PETROGRAPHY AND GEOCHEMISTRY

OF THE GABBRO LAKE SILL

SUPERIOR PROVINCE, NORTHWEST ONTARIO

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By

GLENN EDWARD MCMASTER

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AUTHOR: Glenn Edward McMaster

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SCOPE AND CONTENTS:

A gabbroic intrusion within the Wabigoon Greenstone Belt, southeast of Dryden Ontario, was studied and mapped. Petrographic examination of the sill was carried out and geochemical whole rock data was obtained using X.R.F. methods.

The Gabbro Lake Sill was injected into a mafic pile and subsequently underwent fractional crystallization and differentiation. The sill exhibits good phase layering resulting in its division into six basic units:

- Chilled Margin Gabbro
- Diabasic Gabbro
- Leucocratic Gabbro
- Pyroxenitic Gabbro
- Pegmatitic Gabbro
- Sheared Gabbro

These units are evident in thin section and are distinguishable both modally and texturally. In most cases, variations in the chemistry and norms reflect the units mapped in the field.

Many features of the sill are analogous to other intrusions, and comparisons have been drawn and theories incorporated to explain these features in the Gabbro Lake Sill.

Figure 1. Looking across Boyer Lake towards the O.D.M. base camp, situated on the mafic country rock.

Figure 2. Looking south at a passage on Boyer Lake through the sill.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Mr. C. E. Blackburn of the Ontario Division of Mines for allowing collection of the field data and samples during the 1974 field season and for the advice he provided during numerous discussions concerning the sill. Thanks also goes to the other members of the field party; Mr. E. Sawitzky, Mr. R. George, and Mr. P. Loudon who aided the author in the sampling and mapping of the sill.

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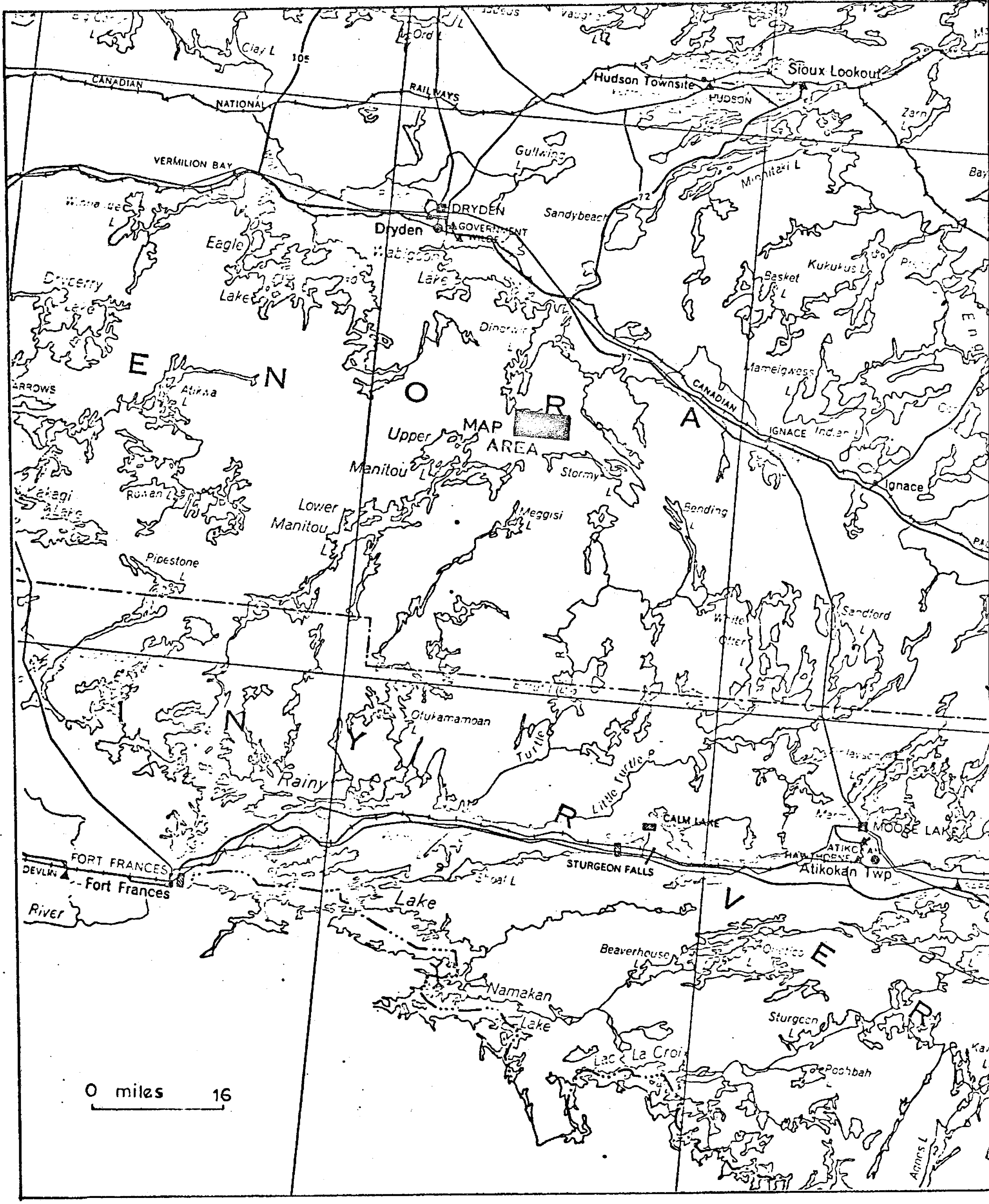
CHAPTER I

INTRODUCTION

i) Location and Accessibility

The Gabbro Lake Sill intrudes mafic lavas in the Wabigoon Greenstone Belt of the Superior Province of the Canadian Precambrian Shield. This sill outcrops through a series of lakes, from Shongwashu Lake in the east to a point northwest of Walmsley Lake. The study area is bounded by the Dryden Sheet (No. 52F) of the National Topographic Series and is included in the geologic map compiled by the Ontario Division of Mines (Thomson, 1933). The meridians and parallels of boundary are Latitude 49°27'N, Longitude 92°30'W, and Latitude 49°28'N, Longitude 92°37'W. The sill is eight and a half kilometers (5.5 miles) long by five tenths of a kilometer (0.35 miles) wide and has been conformably intruded in a northwest-southeast direction. The western extent is unknown as the area there is covered by a thick moraine deposit (Zoltai, 1961).

Access by aircraft or water transport to the study area is possible from Dryden, forty kilometers (25 miles) to the northwest, or from Fort Frances, one hundred and fifteen kilometers (72 miles) to the southwest, see Fig. 3. A road from Fort Frances to Dryden presently under construction will provide somewhat better access in the future.


Sioux Lookout
Hudson Townsite
HUDSON
CANADIAN
NATIONAL
RAILWAYS
VERMILION BAY
DRYDEN
Dryden
Eagle
Lake
Sandybeach
Basket
Kukukus L
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AREA
Upper
Manitou
Lower
Manitou
Stormy
Meggisi
Bending
Pipestone
IGNACE
Ignace
Sandford
Otukamamoan
Turtle
Little Turtle
Rainy
Lake
CALM LAKE
MOOSE LAKE
STURGEON FALLS
Atikokan Twp
FORT FRANCES
Fort Frances
DEVLIN
River
V
E
R
Beaverhouse
Namakan
Lake
Lac La Croix
Sturgeon
Poohbah
0 miles 16

Figure 3

ii) Previous Work

This area has been previously mapped on a reconnaissance scale, (1 mile to 1 inch), as part of a larger mapping project of the Manitou-Stormy Lakes Area (Thomson, 1933). A later more detailed mapping project, ($\frac{1}{4}$ mile to 1 inch), was started in 1972, by the Ontario Division of Mines under the direction of C. E. Blackburn, and in 1974 included the area reported on here. Preliminary results of this work have been published (Blackburn, 1975).

iii) Statement of the Problem

In May and June of 1974 the author spent three weeks investigating a mafic sill in the Boyer Lake area. Thomson (1933) had previously described the sills in the area as "irregularly-shaped areas of plutonic rocks...They consist of gabbro, diorite and quartz diorite, all of which are somewhat altered. In many places it is virtually impossible to distinguish these from the coarse-grained phases of the lava flows. However, in certain locations a definite intrusive contact may be seen,...This relationship may be seen in Boyer Lake."

