0.1	0.6	-	-	1.7	-	-
Apatite	1.4	0.6	1.1	0.2	1.2	1.0	0.9	0.1	0.6
Allanite	-	0.2	0.1	-	-	0.2	-	-	0.4
Opagues	tr	tr	-	tr	-	tr	0.3	-	-

Table A-1 Modal Analyses

Sample	D-25	D-34	D-38	D-39	D-42	D-43	D-46	D-49	D-53
Quartz	15.6	23.2	27.8	22.4	29.8	26.4	23.6	35.3	40.5
Plagioclase	45.4	41.6	33.2	40.1	35.6	45.6	50.8	47.3	46.1
K-feldspar	12.8	20.4	30.8	21.8	10.4	6.6	12.6	0.7	4.5
Hornblende	10.6	6.0	2.8	0.3	11.6	5.4	3.0	-	-
Biotite	11.2	6.6	3.8	1.9	7.6	9.2	5.2	9.3	5.3
Epidote	1.2	0.8	0.4	1.2	0.8	5.6	2.0	5.5	2.3
Chlorite	1.6	1.0	0.3	0.7	2.0	0.4	1.0	0.8	0.8
Sphene	-	-	-	0.5	2.0	0.6	1.8	-	-
Apatite	0.8	-	0.8	-	-	-	-	0.2	-
Allanite	0.8	0.4	-	0.1	0.2	-	-	-	0.1
Opagues	-	tr	tr	0.4	-	tr	0.2	0.5	0.3

APPENDIX B

GEOCHEMICAL WHOLE ROCK DATA

1. ANALYTICAL METHODS

Whole rock and trace element analyses were obtained using a Philips Model 1450 AHP automatic sequential X-ray fluorescence spectrometer. 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, Ni.

To prepare samples for analysis the weathered surfaces were removed. The samples were then crushed to -200 mesh using a Spex Industries shatterbox with tungsten carbide rings.

For whole rock analysis, fused dishes were used. They were made by fusing 3.000 g of a lithium tetraborate and lithium metaborate mixture (flux) with 0.5000 g of rock powder in Pt/Au crucibles for 3-5 minutes at 1200°C. Pressed powder discs were used for trace element analysis.

Table B-1 Whole Rock Analyses (Normalized) in Weight Percent
Oxides Including Loss on Ignition

Sample	D-1	D-5	D-6	D-12	D-15	D-17	D-19	D-22	D-23
SiO ₂	67.02	66.97	67.63	68.29	67.69	67.44	64.01	58.02	59.36
Al ₂ O ₃	15.66	16.02	15.92	15.97	16.06	16.13	15.12	14.69	14.68
Fe ₂ O ₃	3.53	3.32	3.27	2.95	3.03	3.24	5.05	7.06	6.79
MgO	1.85	1.72	1.53	1.24	1.36	1.38	2.38	5.34	4.83
CaO	3.83	3.41	3.40	3.18	3.57	3.45	4.01	5.58	5.53
Na ₂ O	4.88	5.01	4.83	4.76	4.90	5.09	3.93	4.07	3.73
K ₂ O	2.21	2.22	2.48	2.65	2.48	2.33	3.55	2.56	2.96
TiO ₂	0.34	0.34	0.33	0.32	0.31	0.35	0.50	0.61	0.60
MnO	0.06	0.06	0.06	0.04	0.05	0.05	0.10	0.14	0.13
P ₂ O ₅	0.10	0.11	0.09	0.11	0.08	0.11	0.22	0.28	0.27
Loss on Ignition	0.53	0.81	0.46	0.49	0.47	0.43	1.14	1.66	1.12

Table B-1 Whole Rock Analyses (Normalized) in Weight Percent
Oxides Including Loss on Ignition

Sample	D-25	D-34	D-38	D-39	D-42	D-43	D-46	D-49	D-53
SiO ₂	59.98	65.61	67.61	73.58	65.08	68.35	67.72	68.55	72.61
Al ₂ O ₃	16.14	15.53	14.79	14.82	15.77	16.18	16.08	14.87	14.60
Fe ₂ O ₃	6.46	4.17	3.55	1.5	4.08	2.83	3.03	5.12	3.05
MgO	3.05	1.75	1.35	0.36	2.16	1.25	1.25	1.20	0.64
CaO	5.20	3.27	2.83	1.84	4.69	3.68	3.45	4.13	1.70
Na ₂ O	4.10	4.32	3.98	4.03	5.13	4.75	5.02	3.61	4.04
K ₂ O	3.09	4.3	4.74	3.33	1.96	1.97	2.11	1.28	1.95
TiO ₂	0.57	0.37	0.41	0.17	0.53	0.32	0.36	0.55	0.30
MnO	0.11	0.08	0.06	0.04	0.06	0.06	0.05	0.09	0.07
P ₂ O ₅	0.3	0.28	0.21	0.01	0.23	0.15	0.17	0.06	0.03
Loss on Ignition	1.00	0.32	0.46	0.31	0.31	0.46	0.76	0.55	1.01

Table B-2 Trace Element Analyses (ppm)

Sample	Rb	Sr	Y	Zr	Nb	Ni	S
HERON BAY BATHOLITH							
D-1	67	986	-	57	4	22	54
D-5	58	1155	-	73	5	5	76
D-6	80	1069	-	53	7	7	111
D-12	65	1046	-	67	8	1	-
D-15	61	1043	-	51	8	-	47
D-17	69	1112	-	60	5	4	44
PIC BATHOLITH							
D-19	119	841	10	142	14	13	120
D-22	85	719	5	149	7	45	-
D-23	99	803	7	126	12	35	45
D-25	76	985	13	116	14	10	92
D-34	134	1187	16	131	13	5	104
D-38	132	1139	20	121	18	6	-
PUKASKWA GNEISS COMPLEX							
D-39	82	569	-	144	16	5	39
D-42	39	1349	-	162	5	6	44
D-43	42	976	-	90	4	-	106
D-46	41	1179	1	127	7	13	-
D-49	49	343	1	144	11	3	60
D-53	50	216	11	167	2	7	36

