PETROLOGY AND GEOCHEMISTRY AT THE CONTACT OF THE ROUND LAKE BATHOLITH IN ROBILLARD TOWNSHIP, NORTHEASTERN ONTARIO

PETROLOGY AND GEOCHEMISTRY AT THE CONTACT OF THE ROUND LAKE BATHOLITH IN ROBILLARD TOWNSHIP, NORTHEASTERN ONTARIO

by

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The Round Lake Batholith is a composite granitic intrusion into the Archean metavolcanics of the Abitibi Greenstone Belt, Superior Province.

The mafic metavolcanics are mainly high iron tholeiitic basalts of ocean floor origin. The intrusion of the batholith has metamorphosed the metavolcanics to amphibolite grade. Moving towards the contact there is no change in the metavolcanics grain size, but mineralogy changes quickly from the actinolite zone with relict pumpellyite to the hornblende zone.

Field evidence as well as thin section and chemical analyses have shown that the dioritic appearing hybrid rock, near the contact, is a product of the mafic meta volcanics assimilation into the batholith.

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Chapter 1 Introduction

1. Location and Accessibility

The thesis area is bounded by latitudes $47^{\circ}45'15''$ N and $47^{\circ}48'00''$ N and longitudes $80^{\circ}08'45''$ W and $80^{\circ}03'45''$ W (see figure 1). It is located in Robillard township, district of Temiskaming and covers 13.6 square miles, being 3.4 mi. wide by 4 mi. long.

Access is possible from Highway 560 between Elk Lake and Englehart. Highway 560 bisects the map area and joins Highway 11 at Englehart, 30 mi. SE of Kirkland Lake. Numerous paths and overgrown roads transect the area, many of which are visible on air photos.

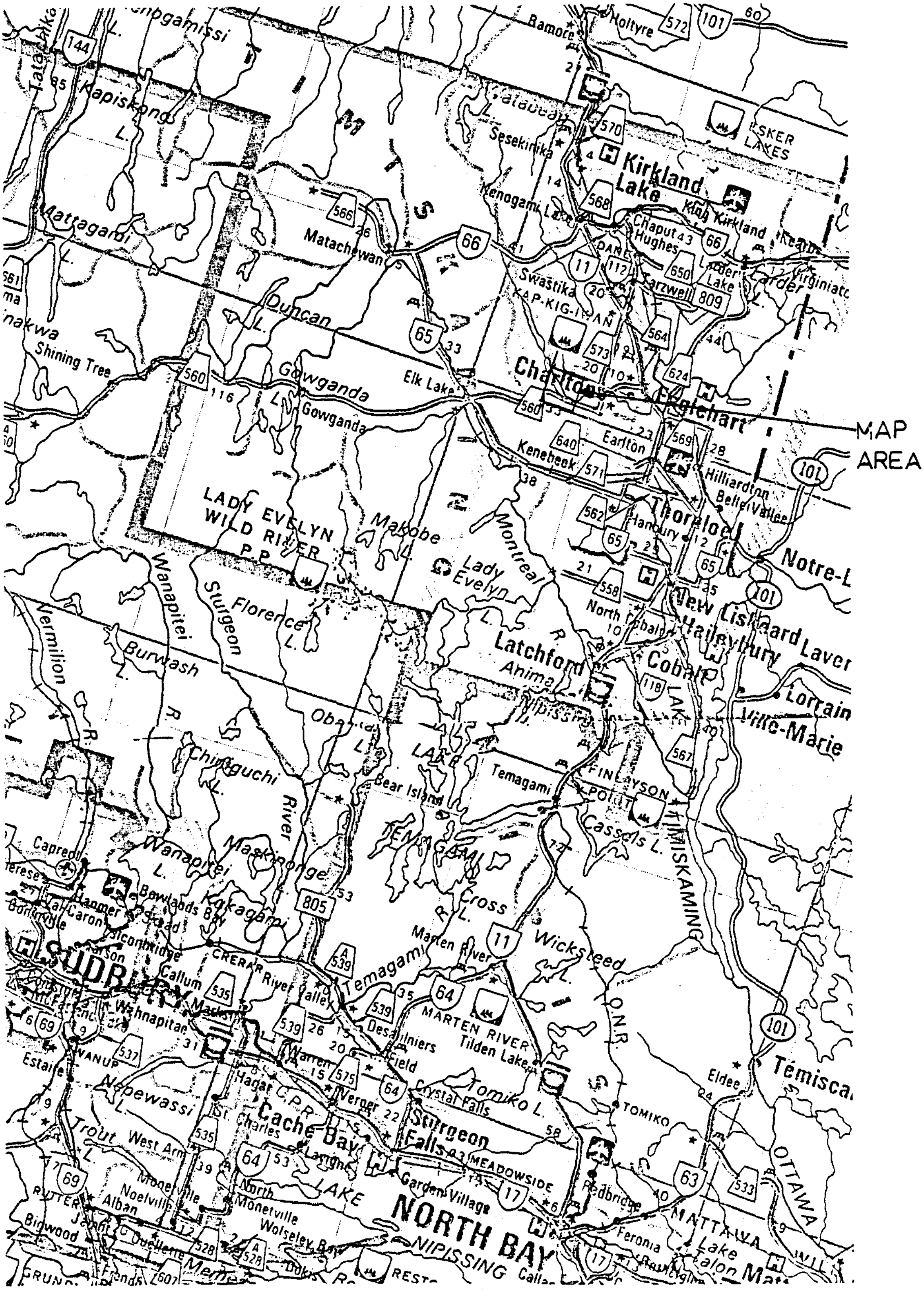
2. Previous Work

The district of Temiskaming was opened up as a result of influx of prospectors, mining men and the building of the Toronto and Northern Ontario Railway. Because of the success in Cobalt and Gowganda, the area was prospected for silver. Remains of old and new trenches can be found scattered through the meta volcanics near shear zones and dikes.

The Blanche River area was mapped by Burrows and Hopkins (1921, 1922) and included Robillard township.

The area was remapped by Moorhouse (1940). The meta volcanics and acid intrusion he called basic volcanics and granodiorite, respectively, but subsequent chemical analysis by the author has shown them to be high iron tholeiitic basalts and trondjhemite.

FIGURE 1: Location Map



3. Statement of Problem

Mapping of the thesis area was carried out in July and August of 1980 by the Ontario Geological Survey crew, made up of Glen Johns, Warren Hoyle and the author. This thesis topic was suggested to the author by Glen Johns, consequently, specific parts were remapped and sampled.

The purpose of the project was to produce a detailed map (4 in. to 1 mi.) of the area to determine:

(a) the position and nature of the contact between the Round Lake Batholith and mafic volcanics,

(b) the origin of the hybrid rocks at the contact, and

(c) changes in metamorphic grade away from the contact.

Fifty-two samples were collected, 7 of these by the O.G.S. for chemical analysis and sodium cobaltonitrate rock slab staining. Of the 45 collected by the author, 20 were taken for thin sections and 16 for chemical analysis.

4. Method of Mapping

Mapping was carried out on a scale of 4 in. to 1 mi., with extra attention given at the contact near Highway 560 and SE along the Cross Lake Fault where most of the information for the thesis problem was gathered. Each individual outcrop was mapped and exposure was 80-90%. Relief here and along the southern margin of the map was in the order of a few hundred feet.

Along the western boundary, exposure was about 10% and easily distinguished on air photos so traverses were run from outcrop to outcrop.

A swamp in the central part of the map area was traversed in a straight line. No outcrops were found and the contact was inferred with the help of a magnetic survey map (Geological Survey of Canada Aeromagnetic Map 1506-G, Charlton Station, 1959).

At the west end of the map area farming extends $\frac{1}{4}$ mile north and south of highway 560. Some of the fields surrounded outcrops and mapping was carried out with the farmers' kind permission.

East of the Cross Lake Fault (see map), no outcrops were found within the map area by Moorhouse (1940).

Chapter 2 General Geology

1. Regional Geology

The Abitibi Greenstone Belt has undergone intensive study because of its wealth in precious and base metals. Recently, Jensen in O.G.S. Summary of Field Work, 1978 and 1979, has done extensive field work and sampling and has developed a classification scheme to subdivide the meta volcanics of the Timmins - Kirkland Lake area. Jolly, (1974, 1978, and 1979), has written on the structural and metamorphic history of the Abitibi Greenstone Belt. Robillard township is in the south central part of the Abitibi Belt.

The following discussion is based on the work of Jensen, (1978 and 1979). The oldest rocks in the area are the Archean mafic volcanics (see figure 2). The lowest member is the Wabewawa group, 8 - 10 000 feet of ultramafic and basaltic komatiites interlayered with calc-alkaline basalts, andesite, dacite, rhyolite tuffs and sedimentary rocks of wacke, argillite, ironstone, chert, and sulphide mineralization and minor conglomerate.

The Catherine group overlies the Wabewawa and is in turn, conformable overlain by the Skead group. The Skead group consists of 15 000 feet of intermediate to mafic, coarse and fine grained pyroclastics.

FIGURE 2

REGIONAL GEOLOGY

CENOZOIC

QUATERNARY

PLEISTOCENE	-Glacio-lacustrine varved clay, sand and gravel

PRE CAMBRIAN

PROTEROZOIC

KEWEENAWAN	-Nipissing quartz diabase sills -Diabase dikes
HURONIAN	-Lorraine quartzite (arkosic) -Gowganda conglomerate and slate
MATACHEWAN	-Diabase dikes

ARCHEAN

LATE	-lamprophyre dikes -quartz and quartz feldspar porphyry -granite, granodiorite, pegmatite -diorite, amphibolite, other hybrid rocks
EARLY	-gabbroic intrusives (near Charlton) -intermediate and acid flows and volcs -basic lavas -Iron formation (S in Bryce twp.)

In the thesis area, the Catherine basalts are dealt with. These basalts are approximately 14 500 feet thick and consist of interbedded flows which vary from pillowed, fine grained, massive sometimes amygduloidal to medium grained flows with occaional flow top breccia.

These volcanics underwent regional burial metamorphism which yielded a prehnite-pumpellyite assemblage. A north-south compressive episode created east-west trending folding. The synclinal basins were filled with conglomerates, arkoses, and greywackes derived from the nearby volcanics containing the prehnite-pumpellyite mineralogy (Jolly, 1974).

The Round Lake Batholith was intruded at the base of the Catherine basalts at 2 605 Ma (Lowden et al, 1963), because this is a biotite K/Ar age, it is considered a minimal value. The Round Lake Batholith is a composite granitic intrusion of two major rock types; an older quartz diorite-oligoclase granite facies of very uniform composition and texture and a younger injection of massive hornblende granite which grades locally into hornblende syenite (Gibb and van Boeckel, 1970). In this same paper, Gibb and van Boeckel have postulated two models for the Batholith and volcanics of Robillard township are each 5 km thick, but, the other shows them to be 10 and 4 km thick, respectively. In each case, the Batholith and volcanics are underlain by granitic basement extending to unknown thickness in the crust.

A wide variety of intrusion related aplitic, felsitic, and pegmatitic dikes and post intrusion lamprophyre and quartz feldspar porphyritic dikes have cut the meta volcanics and trondjhemite. These are all of late Archean age.

Unconformably overlying the meta volcanics in the SW corner is the Cobalt Group of the Huronian Super Group. These sediments are gently dipping, moderately sorted pebble to cobble conglomerates. Above the Cobalt Group is the Lorraine formation of medium grained moderate to well sorted feldspathic arenites with pebbly conglomerates lenses.

Nipissing dikes and sills of hypersthene diabase have intruded into the country rock just west and east of the map area.

The Cross Lake Fault is one of a series of parallel faults forming the Temiskaming Rift Valley (Lovell, 1970). The basin created by the down faulting of the eastern block has been filled by the Pleistocene aged "Little Clay Belt". It is a thick, flat topped blanket of lake clay, grey in colour and invariably varved. In places, streams have trenched through the clay to the bedrock, (Moorhouse, 1941).