The aim of the project was to study in detail one of these sills, searching for differentiation patterns and chemical variations within it, that are typically found in most basic intrusives (Palisade Sill, Muskox, Skaergaard, Bushveld). It was decided to attack the problem by mapping, petrographic study of a representative suite of specimens, and major element whole rock chemical analyses of samples from a vertical section of the Gabbro Lake Sill.

iv) Method of Sampling

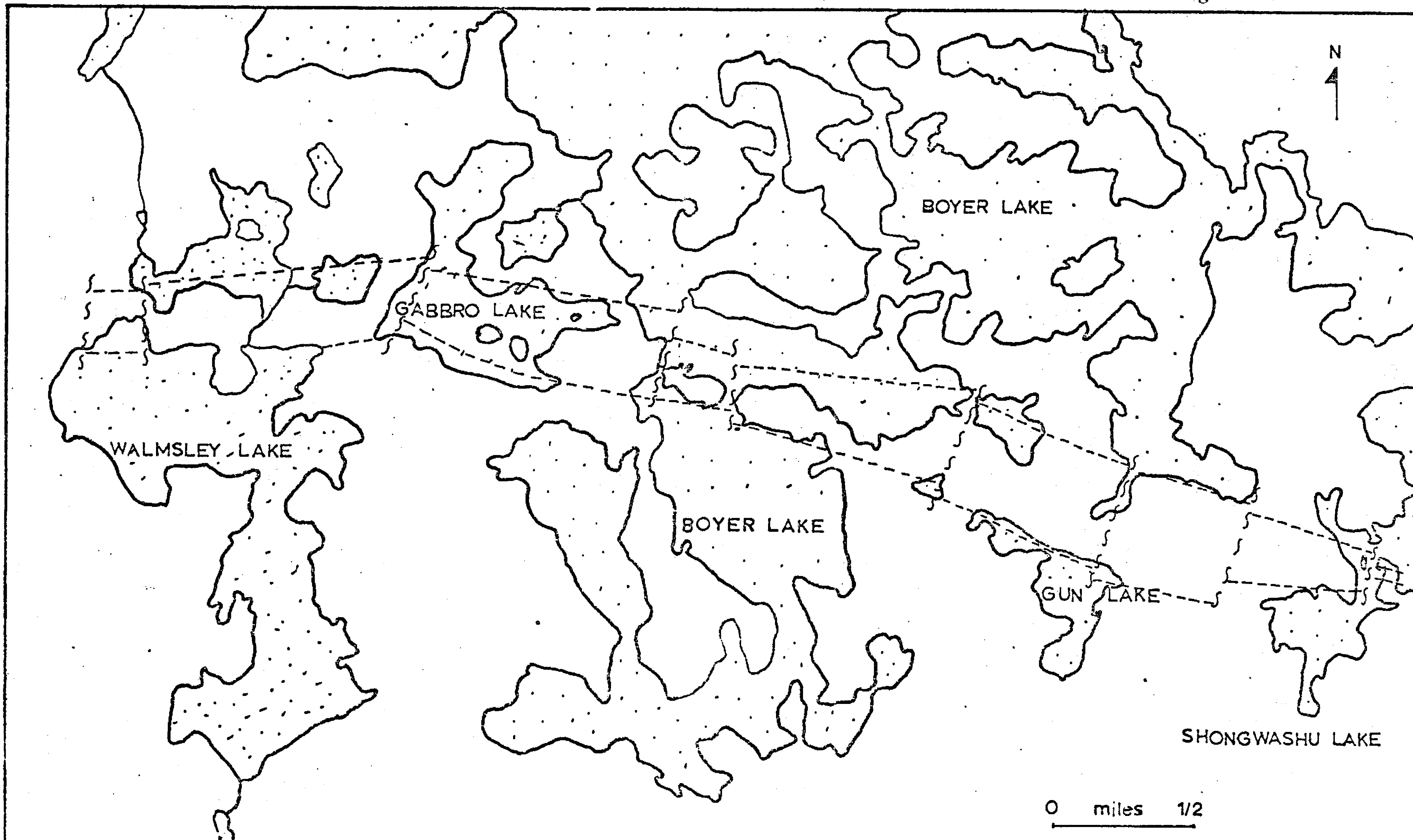
The boundaries of the sill were initially mapped from shoreline outcrops, and extended the previous mapping (Thomson, 1933) westward by three and two-tenth kilometers (2 miles). Traverses across the sill were made at four-tenth kilometer ($\frac{1}{4}$ mile) intervals covering a strike length of eight and a half kilometers. Sample locations are shown on the accompanying map (see Fig. 4). The geology of the country rock is taken from Blackburn's field map of the area (1974).

Two detailed traverses were undertaken. The first was across a contact, where samples were taken at three meter (10 foot) intervals in the country rock and in the sill. The second, for the purpose of geochemical studies, was a complete vertical section across the widest part of the body. Samples were taken at fifteen meter (50 foot) intervals.

After mapping was complete, representative samples for thin sectioning were taken at type outcrops of those petrologic divisions of the sill which were obvious in the field.

Location Map of the Sill

Figure 4.



CHAPTER II

GENERAL GEOLOGY

i) Country Rock

The main rock type in the Boyer Lake area is an extension of the type Keewatin (2700 m.y.) mafic volcanics of the Wabigoon Greenstone Belt (Goodwin, 1972). The lavas are andesitic to basaltic in nature and in the vicinity of the sill are massive to pillowed. The lavas are ordinarily fine-grained but along the northern edge of the sill they assume a coarse-grained texture. However it could not be determined if this was a secondary feature due to contact metamorphism. Porphyritic lava flows are common in the area. In the vicinity of the geochemical traverse, phenocrysts of feldspar, up to three centimeters in diameter, occur in a fine grain devitrified matrix. This layer varies in width from one to three meters. Hurst (1932), has described a rock of similar appearance in the Sioux Lookout area as "leopard rock".

ii) Metamorphism

Metamorphic grade of the Boyer Lake area is lower greenschist facies or low-grade metamorphism (Winkler, 1974). A typical mineral assemblage for both the country rock and the sill is albite-chlorite-actinolite-epidote. The compositions of type specimens are plotted in an ACF diagram (see Fig. 5). The modes are found in Table 2.

ACF Diagram

(Winkler, 1974)