Table B-3 CIPW Norms

Sample	Q	or	ab	an	ap	il	cor	mte	he	di	hy	sp	DI
D-1	19.99	13.06	41.29	14.30	0.23	0.64	-	2.67	-	3.21	3.91	-	75.79
D-5	19.87	13.12	42.39	14.67	0.26	0.65	-	2.67	-	1.21	4.22	-	77.20
D-6	20.93	14.66	40.87	14.44	0.21	0.63	-	2.65	-	1.45	3.57	-	77.83
D-12	22.25	15.66	40.28	14.38	0.26	0.61	-	2.49	0.10	0.53	2.85	-	79.55
D-15	20.78	14.65	41.46	14.50	0.19	0.59	-	2.62	-	2.09	2.52	-	78.07
D-17	20.10	13.77	43.07	14.29	0.25	0.67	-	2.68	-	1.66	2.94	-	78.22
D-19	15.93	20.98	33.26	13.13	0.51	0.95	-	2.90	-	4.30	6.61	-	72.56
D-22	5.33	15.13	34.44	14.26	0.65	1.16	-	3.06	-	9.35	14.49	-	58.29
D-23	8.05	17.49	31.56	14.57	0.63	1.14	-	3.04	-	8.96	12.97	-	60.05
D-25	8.85	18.26	34.69	16.51	0.69	1.08	-	3.00	-	5.98	9.49	-	64.29

Table B-3 CIPW Norms

Sample	Q	or	ab	an	ap	il	cor	mte	he	di	hy	sp	DI
D-34	15.27	25.41	36.56	10.29	0.65	0.70	-	2.71	-	3.31	4.56	-	78.94
D-38	19.47	28.01	33.68	8.49	0.49	0.78	-	2.77	-	3.31	2.38	-	82.58
D-39	33.04	19.68	34.10	8.63	0.02	0.09	1.42	-	1.67	-	0.89	0.31	88.74
D-42	16.31	11.58	43.41	14.22	0.53	1.01	-	2.94	-	5.98	3.51	-	72.70
D-43	23.91	11.64	40.19	17.01	0.35	0.61	-	2.17	0.33	0.21	3.02	-	77.15
D-46	21.86	12.47	42.48	15.11	0.39	0.68	-	2.50	0.13	0.69	2.79	-	78.46
D-49	30.98	7.57	30.55	20.09	0.13	1.05	0.18	2.97	-	-	5.62	-	70.55
D-53	37.03	11.52	34.19	8.24	0.07	0.57	2.83	2.61	-	-	1.82	-	86.64

TABLE B-4

Cation Percentages x100

Sample	D1	D5	D6	D12	D15	D17	D19	D22	D23
Si	6224.8	6228.7	6280.3	6346.3	6282.0	6251.2	6023.5	5445.2	5563.6
Ti	23.7	23.7	23.0	22.3	21.6	24.3	35.3	43.0	42.2
Al	1714.4	1756.3	1742.6	1749.3	1756.8	1762.3	1677.1	1625.0	1621.8
Fe ⁺³	128.4	128.7	127.8	130.7	126.3	129.0	141.6	148.9	148.0
Fe ⁺²	118.0	103.4	100.9	79.2	84.5	96.8	215.6	349.2	330.7
Mn	4.72	4.72	4.71	3.14	3.93	3.92	7.97	11.1	10.3
Mg	256.1	239.8	211.7	171.7	188.1	190.6	333.8	746.9	674.7
Ca	381.1	339.7	338.2	316.6	354.9	342.6	404.2	561.0	555.2
Na	878.7	903.3	869.5	857.5	881.6	914.6	716.9	740.5	677.7
K	261.8	263.3	293.7	314.1	293.5	275.4	426.1	306.4	353.8
P	7.8	7.8	7.0	8.6	6.2	8.6	17.5	22.2	21.4

TABLE B-4/continued

Sample	D25	D34	D38	D39	D42	D43	D46	D49	D53
Si	5624.1	6097.1	6315.5	6873.8	6022.1	6358.3	6305.9	6525.7	6880.9
Ti	40.1	25.8	28.7	11.9	36.8	22.3	25.2	39.3	21.3
Al	1783.8	1701.1	1628.4	1631.9	1720.0	1774.1	1764.1	1668.5	1630.8
Fe ⁺³	146.0	130.7	134.2	117.3	141.3	128.0	130.3	146.8	128.3
Fe ⁺²	309.7	160.8	114.8	-	142.3	70.0	81.7	219.7	89.5
Mn	8.7	6.2	4.7	3.1	4.7	4.7	3.9	7.2	5.6
Mg	426.2	242.3	187.9	50.1	297.9	173.3	173.4	144.7	90.3
Ca	522.3	325.5	283.2	184.1	464.9	366.7	344.1	421.2	172.0
Na	745.3	778.2	720.7	729.8	920.2	856.6	406.2	666.2	742.2
K	369.5	509.7	564.7	396.8	231.3	233.7	250.6	155.4	235.7
P	23.8	22.0	16.6	0.79	18.0	11.8	13.4	4.8	.2.4