2. Field Observations

i) Catherine Basalts

The basalts are alternating pillowed, fine grained and porphyritic, sometimes vesicular flows of varying thickness. Outcrop exposure did not allow for visible contacts so no thickness measurements were made. The rocks are dark green with a brownish green weathered surface. The pillows average 10 - 30 cm in size with 1 - 2 cm selvages. Vesicles are usually less than .5 cm but in some pillows they are upto 4 cm long and oriented perpendicular to the selvages (see figure 3). Hematite mineralization was found between selvages close to an aplitic dike (figure 4). In the SW corner of Robillard twp. some pillows have cherty selvages. Pyrite is present in both disseminated and joint filled occurrences. Epidote is common in veins and lenses. Close to the contact, the meta volcanics are strongly schistosse and xenoliths in the batholith are strongly recrystallized but not schistosse. The meta basalts grade from prehnite-pumpellyite to lower amphibolite. Near the contact they have been assimilated into the batholith.

ii) Hybrid Rocks

Close to the contact between the batholith and meta volcanics, lenses, bodies and veins of a dioritic looking material are found within the meta volcanics. These do not cut the trondjhemite so they were either intruded before the batholith or are an assimilation of the volcanics into the batholith.

The trondjhemite has intruded the meta volcanics along joints, bedding planes and in some cases pillow selvages (figure 5). Dikes of felsic material have angular basaltic xenoliths (figure 6). The hybrid material shows features of both intrusion and replacement. The intrusive mechanisms are shown by xenoliths of basalt (figure 7) and sharp contacts between basalt and hybrid rocks whereas the replacement is shown by a gradation from hybrid rock to fine grained volcanics (figures 8 and 9). The hybrid rock composition varies across the outcrops, but, generally has medium grained dioritic appearance and banding is not uncommon (figure 10). Outcrops tend to have a chaotic appearance of meta volcanics, hybrid, felsic and pegmatite dikes and bodies.

iii) Trondjhemite

The contact with the meta volcanics has been inferred in some places with the aid of a geomagnetic map (G.S.C. 1959). The trondjhemite is coarse grained and shows strong foliation of biotite and amphibole, paralleling the contact. The weathered surface is white and usually pock marked from weathered and plucked biotite. Green margins of chlorite are visible around mafic phenocrysts. The outcrops are frequently cut by small finer grained acid dikes.

iv) Dikes

There is a large, widespread assortment of dikes intruding the Archean rocks. They can be divided into 3 different groups.

Figure 3: Elongated vesicles perpendicular to pillow selvages, northern tip of Fraser Lake.

Figure 4: Hematite and calcite mineralization between pillow selvages, northern tip of Fraser Lake.

Figure 5: Trondjhemite intrusion along pillow selvages, south of highway 560 near Robillard Lake.

Figure 6: Angular xenoliths of basalt in a felsic dike, south of highway 560 near Robillard Lake.

Figure 7: Sub-rounded xenoliths of basalt in the hybrid rock, note the sharp contact with the basalt, at Cross Lake Fault and stream from Mearow Lake.

Figure 8: Gradational contact between the hybrid rock and the basalts, at the Cross Lake Fault and the stream from Mearow Lake.

Figure 9: Gradational contact between the hybrid rock and the basalts, near sample 15.

Figure 10: Banding in hybrid rock, near sample 24.

1. The intrusion related dikes of felsite, aplite and pegmatite cut the meta volcanics and hybrid rock with widths up to a few metres.
2. Quartz feldspar and feldspar porphyry dikes with a grey matrix are post Batholith and probably related to the large porphyritic stock a few miles to the south (Moorhouse 1941). They average a metre in thickness with a low frequency of occurrence.
3. Post porphyry dikes are lamprophyres, hornblende syenites, hornblende lamprophyres and pebbly lamprophyres. The pebbly lamprophyres have rounded intrusions, up to 30 cm in size, of quartz, granite, recrystallized greenstone and porphyry.

v) Huronian Sediments

The Gowganda conglomerate consists of sub rounded, poorly sorted, matrix supported clasts of felsic and mafic volcanics, porphyry and fewer, larger, granitic and gneissic clasts. The matrix has a dark green colour and the weathered surface is brownish orange.

3. <u>Structural Geology</u>

The pillows strike NE and dip steeply to the south. The tops of flows all face consistently south, suggesting that the volcanics, as exposed, are the north limb of a syncline. The inferred south limb is covered by rocks of the Cobalt series (Moorhouse, 1941). Jolly (1980) believes that the meta volcanics were deformed by the intrusion of the Round Lake Batholith. Two sets of jointing in the meta volcanics and trondjhemite are near vertical and trend NNW and ENE. Foliation in trondhjemite is NE in the SW corner, but, has a subtle change to ENE along the N edge. This follows the contact.

In the SE corner of the thesis area, the air photos show two strong sets of lineaments in a N-S and ENE to NE direction as shown by Fraser and Mearow Lakes.

The Cross Lake Fault striking WNW and dipping 65° NE (G.J. Ninacs, 1967) is the structural control of Robillard Lake and parallels the Regional lines of drainage, namely Elk Lake and Lake Temiskaming. It shows dip-slip movement of 3 km vertically (Gibb and van Boeckel, 1970) and approximately 1 1/8 mile sinistrally (see map).

Chapter 3 Petrography

1. Progressive Contact Metamorphism of Mafic Volcanics

In this chapter a section by section description of the mafic volcanics mineralogy and textural differences are listed. The thin sections are described in the form of a traverse from the SW corner of the map, NE to the contact. The full thin section descriptions are listed in the appendix.

i) Slide 35 (10569 feet from the contact)

Most of this section is comprised of very fine grained, fibrous, sometimes spherulitic actinolite with interstitial quartz and possibly albite. Epidote, sphene and relic pumpellyite make up approximately 5%. The actinolite protrudes into quartz amygdules and resembles pumpellyite but the relief is too low (figure 11). The relic pumpellyite has high relief and colourless to pale brown pleochroism (figure 12). The average grain size is less than 0.1 mm.

ii) Slide 20 (9900 feet from contact)

The hand specimen is very blotchy and in thin section shows coarse grained, rounded clumps of hornblende with a ragged to fibrous habit including slightly altered laths of albite (H. Schwarz, personal communication, figure 13). The hornblende is slightly pleochroic, pale green to green. There are also large clumps of fibrous chlorite with cores of hornblende and inclusions of subhedral epidote (figure 14). Medium grained, skeletal ilmenite is altering to sphene. Matrix plagioclase is strongly altered, showing no twinning. The average grain size is 1.2 mm.

iii) Slide 25 (5280 feet from contact)

This slide consists of anhedral, poikiloblastic, olive green to pale green, inequigranular hornblende including quartz, sphene and also smaller hornblendes (figure 15). Plagioclase is interstitial and strongly altered. This section also shows some thin veins of felsic material. The average grain size is less than 0.5 mm.

iv) Slide 45 (660 feet from contact)

This is a schistosse, strongly recrystallized section showing hornblende as subhedral, equigranular crystals. There are a few poikiloblastic hornblendes contianing apatite and quartz. The hornblende is pleochroic, yellow green to olive green. Epidote is present as elongate, polycrystalline clumps of anhedral, fine grained crystals. The plagioclase shows less alteration and some twinning, suggesting some recrystallization of albite to a more calcic plagioclase. Strings of fine grained magnetite parallels schistossity. The average grain size is 0.2 mm.

v) Slide 44 (500 feet from contact)

This is a schistosse, very fine grained, amygduloidal, recrystallized flow. The hornblende is subhedral and pleochroic yellow green to olive green. Quartz is interstitial and along with plagioclase fills vesicles. The plagioclase shows less alteration than slide 45, suggesting more recrystallization. Accessories include apatite, and ilmenite. A very small amount of sphene borders ilmenite grains. The average grain size is less than 0.1 mm.

vi) Slide 39 (165 feet from contact)

This is also a recrystallized, schistosse, very fine grained rock with subhedral yellow brown to dark green-brown hornblende (figure 16). Epidote is very fine grained, anhedral and colourless. Plagioclase is moderately recrystallized and interstitial along with quartz to the hornblende. Sphene is subhedral. A vein parallel to schistossity contains epidote and sphene. The average grain size is 0.3 mm.

vii) Slide 37 (Xenolith in trondjhemite)

This slide is recrystallized, but, non-schistosse with anhedral pale yellow brown to blue green hornblende. Some poikiloblastic hornblende contains anhedral quartz. Epidote shows faint pale green to colourless pleochroism. A vein cutting the slide consists of epidote,quartz, and a fibrous chlorite. This chlorite has a dark brown anomalous birefringence and seems to be a space filler throughout the slide, as opposed to an alteration product (H.D. Grundy, personal communication). The average grain size is 0.5 mm.

Figure 11: Actinolite protruding into the quartz amygdules, sample 35, plain light. Magnification is 63x.

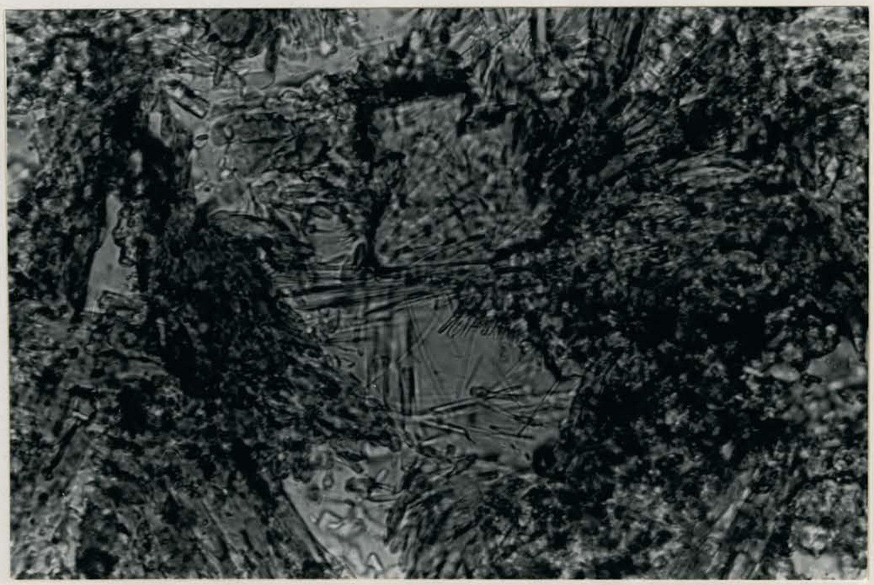


Figure 12: Subhedral,relict pumpellyite surrounded by actinolite and quartz, sample 35, XNICOLS. Magnification is 63x.

Figure 13: Slightly altered laths of albite included in rounded,equigranular crystals of hornblende, sample 20, XNICOLS. Magnification is 25x.

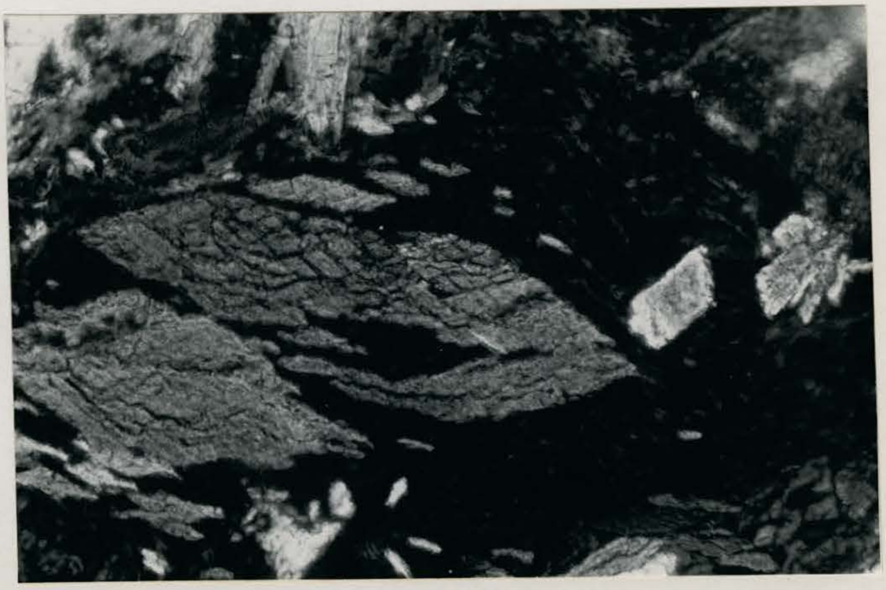


Figure 14: Fibrous chlorite (dark) with cores of hornblende and inclusions of epidote(subhedral), sample 20, XNICOLS. Magnification is 25x.

Figure 15: Poikiloblastic hornblende surrounding quartz, sphene and smaller hornblende crystals, sample 25, XNICOLS. Magnification is 25x.