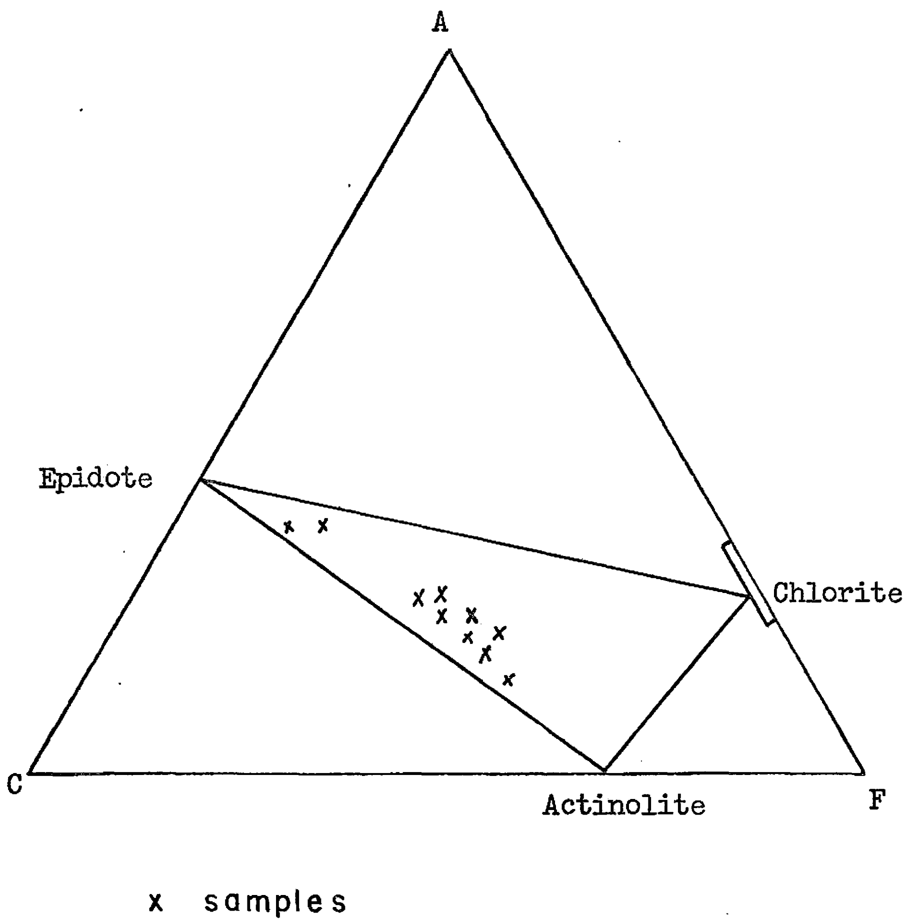


Figure 5

The alteration of pyroxenes (and olivines) and plagioclase to uralite and saussurite is generally ascribed to the action of hydrothermal solutions in a post consolidation process. This type of alteration is common in the sill and is further described in Chapter III. The stable epidote mineral at low grade metamorphism is the iron-poor clinozoisite.

iii) Structure

The Boyer Lake area is, structurally, a syncline. The fold axis trends roughly parallel to the sill and falls along or near the southern edge of the intrusion.

Phase layering of the sill itself indicates tops to the south. This is confirmed by numerous top determinations in pillows of the host mafic volcanics (Fig. 6). To the north of the sill the pillows give tops in the direction $170^\circ - 190^\circ$ in the northeast and $135^\circ - 145^\circ$ in the northwest. The pillows on the south limb of the syncline face the fold axis and give tops in the direction $350^\circ - 10^\circ$.

In general, the sill is stratigraphically conformable with the host rocks. The northern contact represents the basal margin of the intrusive body.

Zones of talc-carbonate schist occur locally in the sill. Along the southern contact the rocks are weakly sheared. Large grains have been brecciated, the rock is finer grained and in hand specimen, shows a weak alignment of mineral grains. This zone of shearing shows no measureable lateral displacement and may be related and/or restricted to axial plane shearing of the syncline.

Figure 6. Pillow basalt with definite selvages and variolitic rims as seen on Boyer Lake, north of the sill.

Faulting on a regional scale has displaced parts of the sill. Displacements, in a north-south direction, of up to eight tenths of a kilometer ($\frac{1}{2}$ mile) are not uncommon. Locally the Gabbro Lake Sill is offset by a series of north-northwest trending faults, that displace the mappeable units on either side of the fault by five to ten meters.

The sill appears to be weathered to a greater degree than the surrounding country rock. The leucocratic horizon forms large ridges, in places thirty to sixty meters above the lake level, suggesting that it is more resistant to weathering. The wall rocks of the contacts tend to weather low. In only one location, at the extreme eastern end on Shongwashu Lake, was the actual contact seen (see Fig. 7). In most places the contact is covered by overburden or swamp.

iv) The Sill

Obvious internal structure is lacking in the sill. In only one instance was foliation observed. On a rôche mountonée in Gabbro Lake, metamorphic (?) banding of white feldspars was contrasted with dark amphibolite (see Fig. 9). Rhythmic layering, igneous lamination, and other igneous-sedimentary features normally associated with stratiform basic intrusives were not observed. A similar absence was noted by Ridler (1966) on the Kakagi Lake sills.

The sill does show excellent phase layering (Wyllie, 1967). A composite cross-section (see Fig. 10) shows from bottom to top: footwall porphyritic basalt, chilled margin gabbro, diabasic gabbro, leucocratic gabbro, pyroxenitic gabbro, pegmatitic gabbro, sheared gabbro and hanging wall massive basalt. The chilled zone, leucocratic and pegmatitic horizons are the most persistent along strike.

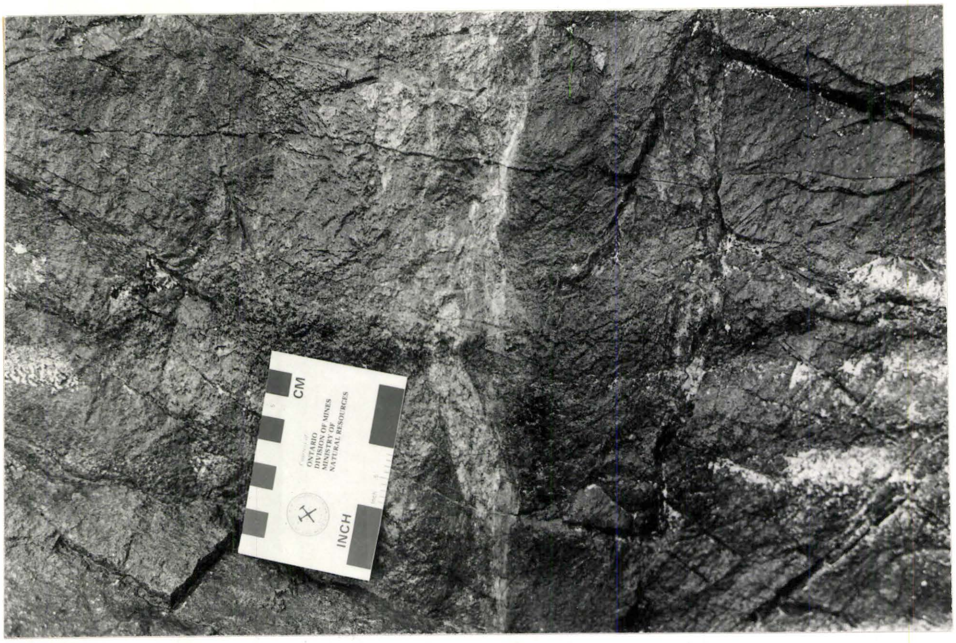


Figure 7. Contact as exposed on Shongwashu Lake. The sill is to the left.

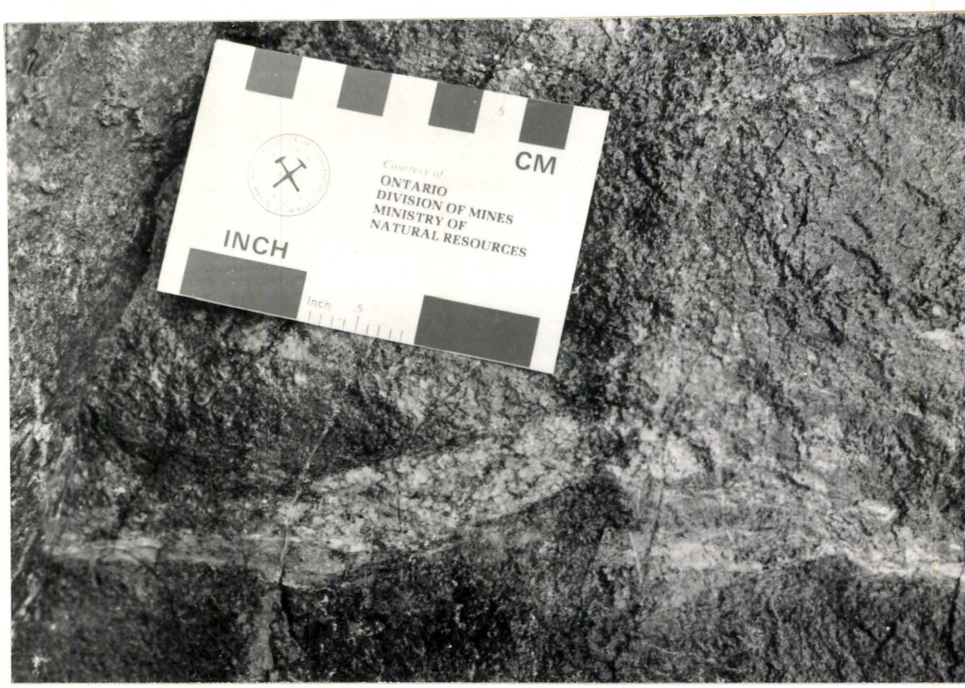


Figure 8. Contact, as above, with the scale in the chilled margin of the sill.