Figure 16: Subhedral, very fine grained hornblende showing schistosity, sample 39, plain light. Magnification is 63x.

2. Summary of Metamorphic Changes

i) Jolly (1974) determined that the rock in the area grades from the actinolite zone with relic pumpellyite to the actinolite zone. The author has found that the rocks grade from the actinolite zone with relic pumpellyite quickly into the hornblende zone.

ii) With increasing grade the plagioclase appearance gets cleaner, suggesting progressive recrystallization.

iii) The colour of the hornblendes becomes darker as you approach the contact. Pleochroism changes from pale green/green to pale greenish yellow/dark greenish brown.

iv) The hornblendes form changes habit from ragged and fibrous to anhedral and poikilitic to subhedral and equigranular.

v) The amount of sphene increases away from the contact.

vi) Close to the contact, the rocks are schistosse parallel to the contact, but, xenoliths in the batholith are not.

vii) Apatite first appears close to the contact.

viii) Although the bulk compositions of the mafic volcanics are very similar, the proportion of plagioclase increases with increasing grade while that of hornblende decreases.

ix) Close to the contact, the rocks are cut by veins of epidote, chlorite, sphene and pyrite.

x) Epidote is stable throughout.

3. Hybrid Rock

The following is a summary of the examination of thin sections of the hybrid rocks.

i) Amphibole

Hornblende makes up 10 to 70% of the rocks. The larger the proportion of hornblende, the less plagioclase and vice-versa. The hornblende is fine to medium grained, subhedral to anhedral, sometimes poikilitic containing quartz. They almost always have a chewed up appearance and are altering to chlorite or biotite. Pleochroism is from pale yellow green or pale green to dark green or olive green. In some the colours are patchy. Complex and simple twinning is not uncommon.

ii) Plagioclase

The highly altered, subhedral, fine to medium grained feldspars make up 10 to 70% of each section. They show a combination of saussuritization and sericitization. The alteration starts along twin planes and fractures and covers some grains to a point where only relic twinning remains. Hand sample DJG-12 shows a pink colouring which is hematite dust scattered on the feldspars. The plagioclase is interstitial to the hornblendes and also tends to isolate the mafics from the quartz (figure 17).

iii) Chlorite

This phase is found as an alteration product from epidote and less commonly hornblende and biotite. It

Figure 17: Pseudo zoning of hornblende to plagioclase to quartz. The hornblende is dark and the quartz is colourless, sample 4, plain light. Magnification is 25x.

occurs as fibrous clusters around mafic crystals or along cleavage planes, especially those of biotite. It is weakly pleochroic, pale green with an anomalous berlin blue or dark brown birefringence and doesn't usually make up more than 10%.

iv) Biotite

Biotite is minor, if present, and occurs as fine grained plates, generally with chlorite along cleavage planes.

v) Quartz

Quartz is invariantly equigranular, mosaic, anhedral and interstitial, never making up more than 15% per section.

vi) Accessories

There are minor amounts of apatite, epidote, calcite, ilmenite, leucoxene, sphene, magnetite, pyrite, and limonite. The ilmenite commonly has a skeletal habit with rims of leucoxene or sphene. The pyrite is usually subhedral and altering to limonite. Apatite as well as magnetite is subhedral and very fine grained. Calcite is secondary and present in microfractures.

4. Hornblende-Biotite Trondjhemite

This is a gneissic, glomeroporphyritic, equigranular medium to coarse grained mosaic or interlocking textured rock. Major minerals include biotite, hornblende, epidote, plagioclase and quartz. It's appearance is almost constant across the map area, except at the contact where metasomatism and assimilation has occured. The mafics in order of decreasing abundance, biotite, hornblende and epidote, form elongated clusters giving the trondjhemite a porphyritic appearance. The hornblende is pale yellow green to dark green with some alteration to biotite and even less chlorite. The epidote shows high relief and very slight pleochroism from colourless to pale yellow green and commonly has quartz inclusions. The quartz makes up mosaic aggregates with wavy extinction. The plagioclase is anhedral and strongly altered to show only some relic twinning. Accessories include magnetite, sphene, and apatite.

5. Basaltic Dikes

These show unaltered characteristics. The complexly twinned, zoned and euhedral hornblende are aligned in an aphanitic, sugary matrix. Calcite (up to 10%) fills vesicles and microfractures along with some pyrite. The pyrite is euhedral with rims of limonite.

Chapter 4 Geochemistry

1. Analytical Procedure

Whole rock and trace element analyses for 16 samples were made using a Philips, Model 1450 AHP, automatic, sequential, X ray fluorescence spectrometer, within the Geology department at McMaster University.

In preparation for analysis, care was taken to remove all weathered surfaces from the samples. They were crushed to -200 mesh using a Spex Industries shatter box with tungsten carbide rings. A lithium tetraborate and lithium metaborate flux was mixed with the rock powder in a 6:1 ratio. This was fused in Pt/Au crucibles for 3-5 minutes at 1200°C. These fusion pellets were analyzed using a Cr X-ray tube for the major elements: Si, Al, total Fe, Mg, Ca, Na, K, Ti, Mn and P.

Pressed powder pellets were made following a procedure outlined by Marchand (1973). These pellets were analyzed using a Mo X-ray tube for the trace elements: Rb, Sr, Y, Zr, Nb, Ce, Nd, La, Ba, Cr, Co, Pb, Cu, Zn, As, V, Ni and S.

The loss on ignition was less than 3% and H_2O and CO_2 contents were below 2% so all analyses were accepted.

CIPW norms were calculated using a program, courtesy of Andy Fyon. The OGS analyzed three samples by fire assay to determine Au content, and they showed only trace amounts (less than .01% Au). The chemical analyses as well as a discussion of errors can be found in the appendix.

The purpose of doing the descriptive Geochemistry is as follows:

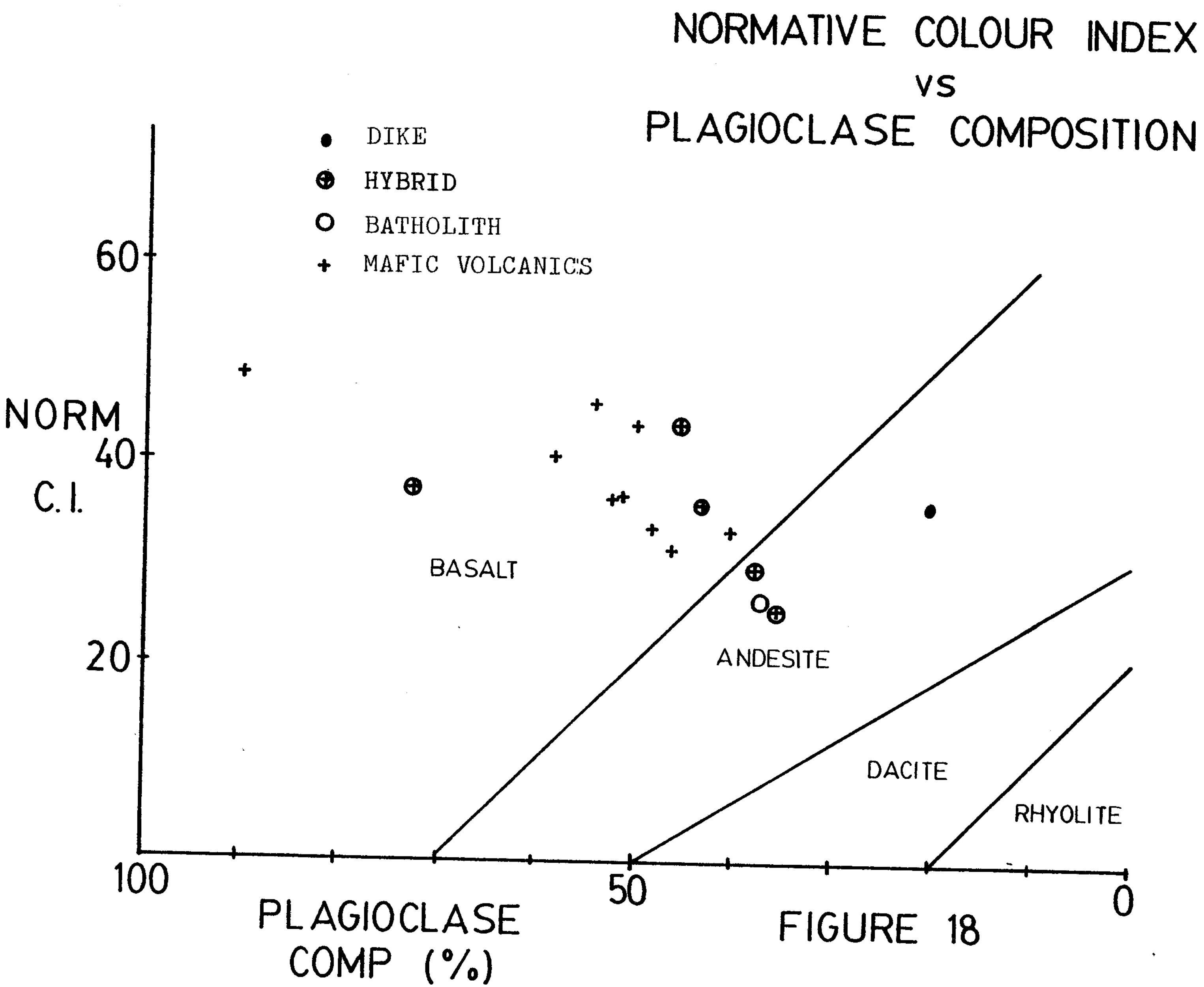
1) to chemically classify the rocks.
2) to help determine an origin for the hybrid rocks using any chemical relationships between the hybrid rocks, mafic volcanics and the batholith.
3) to detect any chemical changes in the mafic volcanics moving towards the contact.

2) <u>Classification - Major Element Characteristics</u>

Irvine and Baragar (1971) use AFM diagrams, Harker diagrams ($Na_2O + K_2O$ vs SiO_2) and a normative colour index vs. normative Anorthite content to discriminate between Calc Alkaline and Tholeiitic basalts. Recently, the Jensen cation plot (Jensen, 1975) has gained popularity in Archean rocks. It plots the cation per centages of Al, Mg and Ti + total Fe. These cations show much less tendency for mobility, and thus are less affected by metamorphic alteration.

3) <u>Results</u>

i) The normative colour index vs normative plagioclase composition (figure 18) shows the mafic volcanics to be basalts. The hybrid rocks tend towards the andesitic region, but, are not true volcanics. The dike rock plots within the Andesite range. Sample 26 has unusual Ca



NORMATIVE COLOUR INDEX
VS
PLAGIOCLASE COMPOSITION
DIKE
HYBRID
BATHOLITH
MAFIC VOLCANICS
NORM
C.I.
60
40
20
BASALT
ANDESITE
DACITE
RHYOLITE
100
50
0
PLAGIOCLASE
COMP (%)

FIGURE 18

enrichment, but, this is thought to be due to contamination.

ii) In the Harker diagram (figure 19), the basalts plot in the subalkaline field at the low SiO_2 (ie. basaltic) end of the Archean trend of Goodwin.

iii) The AFM diagram (figure 20) shows the basalts to be enriched in Fe in comparison to the Archean trend of Goodwin and West.

iv) The Jensen Cation Plot (figure 21) shows this Fe enrichment as the mafic volcanics plot as high iron tholeiitic basalts. The exception is sample 19 which plots in the komatiite field. Sample 26 is slightly contaminated with felsic material so plots to the left of the tholeiite field. The hybrid rocks and trondjhemite plot within the andesite dacite range.

4. <u>Trace Element Characteristics</u>

i) On a log plot of K vs Ba (figure 22), the hybrid rocks plot between the trondjhemite and basalts. The komatiite shows a K/Ba ratio of 560 whereas all the others fall within a range of 30 to 100.

ii) The Sr vs Ba log plot (figure 23) shows that the high iron tholeiites overlap the ocean floor basalts region of Kay et al, 1970. The Sr/Ba ratios of the high iron tholeiites, hybrids and trondjhemite are between 1.0 and 10 and decreases respectively.

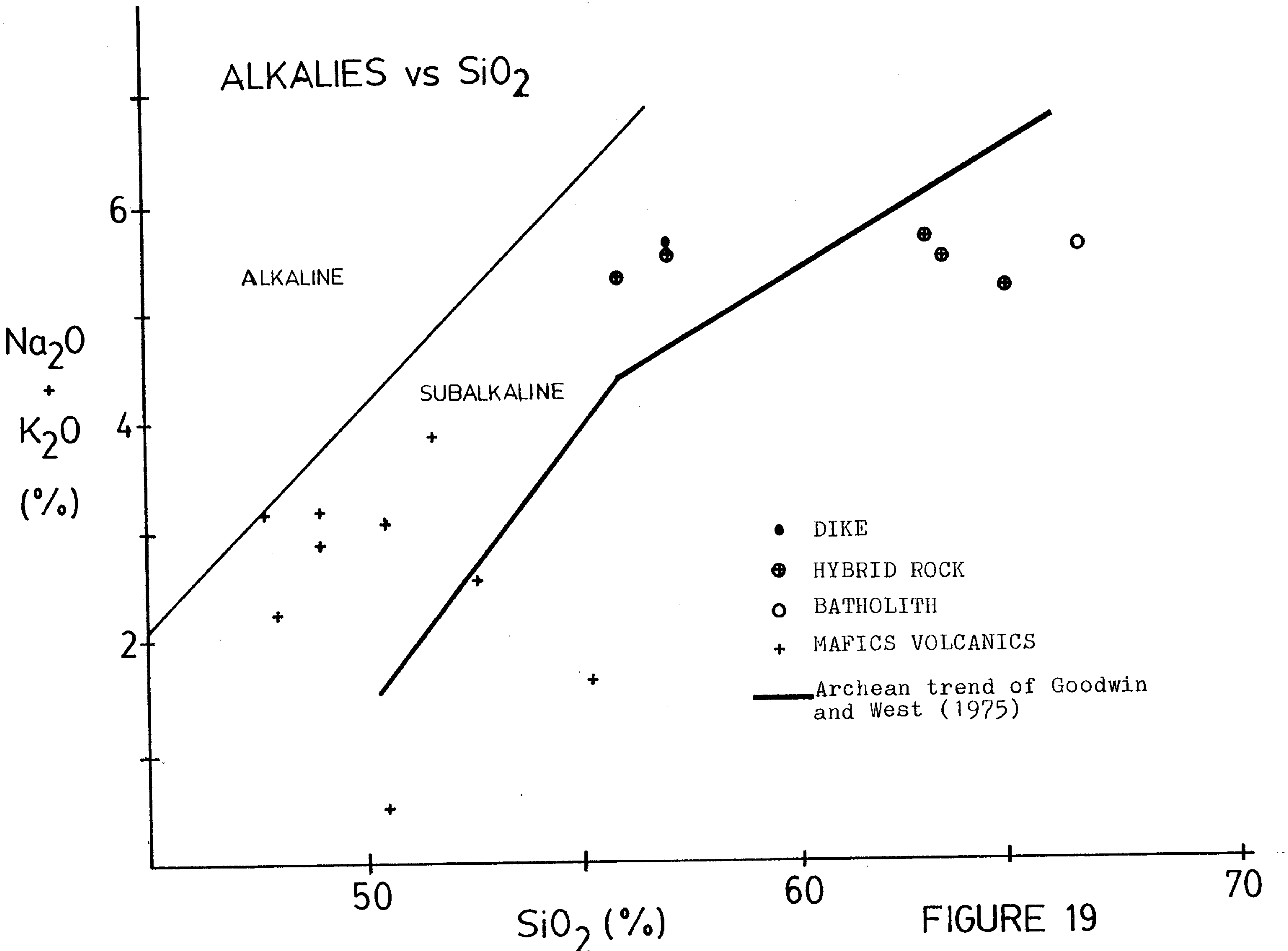

ALKALIES vs SiO2
ALKALINE
SUBALKALINE
Na2O + K2O (%)
6
4
2
50
60
70
SiO2 (%)
DIKE
HYBRID ROCK
BATHOLITH
MAFICS VOLCANICS
Archean trend of Goodwin and West (1975)

FIGURE 19

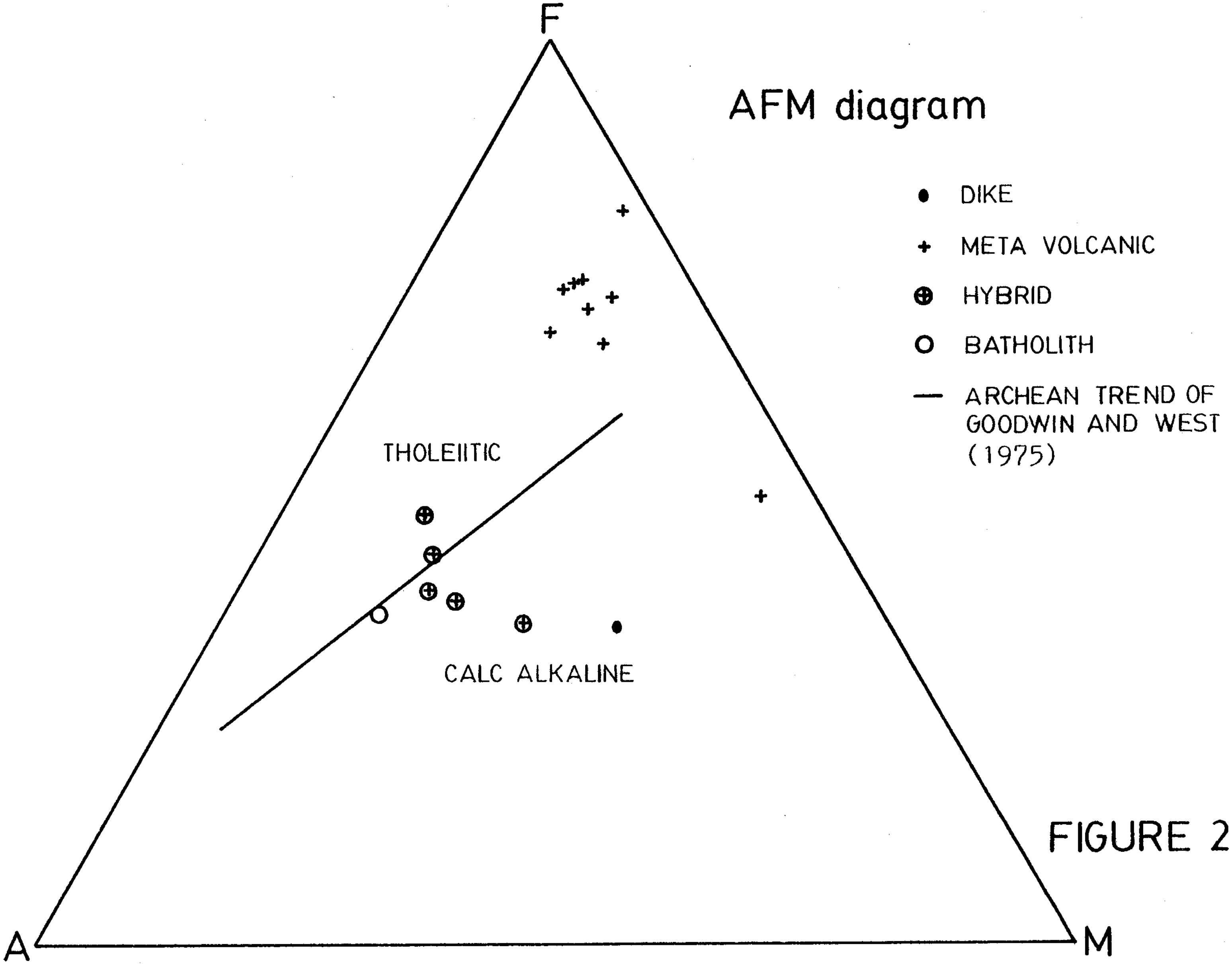

F
AFM diagram
DIKE
META VOLCANIC
HYBRID
BATHOLITH
ARCHEAN TREND OF GOODWIN AND WEST (1975)
THOLEIITIC
CALC ALKALINE
A
M

FIGURE 20

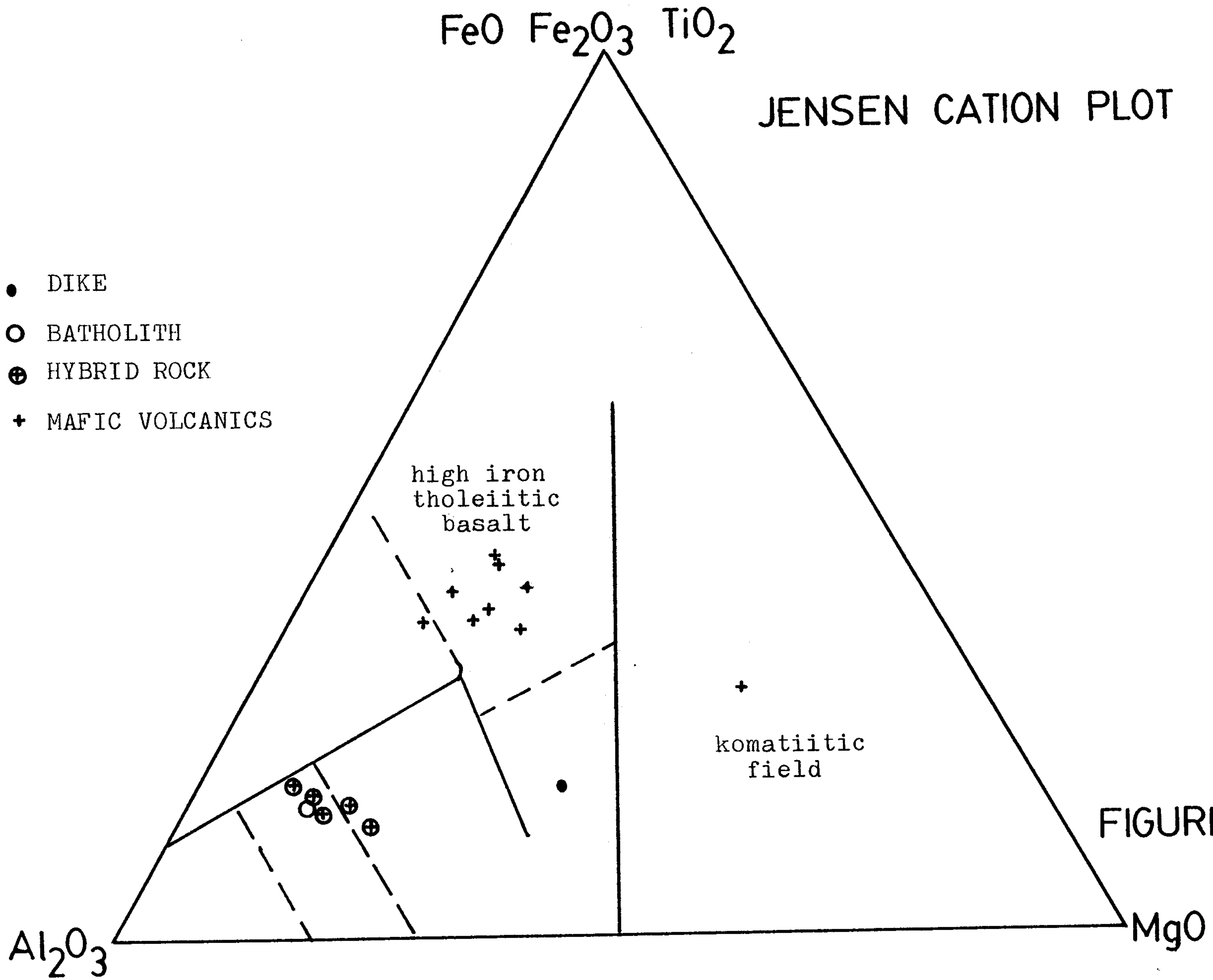

FeO Fe2O3 TiO2
JENSEN CATION PLOT
DIKE
BATHOLITH
HYBRID ROCK
MAFIC VOLCANICS
high iron tholeiitic basalt
komatiitic field
Al2O3
MgO