Stratigraphic Section

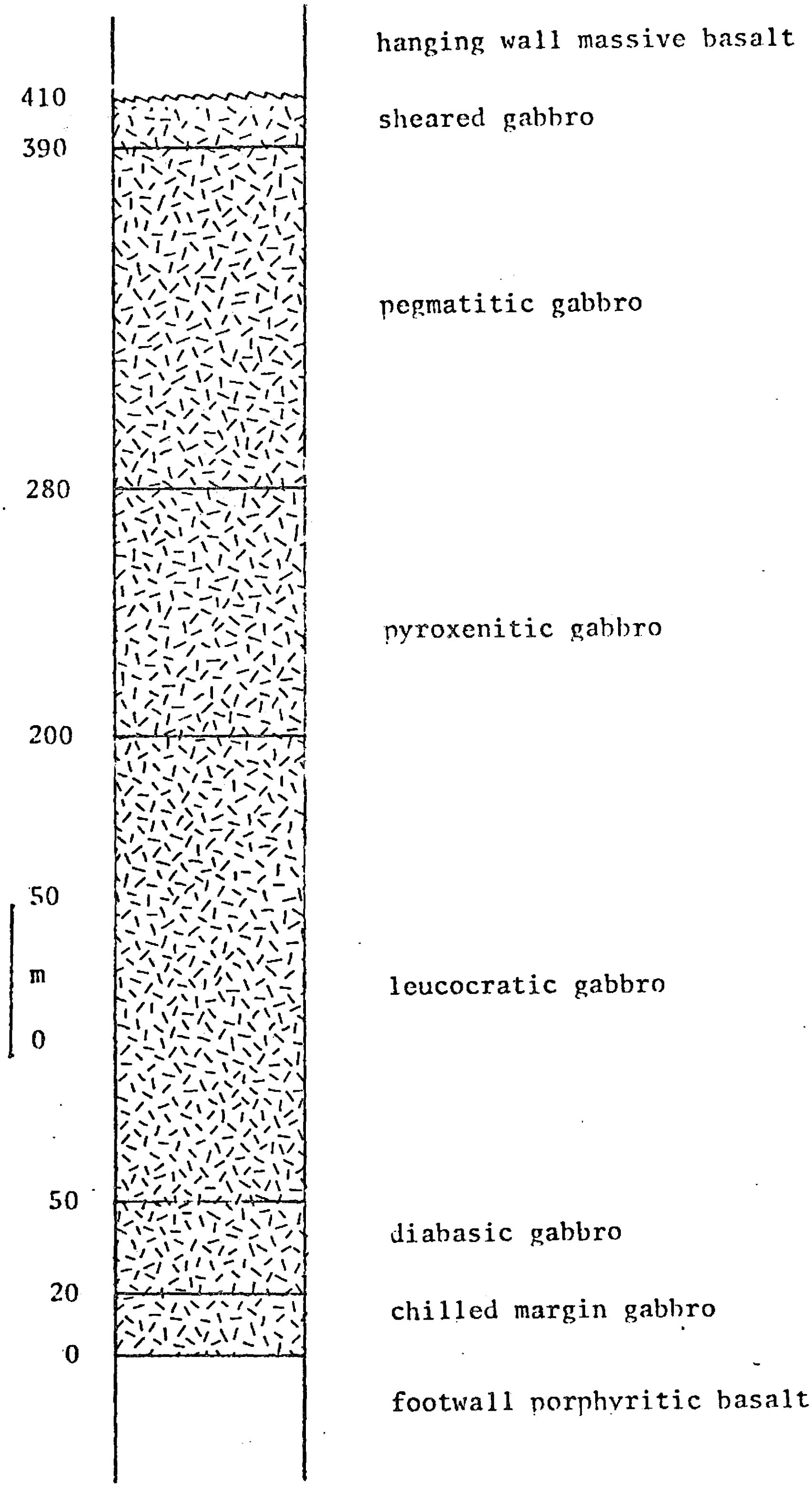


Figure 10.

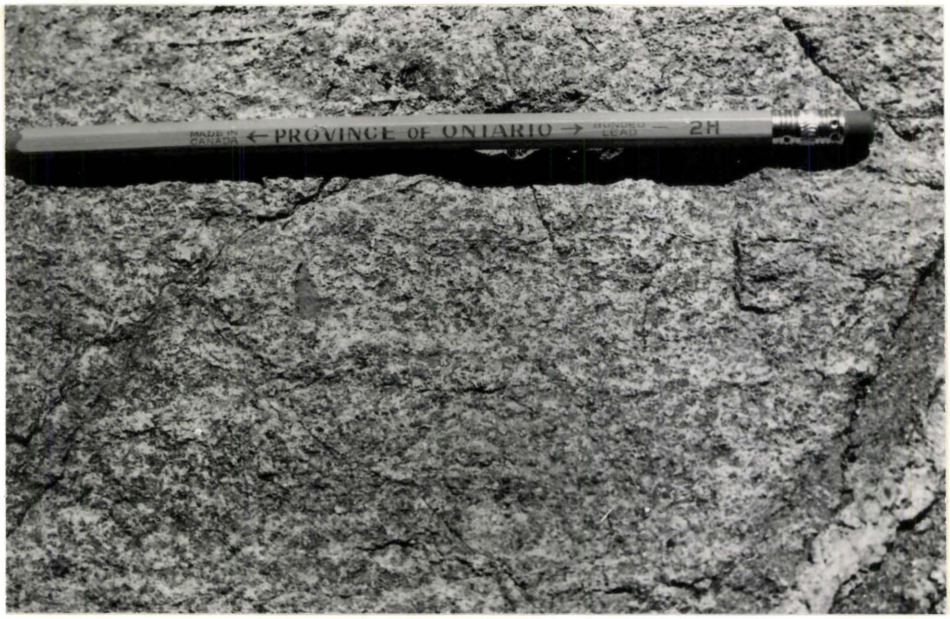


Figure 9. Metamorphic banding of white feldspars and dark amphibolite as seen on Gabbro Lake. Banding is parallel to the pencil.

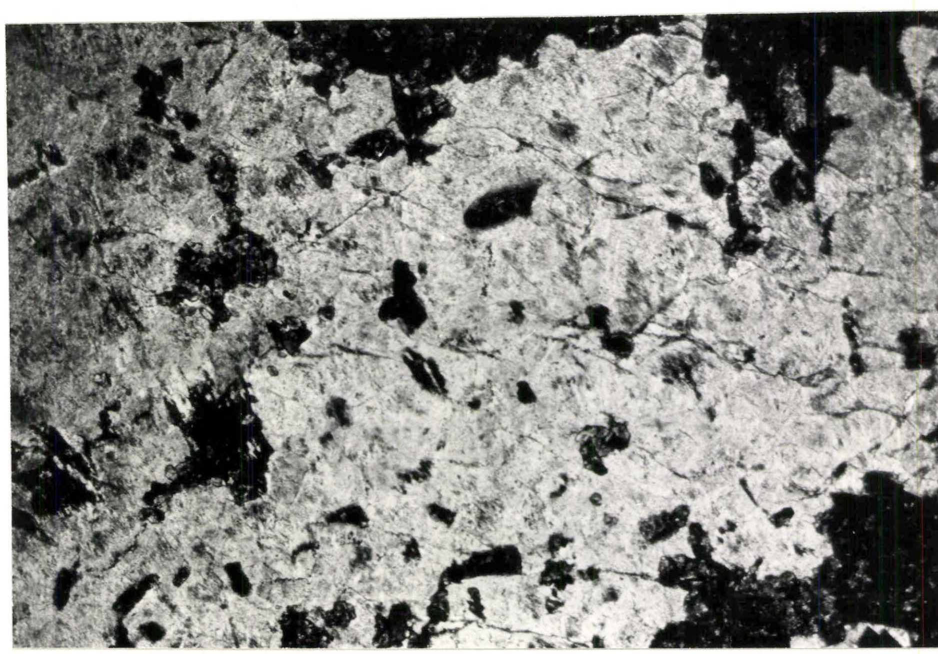


Figure 11. Photomicrograph of a phenocryst of olivine taken from the mafic country rock, sample C-46. Magnification is 63X.