FIGURE 21

K vs Ba

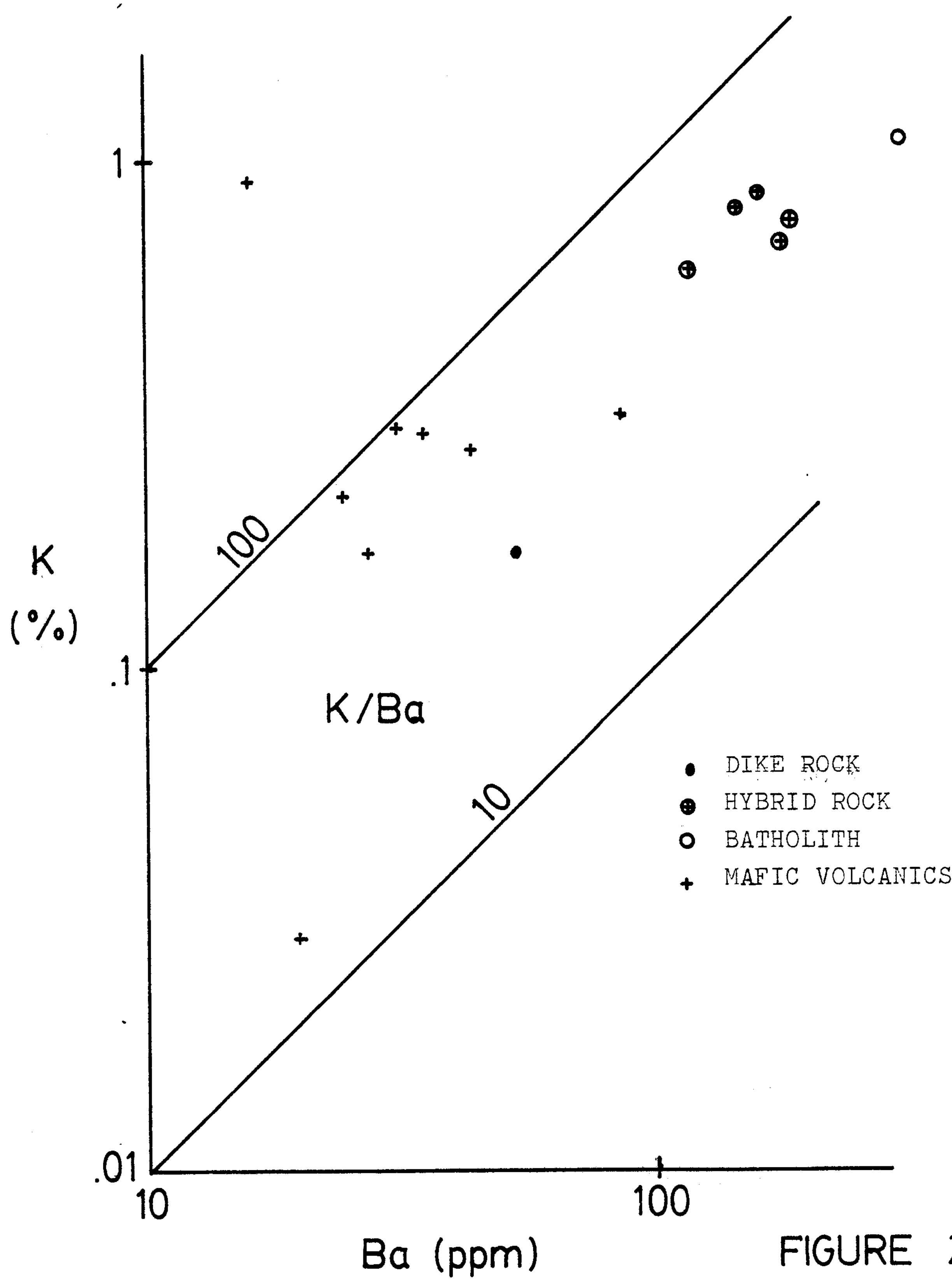


FIGURE 22

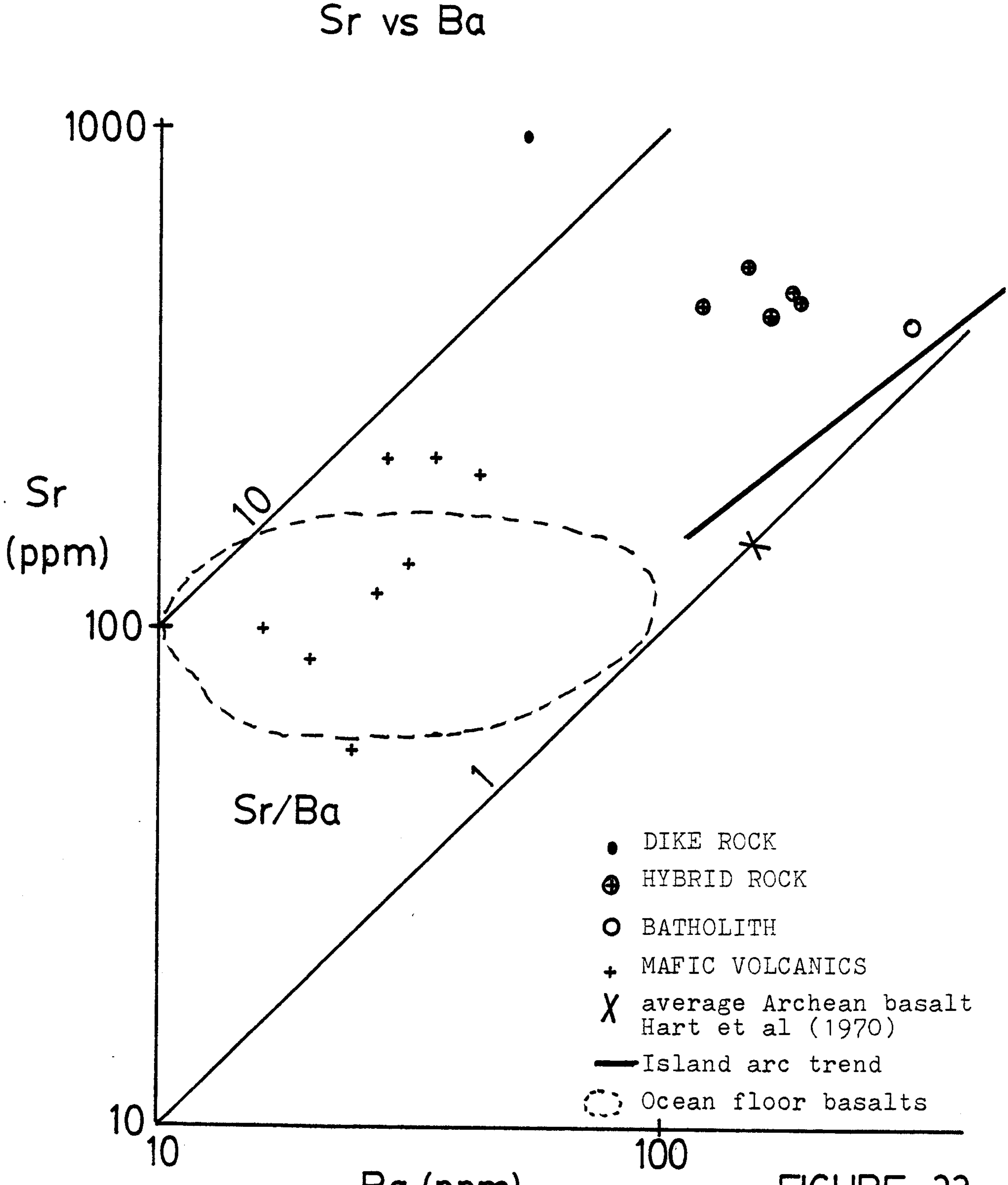

Sr vs Ba
1000
100
10
Sr
(ppm)
10
100
Ba (ppm)
10
1
Sr/Ba
DIKE ROCK
HYBRID ROCK
BATHOLITH
MAFIC VOLCANICS
average Archean basalt
Hart et al (1970)
Island arc trend
Ocean floor basalts

FIGURE 23

iii) The plot of CaO vs Y (figure 24) shows a decrease in total Ca and Y but a slight increase in the Ca/Y ratio from 1340 to 2000 with increasing felsic content. Sample 26 is much richer in CaO than the others form contamination. The dike rock and komatiite have lower CaO and Y values than the tholeiites.

iv) The K/Rb log plot (figure 25) shows as increase in the K/Rb ratio and K_2O with increasing felsic content. The Rb values for the mafic volcanics averages 30 ppm which is high for tholeiitic basalts. Shaw (1968), and Mc Master (1978), have average Rb contents of less than 10 ppm for tholeiitic basalts.