The upper and lower contacts show very marked differences. The lower contact is a chilled zone. It is fine grained and shows no reaction with the country rock and no recognizable thermal metamorphism in the wall rock. The upper contact is generally sheared with fragmentation of the pyroxene and plagioclase phenocrysts and a high modal abundance of carbonate.

The phase layering is gradational. No sharp boundaries are found between units. Further descriptions of the units can be found in Chapter III. Figure A, a field map constructed by the author can be found in the back pocket.

The overall shape of the sill is a plano-convex lens with a flat southern edge. It thins at both ends, in the east to approximately thirty meters. The original thickness of the sill, assuming vertical dips, at its maximum is six hundred meters (2,350 feet). The mapped strike length is eight and a half kilometers, with the total estimated length being eleven kilometers. No conduits or feeder dikes were found.

In regional setting, the Gabbro Lake Sill is one of two sills in the Boyer Lake area. To the north a smaller sill of similar lithology and shape bends around to join the Gabbro Lake Sill northwest of Walmsley Lake. The exact relationship could not be determined.

CHAPTER III

PETROGRAPHY

A petrographic study of a suite of selected rocks was undertaken. The petrographic descriptions appear in Appendix A. The suite was composed of specimens from each of the various phases within the sill and from the surrounding country rock. The sample locations are plotted on Figure 4 and exact ODM coordinates[1] are listed along with the descriptions.

Modal abundances were based on five hundred point counts per section. In making the point counts, the author attempted to approximate the original mineralogy. Thus amphibole alteration of pyroxene plus primary pyroxene were counted under one heading, uralitized pyroxene. Similarly saussuritized plagioclase encompassed fresh and inferred plagioclase.

i) Country Rock

Most of the surrounding area is made up of mafic flows. In places these are porphyritic with phenocrysts of feldspar up to two and a half centimeters in diameter. These flows outcrop as greenish-black weathered rocks. Two samples were examined from the country rock C-46 and C-48. The average mode of these is:

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[1] O.D.M. coordinates based on Ontario Grid System

		Range
Matrix	49%	45 – 52%
Altered Plagioclase	20%	18 – 21%
Carbonate	15%	14 – 15%
Opaques	7%	3 – 12%
Quartz	6%	2 – 10%
Olivine	3%	1 – 6%

The rock is generally hypocrystalline and varies from porphyritic to amygdaloidal in texture. By far the largest constituent is the devitrified matrix. This fine grained, black matrix contains chlorite, calcite, plagioclase, leucoxene and ilmenite. Grains of sericitized plagioclase microlites, 0.2 mm to 0.3 mm in size, are found imbedded in the matrix. Large phenocrysts of olivine, 3 mm to 4 mm in diameter, are found randomly oriented in the matrix (see Fig. 11). These phenocrysts are irregularly fractured and partially replaced by fibrous actinolite. In some instances the rock is vesicular and the cavities have been partially filled by late crystallizing, interlocking, granular quartz.

ii) Chilled Margin Gabbro

The basal phase of the sill is a fine-grained gabbro, probably formed by fast cooling or "chilling" where the hot magma came in contact with the old country rock. It outcrops along the north edge of the body and varies from a few meters to twenty-five meters in width. The samples examined from the chilled phase were C-50, C-52 and C-54.

They with the country rock basalts, form part of a detailed section across the contact. The average mode of these samples is:

		Range
Saussuritized Plagioclase	39%	34 – 42%
Uralitized Pyroxene	27%	14 – 56%
Carbonate	13%	0 – 26%
Matrix	7%	5 – 11%
Quartz	6%	3 – 11%
Opaques	6%	2 – 11%

The rock is comprised of altered crystals of plagioclase and pyroxene generally less than 1 mm in size, in a very fine grained aphanitic matrix. Relict textures are absent and both plagioclase and pyroxene have altered to saussurite and actinolite respectively. Carbonate, typical of both margins of the sill, occurs as hypidiomorphic crystals disseminated throughout the slide. It appears to have formed at the expense of both plagioclase and pyroxene. Carbonate is also present as crosscutting veins. Section C-54 contains two conspicuous fracture fillings (see Fig. 12). The vein material consists of coarse quartz, up to 3 mm in size, actinolite needles 2 mm long, euhedral, 1 mm carbonate crystals and pyroxene grains 2 mm in diameter, in an interlocking configuration. All except the carbonate grains are very anhedral and may be parent rock fragments that have been recrystallized. Quartz occurs as small allotriomorphic grains that are shattered and broken. The matrix is hypocrystalline with fine grained pieces of broken pyroxene and plagioclase and very small crystals of calcite

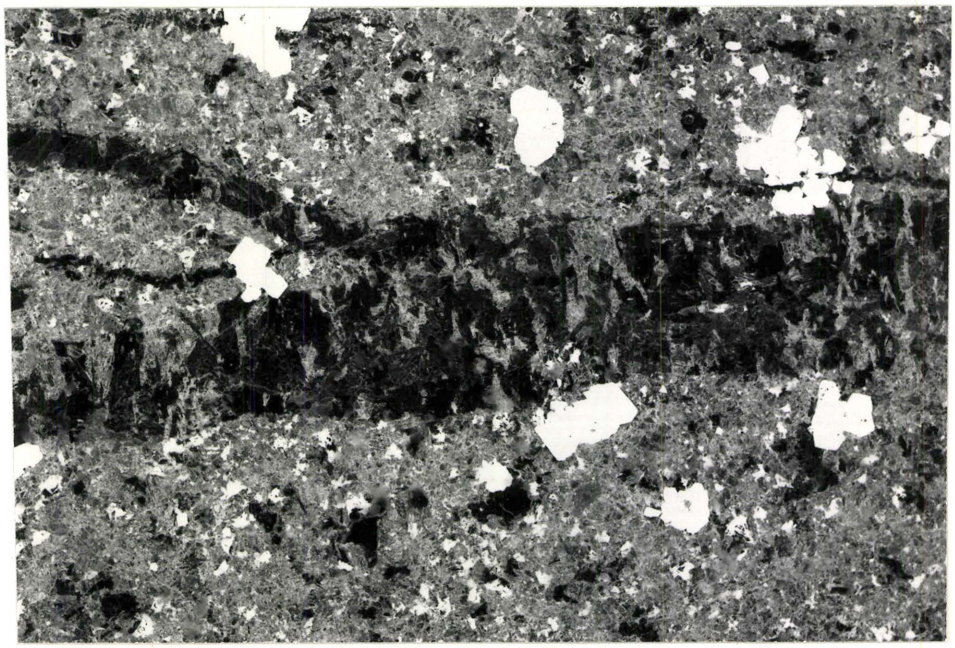


Figure 12. Taken from sample C-54 this photomicrograph shows one of the crosscutting veins in the chilled margin gabbro. Magnification is 100X. This is a photonegative.

and quartz. The opaque mineral is leucoxene, an alteration product of ilmenite.

iii) Diabasic Gabbro

This phase which lies gradationally above the chilled zone is the diabasic phase. It is a field term used to describe a rock where pyroxene grains are surrounded by, or fill the interstices between, laths of feldspar. It is not continuous along strike and is absent from sections in the eastern and western ends of the sill. At its maximum, it is approximately eighty meters wide, but generally is only thirty meters wide. The "type" outcrop of diabasic gabbro occurs on the northeastern shore of Gabbro Lake. The samples examined from the diabasic phase were 1041-2, M-93, M-79, and 1037-1. The average mode of these is:

		Range
Saussuritized Plagioclase	45%	41 - 50%
Uralitized Pyroxene	43%	39 - 46%
Opaques	5%	3 - 7%
Matrix	3%	2 - 5%
Chlorite	1%	0 - 3%
Carbonate	1%	0 - 3%
Quartz	trace	

The rock is an idiomorphic granular gabbro with altered plagioclase enclosing pyroxene in a subophitic texture (see Fig. 13). The plagioclase crystals are poikilitic, riddled by inclusions of clinozoisite, carbonate and chlorite. These saussuritized grains are 0.5 mm to 2 mm in size and Michél-Levy tests on relict twins give

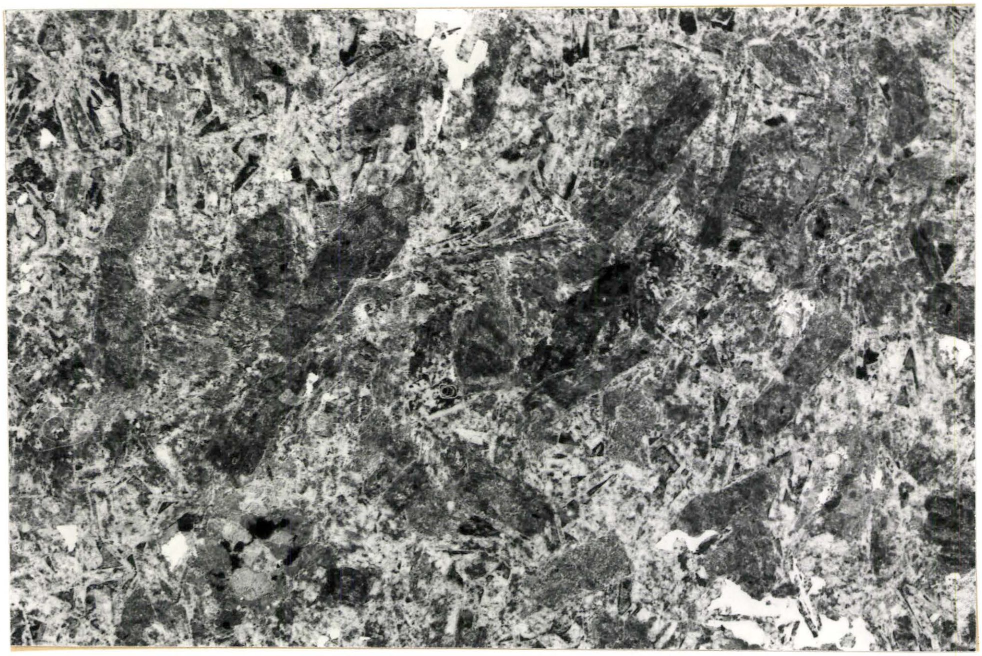


Figure 13. Subophitic texture, typical of the diabasic phase, is seen in this photomicrograph of sample M-93. Magnification is 100X. This is a photonegative.

Figure 14. Taken from sample M-93 this photomicrograph shows relict twinning in clinopyroxene. Magnification is 25X.

compositions in the range An_{60}-An_{80}, labradorite to bytownite. These euhedral laths are intimately intergrown with each other. As saussuritization increases the twins become obliterated. The interstitial pyroxene is irregularly fractured and replaced by fibrous amphibole. These crystals are 1 mm to 2 mm in size and some display relict twinning, typical of augite (Fig. 14). The uralitization of clinopyroxene yielding platey pleochroic fibers of actinolite is probably produced by the same agencies as those responsible for the saussuritization of the feldspars. A fine grained needle matrix of fibrolamellar antigorite occurs as pseudomorphs after pyroxene (olivine?). Both leucoxene and siderite are present in this phase and occur as irregular anhedral grains.

iv) Leucocratic Gabbro

Gradationally above the diabasic gabbro is the leucocratic phase. "Leucocratic" gabbro is a field term used to describe a whitish-light coloured rock, more specifically a gabbro with less than thirty percent dark minerals. It is continuous along strike and increasingly abundant towards the eastern end of the sill. At its maximum it is approximately two hundred and forty meters wide, but is generally one hundred and twenty to one hundred and fifty meters. The "type" outcrop occurs on the small bay at the southeastern end of Boyer Lake where the gabbro crops out in a sixty meter high cliff. The cliff is jointed and large blocks have fallen to its base. The samples examined from the leucocratic phase of the sill were 3060-1, M-29, and 1046-1. The average mode of these is:

		Range
Saussuritized Plagioclase	66%	65 - 68%
Uralitized Pyroxene	19%	19 - 20%
Altered Olivine	7%	0 - 10%
Quartz	3%	0 - 7%
Opaques	3%	0 - 6%
Carbonate	2%	0 - 3%

The rocks of this phase are coarsely crystalline, comprised of euhedral to subhedral plagioclase laths, 1 mm to 2 mm in size, with interstitial chlorite, opaques, pyroxene and olivine. The plagioclase laths are riddled by inclusions of chlorite, and carbonate and in some instances are completely replaced by clinozoisite (see Fig. 15). In the latter case, boundaries between individual laths were absent; thus grains seemed to merge into each other. In other grains, relict twins were visible and gave An values of 58 - 68. The pyroxenes occur subophitically between plagioclase laths. They are found as lath-like tabular crystals, 1 mm to 2 mm in size, with compositional plane twinning. The actinolite replacement, concentrated around the peripheries results in a jagged terminus to the pyroxene grains. Larger phenocrysts of pyroxene, 2 mm to 2.5 mm in size, are pseudomorphs of olivine. The olivine is irregularly fractured and replaced by both chlorite and pyroxene. Only in the leucocratic phase does olivine occur in more than trace quantities. Quartz occurs as small anhedral grains with very sharp boundaries. Chlorite occurs both as aggregates of anomalous blue

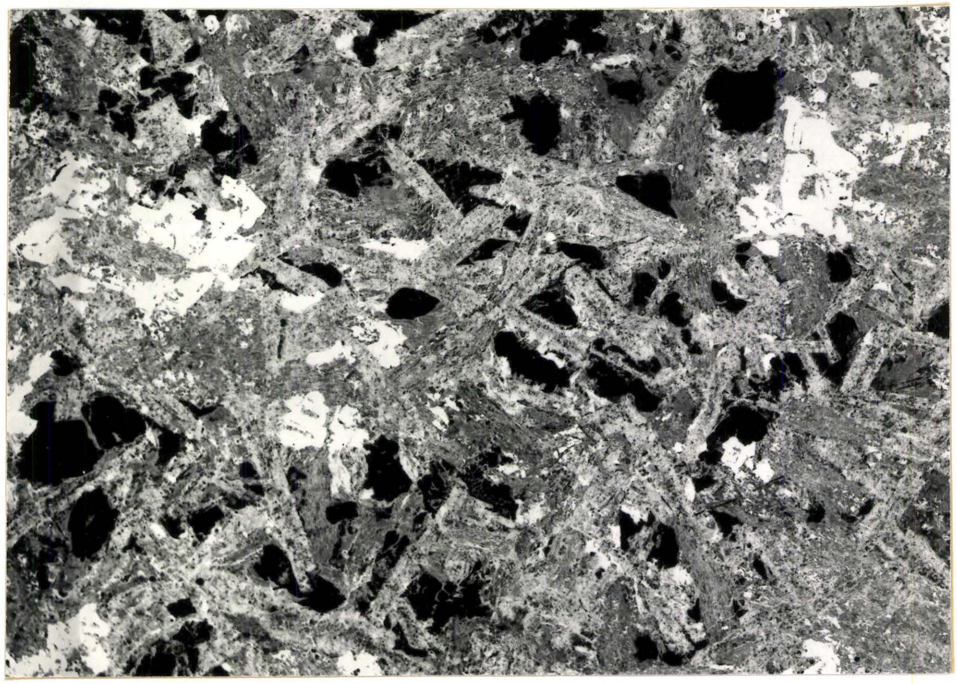


Figure 15. Photomicrograph of idiomorphic plagioclase laths riddled by inclusions of chlorite and carbonate and replaced by clinozoisite in section M-29. Magnification is 10X. This is a photonegative.