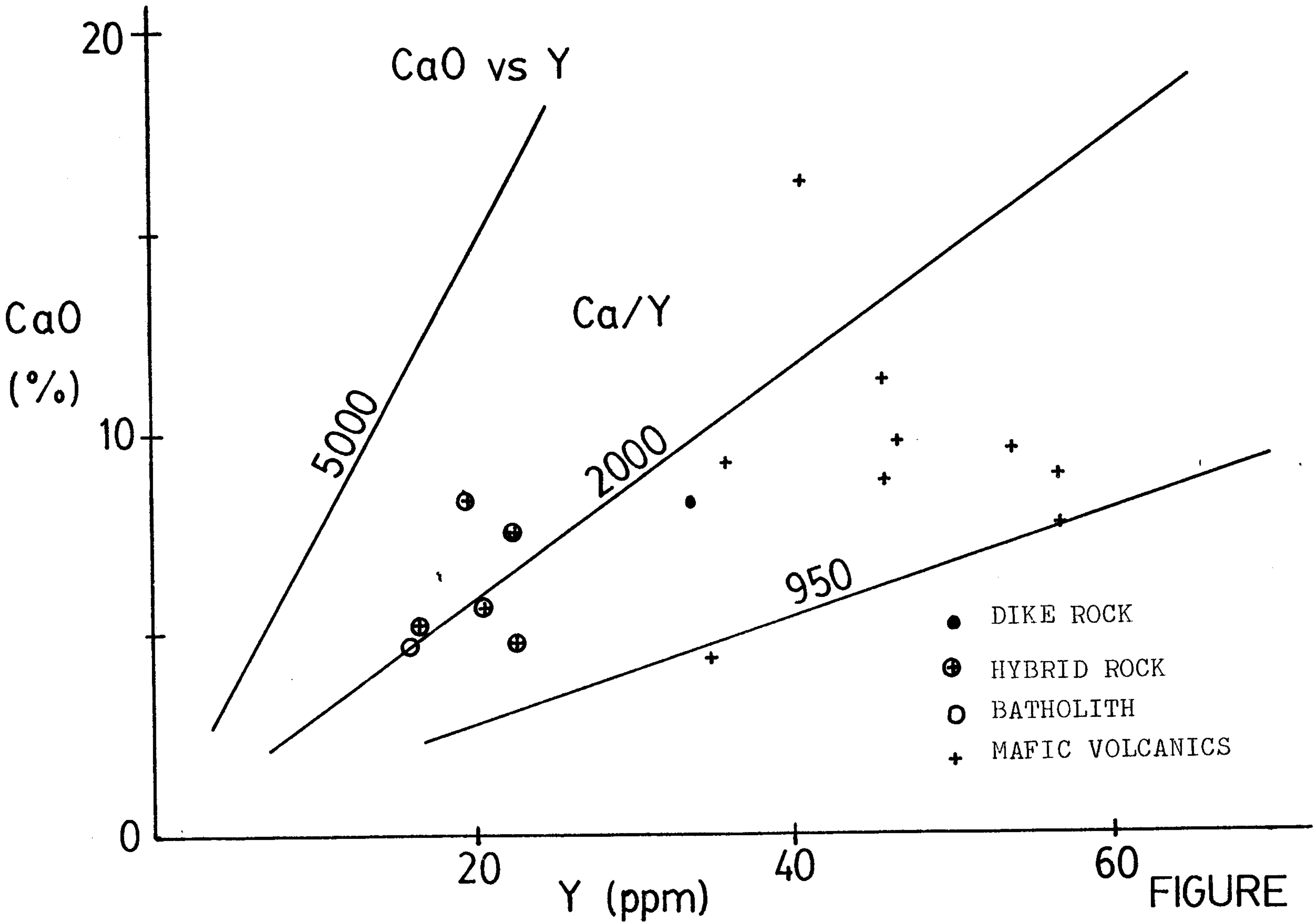

CaO vs Y
CaO
(%)
Ca/Y
5000
2000
950
20
10
0
20
40
60
Y (ppm)
DIKE ROCK
HYBRID ROCK
BATHOLITH
MAFIC VOLCANICS

FIGURE 24

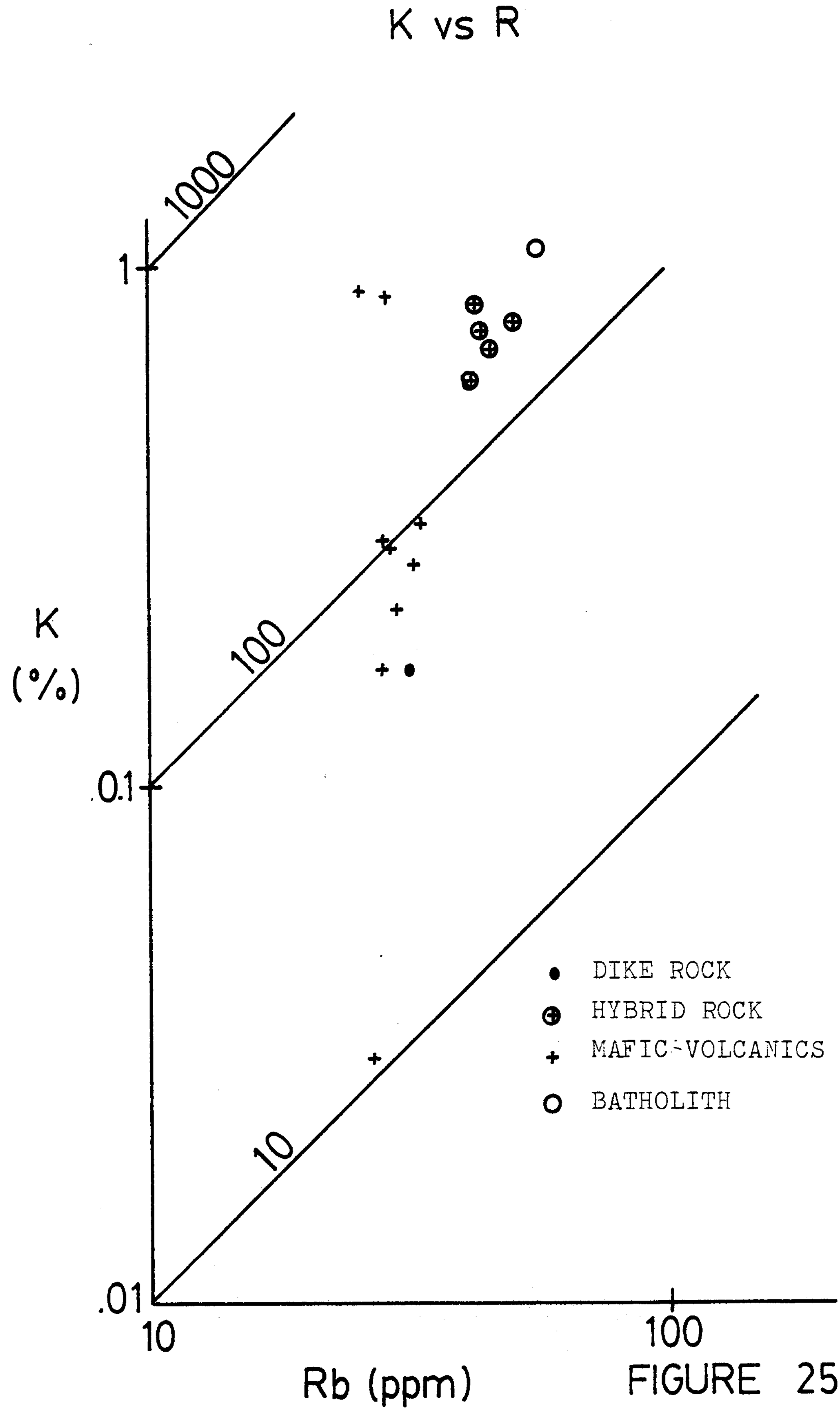

K vs R
1000
100
10
1
.01
.0.1
K (%)
10
100
Rb (ppm)
DIKE ROCK
HYBRID ROCK
MAFIC-VOLCANICS
BATHOLITH

FIGURE 25

Chapter 5 Discussion and Conclusions

i) Assimilation of Basalts into Granite

Recall that the Round Lake Batholith causes progressive metamorphism of an originally prehnite-pumpellyite grade meta volcanic. Whether the granitic magma originated from partial fusion of pre-existing rocks or from differentiation, it is unlikely that any of the melt was superheated (Turner and Verhoogen, 1960). This plus the solid nature (gneissic texture) of the margin of the pluton, the lower amphibolite grade of the meta volcanics as well as the relative narrowness of the metamorphic aureole suggests a temperature of intrusion too low to melt any of the mafic volcanics. Therefore, at the contact, there is a forceful intrusion and brecciation of the hornblende biotite trondjhemite into the basic volcanics. Marginally, the end result of intrusion and brecciation is disintegration of xenoliths into the batholith. The xenocrysts and microaggregates of hornblende and plagioclase so formed, then become strewn through the adjacent contaminated granite.

ii) Origin of the Hybrid Rocks near the Contact

In the field, the hybrid rocks are found close to the batholith and sometimes separate basalts from the batholith. On the outcrop scale, the hybrid rock shows heterogeneity with respect to both the grain size and composition, and, as already discussed in Chapter 2, a chaotic association with the basalt. Contacts between the basalt and hybrid rock commonly show grading from fine grained basalt to coarser grained basalt with veining of felsic material and finally to the fine or medium grained dioritic looking hybrid.

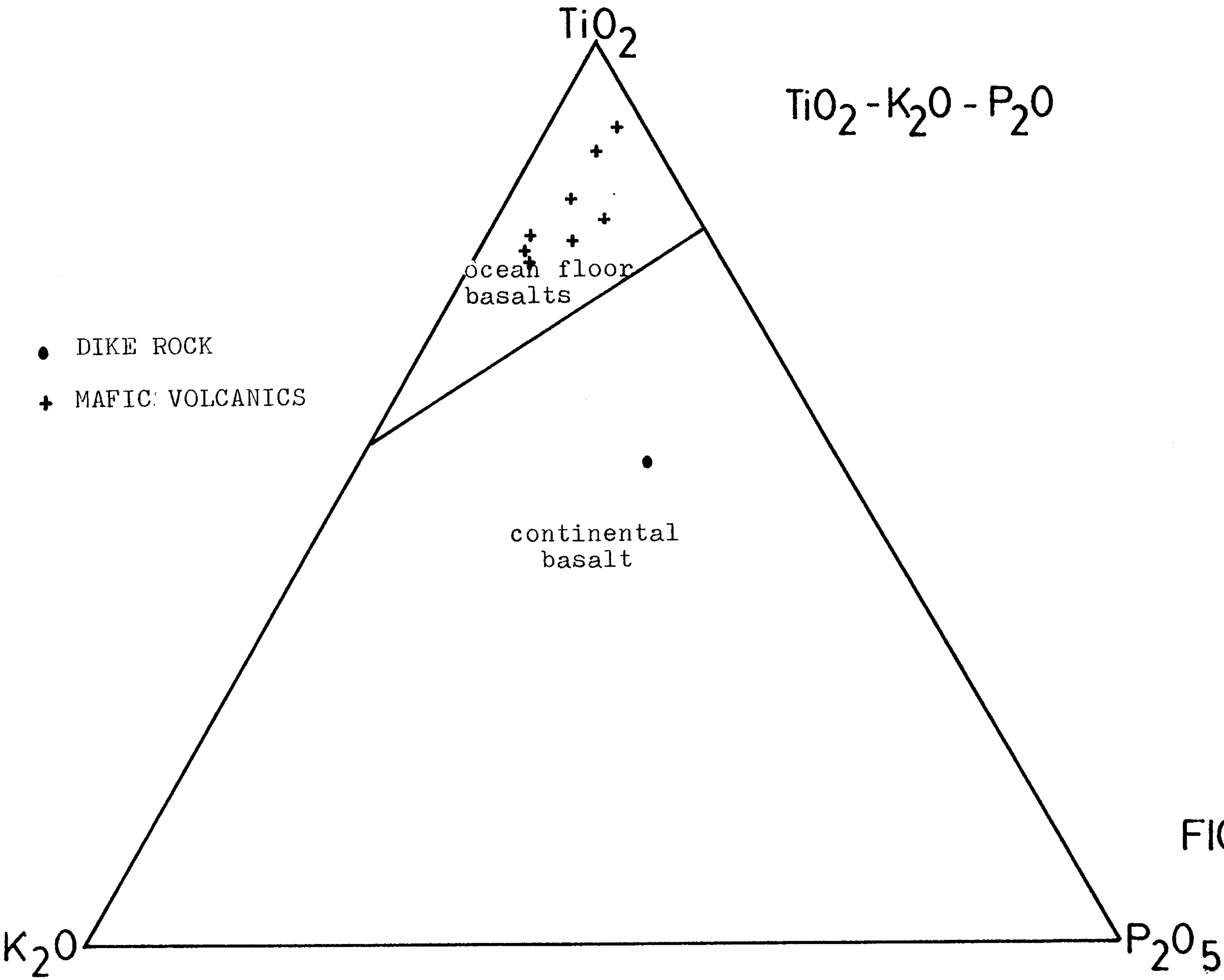
On the thin section scale, there is a large variation in hornblende and plagioclase contents, which might depend on the degree of mixing. Figure 17 shows a common zonal relationship where plagioclase surrounds and separates the hornblende from the quartz. In other sections rich in hornblende, the plagioclase and quartz are interstitial to the hornblende, and sometimes in veins.

In figures 18-20 and 22-25, the chemical data suggests a linear or curved relationship among the basalt, hybrid rock and batholith. That is, the hybrid rock always plots between the trondjhemite and basalt. This is best shown on figures 22 and 25.

Therefore, field relationships as well as thin section work and chemical evidence show the hybrid rock to be a product of basalt assimilation into the batholith.

iii) Chemistry of Basalts

Volcanic activity on the Earth is concentrated in 4 geotectonic settings; 1) ocean ridge systems, 2) island arcs, 3) mid plate, oceanic islands and 4) continental basalts. Figures 26-29 are divided into environmental regions using rocks from todays environments.



$TiO_2 - K_2O - P_2O$
TiO_2
ocean floor basalts
DIKE ROCK
MAFIC VOLCANICS
continental basalt
K_2O
P_2O_5