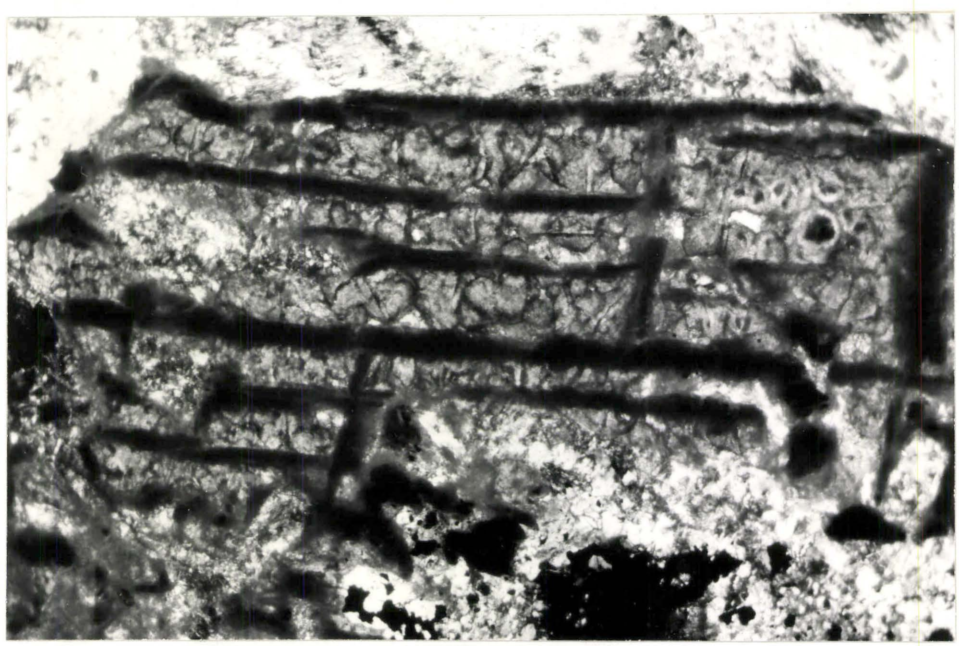


Figure 16. The photomicarograph of sample 1107-2 shows translucent siderite, with definite orthogonal cleavage with fine euhedral to subhedral crystals of carbonate between the cleavage traces. Magnification is 63X.

penninite and as scaley masses of prochlorite, and replaces from thirty to seventy percent of the primary minerals.

v) Pyroxenitic Gabbro

This phase lies gradationally above the leucocratic zone. Pyroxenitic gabbro is a field term used to describe a medium to coarse grain rock consisting mainly of pyroxene. The rock is generally very dark, near ultramafic in nature. Both weathered and fresh surfaces reflect the high content of mafics. This phase is not continuous along strike, but is prominent in the Boyer Lake area. At its maximum it is one hundred meters wide, with an average thickness of eighty meters. The "type" outcrop of pyroxenitic gabbro occurs at the tip of the bay in the southeast end of Boyer Lake. The samples examined from this phase of the sill were 1106-1 and 1107-2. The average mode of these is:

		Range
Uralitized Pyroxene	60%	59 - 61%
Matrix	24%	19 - 29%
Opaques	5%	4 - 7%
Carbonate	3%	2 - 4%
Saussuritized Plagioclase	2%	0 - 5%
Quartz	2%	2%
K-spar	2%	2 - 3%

Uralitized crystals of pyroxene lie in a medium to fine grained matrix of feldspars, carbonate and quartz. Relict pyroxene cleavage is observed. The pyroxene is irregularly fractured, the fractures filled by chlorite. The amphibole is prismatic to fibrous actinolite, commonly having diamond-shaped cross-sections. Grain size varies from 1 mm to 2.5 mm in size. In some instances the pyroxene is zoned with a greenish diopsidic core.

Patches of polygonized quartz and feldspar also occur in the matrix. Two types of feldspar are present. Plagioclase phenocrysts up to 1.8 mm, but characteristically less than 0.1 mm, have been saussuritized and the weak albite twinning is thereby masked. Some of the feldspars exhibit normal zoning. Orthoclase occurs along with quartz as large, 1 mm to 2 mm, anhedral grains that are slightly poikilitic. Brown stained, transluscent to opaque siderite exhibits definite orthogonal cleavage, contains blebs of black oxide and between the cleavage traces fine euhedral crystals of carbonate are visible (see Fig. 16).

vi) Pegmatitic Gabbro

The next phase that rests above the pyroxenitic gabbro is a pegmatitic gabbro. The term is used to describe rocks of a very coarse grain size. Generally the rocks have radiating grains of pyroxene in a lightish brown weathered surface (see Fig. 17) and it is by far the most distinctive and continuous phase of the sill. "Type" outcrops of this phase occur both on Gabbro Lake and Boyer Lake. Grains up to four to five centimeters in length are not uncommon and are the coarsest in the sill. At its maximum this unit is approximately one hundred and fifty meters wide with an average width of one hundred meters. The samples examined from the pegmatitic phase were M-98, M-1040, and G-220. The average mode of these is:

Figure 17. Photograph of the weathered surface of the pegmatitic gabbro phase with radiating laths of pyroxene.

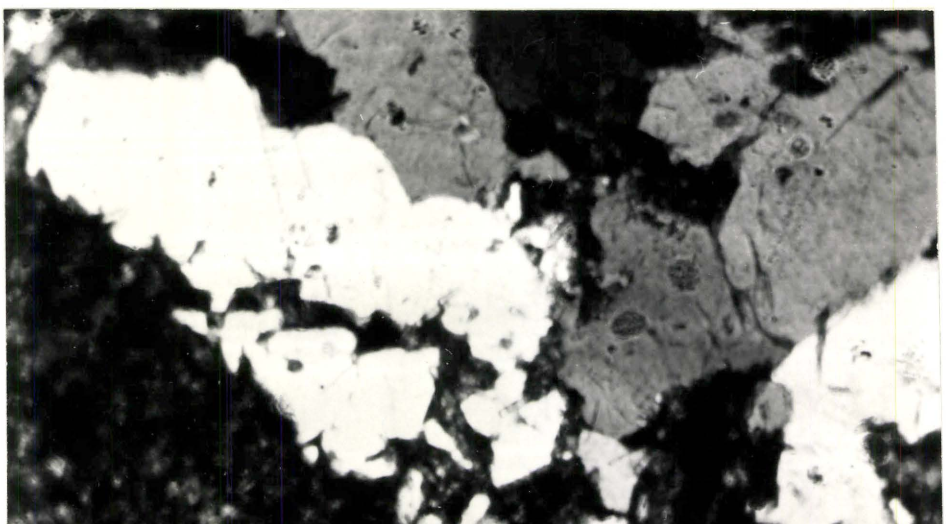


Figure 18. Taken from sample M-98 this photomicrograph shows shattered quartz with well preserved, very angular fractured surfaces. Magnification is 63X.

		Range
Saussuritized Plagioclase	37%	35 - 39%
Uralitized Pyroxene	29%	28 - 31%
Quartz	17%	11 - 26%
Matrix	8%	2 - 12%
Opaques	6%	6 - 7%
Chlorite	2%	0 - 7%
Carbonate	1%	0 - 2%

These rocks contain roughly equal amounts of altered plagioclase and pyroxene with a relatively large amount of quartz.