FIGURE 26

Ti/100 - Zr - Yx3

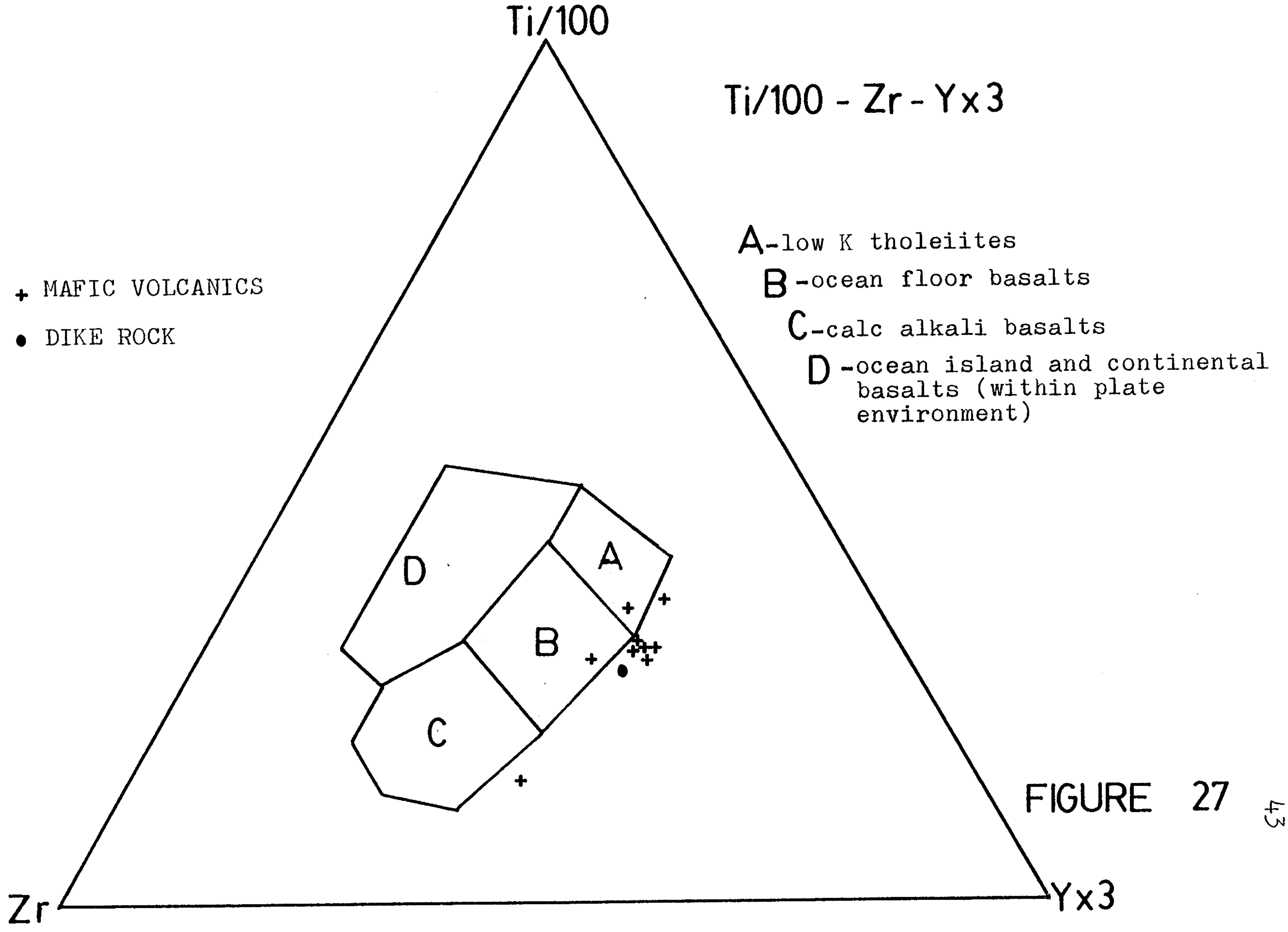


FIGURE 27

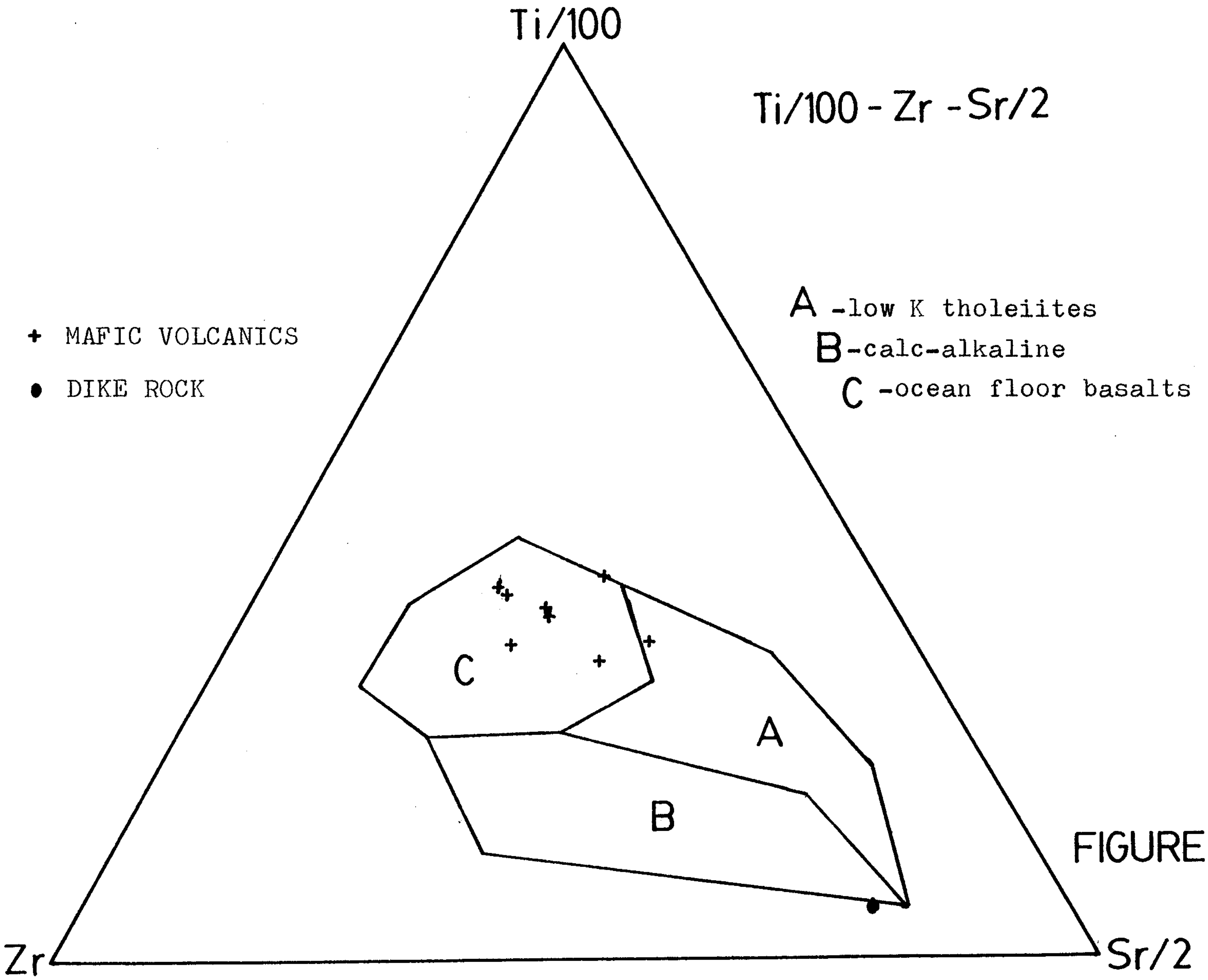

Ti/100
Ti/100 - Zr - Sr/2
A -low K tholeiites
B-calc-alkaline
C -ocean floor basalts
+ MAFIC VOLCANICS
● DIKE ROCK
C
A
B
Zr
Sr/2

FIGURE 28

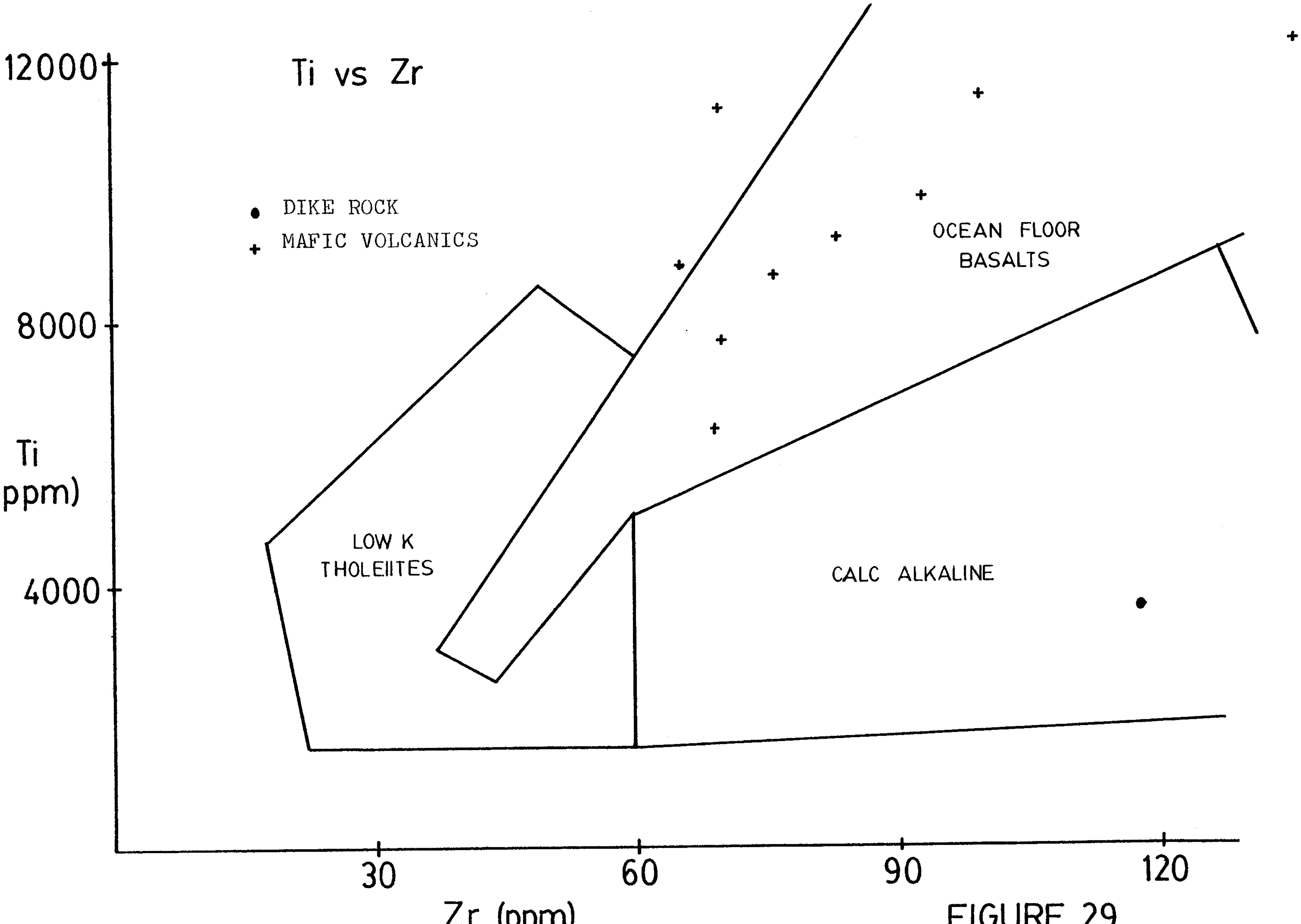

Ti vs Zr
DIKE ROCK
MAFIC VOLCANICS
12000
8000
4000
Ti
ppm)
OCEAN FLOOR
BASALTS
LOW K
THOLEIITES
CALC ALKALINE
30
60
90
120
Zr (ppm)

FIGURE 29

The components Ti, Zr, Sr, K and P are used. It has been suggested that Zr, Ti, and Y are resistant to alteration, but Sr, P and K are not (Pearce and Cann, 1973). Assuming the rock forming environments of three billion years ago are the same as todays, then it is possible to plot the Archean rocks to determine their tectonic setting.

The basalts from the study area plot in the field of ocean floor basalts (figure 26, 28 and 29), and as previously demonstrated, are high iron tholeiites. In figure 27 the relationship is not so clear. It seems the basalts are enriched in Y, so plot just outside the basalt region. However, these results may be due to analytical error.

Tables 1 and 2 show the trace element and major element comparison of the thesis area basalt to averages for ocean floor basalts, island arc tholeiites and back arc basalts.

The komatiite is called a komatiite by chemical evidence alone. Figures 18-25 all show the basaltic dike and komatiitic flow plot outside of the region of the high iron tholeiites, suggesting no genetic relationships. The dike rock looks like a calc-alkaline basalt (figures 26-29). The komatiite may be an interlayered flow from a different volcanic source than the high iron tholeiites. This agrees with Jolly (1980).

Table 1: Trace Element Comparison Chart

ppm	Sample 20	OFB	IAT	BAB
Rb	32	1	7	5
Sr	201	115	207	186
Ba	43	15	100	38
Y	36	30	19	-
Zr	66	95	52	-
Ni	56	125	20	69
K	2700	1400	2500	4100

OFB, ocean-floor basalt (Engel et al., 1965)
IAT, island-arc tholeiite (Jakes and White, 1972)
BAB, back-arc basalt (page, 1977)

Table 2: Major Element Comparison Chart

wt %	Sample 20	OFB	IAT	BAB
SiO_2	48.06	49.94	51.57	49.25
TiO_2	1.47	1.51	0.80	1.66
Al_2O_3	13.85	16.69	15.91	17.74
Fe++	14.82	11.49	9.78	9.15
MnO	0.27	0.18	0.17	0.11
MgO	6.09	7.28	6.73	5.92
CaO	9.18	11.86	11.74	11.23
Na_2O	2.88	2.76	2.41	3.26
K_2O	0.33	0.16	0.44	0.45
P_2O_5	0.08	0.16	0.11	0.14

OFB, IAT and BAB are the same as for Table 1.

As discussed in Chapter 4, the Rb values (see figure 25) are high for these basalts. Rb is a mobile element (Shaw, 1970), so the question is whether all the rocks in the area were altered during or after the emplacement of the Round Lake Batholith.

The K/Rb ratio of the batholith is 200, which is close to 226, the normal average of Granitic intrusions (shaw, 1968). The Rb content of the batholith is 56 ppm and this is close to 66 ppm, the average of 7 trondjhemite samples analysed by Kusmirski (1977). It is possible therefore, that magmatic waters of the batholith have increased the Rb content of the surrounding mafic volcanics.

iv) Contact Metamorphic Effects on the Basalt

There is no regular change in basalt chemistry in the thesis area, moving towards the contact, therefore metamorphism occurred in a closed system.

In the field, the basalts don't show any changes in grain size towards the contact.

All the metamorphic changes were seen in thin sections mineralogy. The rocks change quickly from actinolite with relict pumpellyite to the hornblende zone. Refer to the summary of metamorphic changes in Chapter 3.

v) Conclusions

1) The hybrid rock is a product of basalt assimilation into the batholith.

2) The basalts are high iron tholeiitic basalts.
3) The basalts are ocean floor basalts.
4) Mineralogy changes from the actinolite with relict pumpellyite zone to the hornblende zone moving towards the contact.
5) There is no change in grain size moving towards the contact.
6) Metamorphism occurred in a closed system.

APPENDIX

Table A-1

Whole Rock Analyses
in
Weight Percent Oxides

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	loss on ignition
4a	63.42	16.25	5.59	2.13	4.72	4.31	0.80	0.49	0.05	0.15	1.43
8	62.41	17.50	5.18	2.38	5.00	4.67	0.72	0.48	0.06	0.10	2.20
12	63.01	16.54	5.50	3.01	5.59	4.63	1.04	0.60	0.10	0.09	1.64
15	55.44	19.70	5.48	4.43	8.28	4.42	0.90	0.46	0.08	0.01	1.96
18a	44.51	11.63	18.32	5.09	8.96	1.92	0.18	1.73	0.24	0.07	1.63
19	54.27	8.28	15.01	13.42	4.23	1.53	0.11	1.04	0.31	0.15	2.21
20	46.75	13.47	17.30	5.92	8.93	2.80	0.32	1.43	0.26	0.08	1.64
24	56.68	19.60	7.18	1.97	7.45	4.63	0.94	0.78	0.09	0.20	1.85
26	48.55	13.21	14.00	2.73	15.55	0.46	0.04	1.25	0.25	0.09	1.17
29	54.46	13.10	7.41	7.92	7.85	5.29	0.21	0.60	0.11	0.31	2.55
31	65.96	16.23	4.30	1.74	5.00	4.22	1.33	0.42	0.07	0.06	0.93
35	52.35	12.49	16.20	4.21	9.47	2.47	0.11	1.64	0.34	0.12	1.35
37	49.38	11.98	19.63	4.04	7.32	2.69	0.34	1.99	0.27	0.22	0.74
39	46.39	13.90	17.69	3.45	10.80	2.75	0.35	1.41	0.41	0.11	0.46
44	51.84	13.61	16.06	4.31	8.54	3.52	0.38	1.55	0.33	0.11	2.36
45a	47.52	11.73	18.67	3.99	8.28	2.53	0.25	1.81	0.27	0.14	0.68

Table A-2

Trace Element Analyses (ppm)

Sample	Rb	Sr	Y	Zr	Nb	Ce	Nd	La	Ba
4	46	478	23	133	14	21	16	12	180
8	42	450	17	97	11	4	7	5	119
12	43	426	21	71	11	22	16	13	163
15	44	456	20	50	11	10	13	7	185
18	28	116	47	69	12	0	7	3	27
19	29	99	35	70	14	10	9	0	16
20	32	201	36	66	1	10	13	4	43
24	51	516	23	67	12	19	15	12	146
26	29	86	41	70	13	6	8	3	20
29	32	969	34	118	11	152	60	90	53
31	56	400	17	100	15	22	15	15	304
35a	26	218	54	93	12	9	12	1	28
37	29	217	57	136	11	23	27	12	35
39	28	132	46	76	10	7	15	10	31
44a	33	109	46	83	11	9	13	4	85
45	30	174	57	102	13	7	14	6	24

Table A-3

Trace Element Analyses (ppm)

Sample	Cr	Co	Pb	Cu	Zn	As	V	Ni	S
4a	210	19	19	47	67	0	70	10.0	14
8	198	17	11	11	58	0	70	20.7	0
12	260	17	15	38	63	0	119	29.0	28
15	202	27	18	5	57	3	71	77.1	0
18a	39	76	10	149	121	0	191	439.2	254
20	58	65	7	136	118	0	317	55.8	76
24	103	22	11	263	59	0	113	6.5	95
26	188	53	7	49	128	0	277	45.7	136
29	414	32	16	33	76	0	106	198.9	311
31	280	10	19	6	62	0	38	22.0	0
35a	201	62	8	128	168	0	338	31.5	407
37	52	78	6	43	119	0	326	0.0	178
39	57	60	8	89	130	2	312	49.6	138
44a	73	59	7	57	123	0	329	23.7	46
45	41	70	6	122	92	0	351	0.0	461

Appendix B

Accuracy of XRF Determinations

1. Major Element Oxides

To check the accuracy of the XRF analyses, the samples were run with a series of standards used as unknowns. The recommended values of the standards were determined by Abbey, 1975.

	BCR-1 (recommended)	BCR-1 (unknown)	W-1 (recommended)	W-1 (unknown)
SiO_2	54.85	54.67	52.72	52.98
Al_2O_3	13.68	13.33	14.87	14.59
Fe_2O_3	13.52	13.33	11.11	11.52
MgO	3.49	3.90	6.63	6.55
CaO	6.98	7.01	10.98	10.83
Na_2O	3.29	3.72	2.15	2.01
K_2O	1.68	1.68	0.64	0.69
TiO_2	2.22	2.55	1.07	1.09
MnO	0.19	0.23	0.17	0.17
P_2O_5	0.33	0.39	0.14	0.16

Errors are negligible.

2. Trace Elements

For the trace elements, as for the major elements, standards were run as unknowns. For Rb, Sr, Y, Zr and Nb The standards NIM-G, GSP-1, NIM-S, SY-1, BCR-1, W-1, NIM-L and AU1-1 to AU1-4.

ppm	GSP-1 (recommended)	GSP-1 (unknown)	BCR-1 (recommended)	BCR-1 (unknown)
Rb	250	270	47	32
Sr	230	280	330	268
Y	32	41	46	32
Zr	-	570	185	163
Nb	29	30	14	1

Errors are neglible.

Similar results were obtained for other standards used in determining Ce, Nd, La, Ba, S, Cr, Co, Pb, Cu, Zn, As, V, and Ni.

Appendix C

Thin Section Descriptions

i) Slide 37

-hornblende	-40%	-pale green to brown green, subhedral, very fine grained.
-plagioclase	-30%	-altered
-opaques	-5%	-ilmenite altering to sphene -pyrite altering to limonite
-quartz	-10%	-anhedral, interstitial.
-epidote	-10%	-in veins and disseminated forms.
-biotite	-trace very fine grained plates.	
-chlorite	-5%	-space filler.

ii) Slide 39

-hornblende	-60-70%	-subhedral
-plagioclase	-20-30%	-altered
-epidote	-10-20%	-altering to chlorite
-sphene	-5%	-very fine grained
-quartz	-1-2%	-interstitial
-ilmenite	-trace in sphene cores	
-calcite	-trace in amygdules	

iii) Slide 44

-hornblende	-60-70%	-euhedral, fine grained
-plagioclase	-20%	-altered
-quartz	-10%	-interstitial
-epidote	-5%	-laths
-calcite	-trace	
-chlorite	-trace	
-ilmenite	-trace with rims of sphene	
-pyrite	-trace	

iv) Slide 45

-hornblende	-70-80%	-euhedral, fine grained
-plagioclase	-10-15%	
-epidote	-5%	
-quartz	-5%	
-opaques	-2%	

v) Slide 25

-hornblende	-70%	-large poikilitic clumps
-plagioclase	-10-15%	-interstitial
-quartz	-2-5%	-interstitial and inclusions in hornblende
-epidote	-5%	
-ilmenite	-2-5%	-with rims of sphene

vi) Slide 20

-hornblende	-60%	-poikilitic, equant grained
-plagioclase	-20%	-strongly altered
-epidote	-5-10%	-tabular crystals and altering to chlorite
-chlorite	-5-10%	-alteration product
-ilmenite	-trace with rims of sphene	

vii) Slide 35

-actinolite	-70-80%	-fibrous to columnar pale green
-chlorite	-trace	-in very fine grained matrix
-quartz	-25-30%	-interstitial
-pumpellyite	-trace	-relict, subhedral, very fine grained
-sphene	-5%	-with cores of ilmenite

ble C-1

CIPW Norms

mple	qtz	or	ab	an	di	hy	ol	ct	il	ap	sp	he	mte	cor
4	21.79	4.85	37.23	20.78	-	9.86	-	.75	.95	.37	-	-	2.90	0.86
8	17.17	4.31	40.03	24.50	-	9.61	-	-	.93	.23	-	-	2.89	3.00
12	36.74	.53	8.80	22.97	-	17.36	-	-	1.12	-	-	-	3.18	6.29
15	2.13	5.38	37.74	31.49	7.90	11.60	-	-	.89	.02	-	-	2.86	-
18a	.25	1.18	17.52	24.39	19.48	28.60	-	-	3.53	.19	-	-	4.87	-
19	8.44	.65	13.20	15.65	3.83	52.16	-	-	2.01	.35	-	-	3.71	-
20	-	1.95	24.37	23.89	17.73	12.26	12.52	-	2.79	.19	-	-	4.31	-
24	6.35	5.61	39.35	30.05	4.79	8.56	-	-	1.48	.46	-	-	3.31	-
26	10.50	.24	4.06	35.22	37.86	5.39	-	-	2.47	.23	-	-	4.06	-
29	-	1.24	46.03	11.72	15.49	15.93	3.22	2.50	1.16	.74	-	-	3.06	-
31	22.97	7.92	35.96	21.55	2.44	5.41	-	-	.82	.14	-	-	2.80	-
35	7.66	.65	20.99	22.84	19.98	19.91	-	-	3.13	.28	-	-	4.57	-
37	3.76	2.07	23.27	20.02	13.27	28.08	-	-	3.87	.53	-	-	5.13	-
39	-	2.13	23.86	25.27	24.90	5.95	10.61	-	2.75	.26	-	-	4.28	-
44	1.27	2.25	29.70	20.15	18.12	20.95	-	-	2.93	.23	-	-	4.41	-
45a	2.49	1.54	22.51	20.94	18.13	20.54	-	-	3.61	.32	-	-	4.93	-

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THESIS AREA
0
1 KM
SCALE
1 MILE
LEGEND
SYMBOLS
PROTEROZOIC
6 COLEMAN CONGLOMERATE
LATE ARCHEAN
DIKE ROCKS
5a HORNBLENDE LAMPROPHYRE
5b SYENITE LAMPROPHYRE
4a FELDSPAR PORPHYRY
4b QUARTZ FELDSPAR PORPHYRY
INTRUSION RELATED ROCKS
3 HYBRID ROCK (DIORITIC)
2 TRONDJHEMITE
2a FELSITE
2b PEGMATITE
2c APLITE
2d SYENITE
EARLY ARCHEAN
MAFIC VOLCANICS
1a MASSIVE, FINE GRAINED
1b MASSIVE, MEDIUM GRAINED
1c PILLOWED
SMALL OUTCROP
OUTCROP
GEOLOGICAL CONTACT (KNOWN, INFERRED)
FAULT
FOLIATION (INCLINED, VERTICAL, DIP UNKNOWN)
SHEARING
SCHISTOSSITY (INCLINED, VERT., DIP UNKNOWN)
BEDDING (INCLINED, VERTICAL)
PILLOWS POINTING FLOW TOP
JOINTING (INCLINED, VERTICAL)
MARSH
INTERMITTENT STREAM
GRAVEL PIT
ROAD
BUILDING
26 SAMPLE NUMBER
0 60 mi
Timmins
Kirkland Lake
Map area
Sudbury
N
47°48'00"
80°09'00"
47°45'30"
80°02'45"
RYAN ISLAND
thick cover of varved clay
ROBILLARD LAKE
HWY 560
McLEOD LAKE
CROSS LAKE FAULT
MEAROW LAKE
FRASER LAKE
trench
GEOLOGY BY D. GOOD, G. JOHNS AND W. HOYLE, 1980