The plagioclase has been saussuritized and replaced by idiomorphic cubes and polygons of clinozoisite. Some relict twins are still visible but saussuritization has clouded most of the laths. Grain boundaries are poorly preserved and in some cases totally lacking. The pyroxene occurs as very coarse grain tabular crystals, 2 mm to 5 mm in length. They have been altered to chlorite, serpentine and amphibole. Diamond-shaped cross-sections of actinolite are common. The high percentage of quartz is ubiquitous. It occurs in three forms: first as an interstitial mineral to the plagioclase laths, medium grain size (1 mm to 1.5 mm), irregularly fractured and shattered. The fractured surfaces are very angular and well preserved. The state of preservation is so good, that if they were pieced back together they would interlock almost perfectly (see Fig. 18). The voids between shattered sections are filled by chlorite and clinozoisite. Stringers of lenses or pods of different birefringence, that display a weak but visible planar alignment are found in some quartz crystals. Quartz also occurs graphically intergrown with feldspars (see Figure 19), showing a very regular and cuneiform character. Section G-220, has a particularly high percentage (26%) of quartz. Quartz occurs in both the above forms and as myrmekite. Typical late magmatic growth of differentiated intrusives show "worm-like" or "finger-like" intergrowths of feldspar and quartz described as myrmekite (see Figure 20). Thus this section could be called a granophyric differentiate (Hotz, 1953). Bluish penninite occurs in pseudomorphs of pyroxene and as cavity filling material. The equigranular matrix consists of plagioclase, quartz, clinozoisite and carbonate. The translucent to opaque mineral is siderite. It has perfect rhombohedral cleavage, and the entire crystal has a roughly hexagonal form. It is highly altered and a definite magnetite association along the cleavage partings is seen.

vii) Sheared Gabbro

The top layer of the sill is a shear zone. Minor shearing is present in hand specimen and a weak preferred orientation of grains is visible. Cores drilled by Massval Mines Ltd. (1959) show the contact between the country rock and the sill to be sheared. It is not seen continuously along strike, the exact relationships in the west being unclear. At its maximum it is fifteen meters wide but averages eight meters. The "type" outcrop occurs on the southeastern shore of Gabbro Lake, where the drilling took place. The samples examined from the sheared zone of the sill were, M-100 and M-103. The average modes

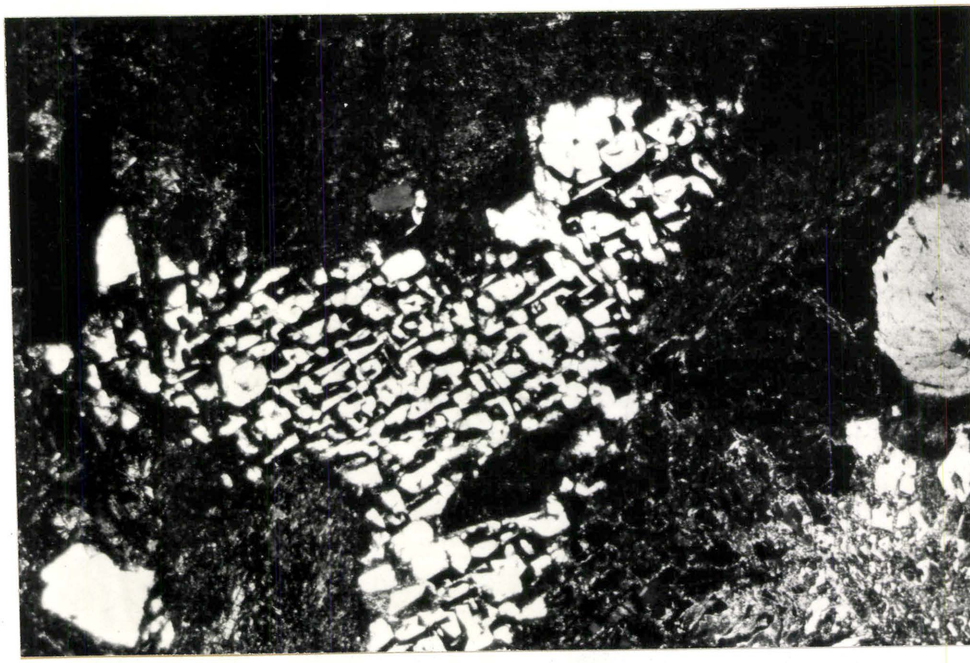


Figure 19. Sample M-98 showing graphic intergrowth of quartz and feldspar. Magnification is 63X.

Figure 20. Taken from sample G-220 this photomicrograph shows myrmekitic, "worm-like" or "finger-like", intergrowth of feldspar and quartz. Magnification is 63X.

of these is:

		Range
Carbonate	42%	39 - 45%
Matrix	25%	24 - 26%
Quartz	16%	14 - 17%
Uralitized Pyroxene	7%	7 - 8%
Saussuritized Plagioclase	6%	6
Opaques	3%	3 - 4%

These rocks are comprised of fine grain carbonate and a fine cryptocrystalline matrix of quartz and feldspar. The feldspar is replaced by clinozoisite. The matrix is a microcrystalline aggregation of quartz, feldspar and chlorite. The quartz and feldspar are graphically intergrown with the matrix. No relict textures remain. The pyroxene is replaced by very fine broken needles of actinolite. By far the most important constituent of the rock is the carbonate. Very idiomorphic rhombs of calcite, with good rhombohedral cleavage are clustered together (see Figure 21). The carbonate forms at the expense of both plagioclase and pyroxene. Siderite also has been broken up. The fragmental nature of most of the constituents suggests that this rock underwent a period of mechanical deformation after metamorphism. This may have been a weak fault or shear zone.

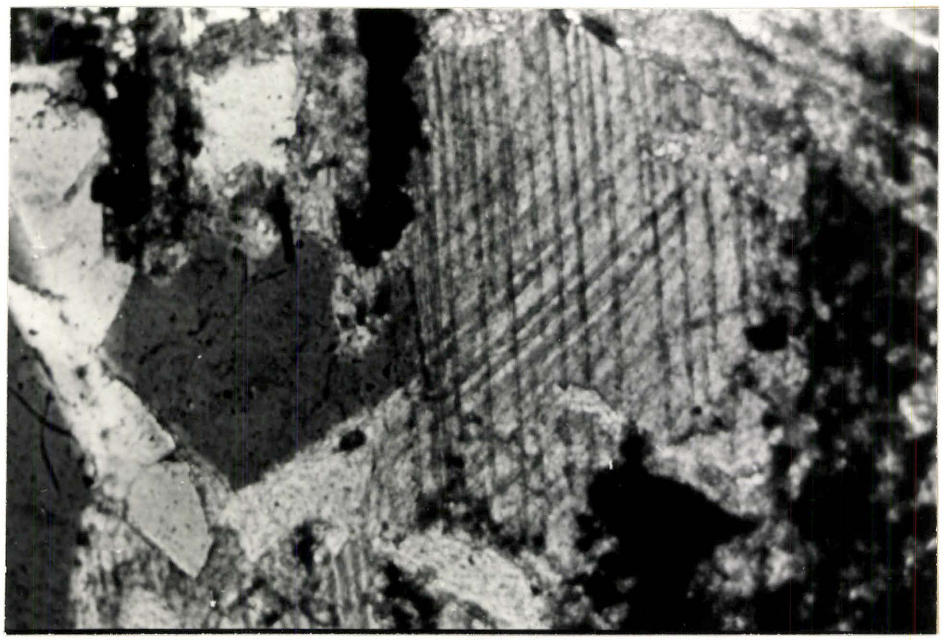


Figure 21. This photomicrograph of sample M-100 shows the good rhombohedral cleavage of calcite. Magnification is 63X.

Summary

1. The basal zone is a fine grained chilled margin of equal amounts of plagioclase and pyroxene.
2. The diabasic phase shows a slight increase in grain size of the accumulating plagioclase and pyroxene.
3. The leucocratic phase is characterized by abundant plagioclase and minor pyroxene with a relatively high modal abundance of olivine.
4. The pyroxenitic phase is dominated by pyroxene with little or no plagioclase.
5. The pegmatitic phase is the coarsest and contains equal amounts of plagioclase and pyroxene. It has a high modal abundance of quartz which is graphically and myrmekitically intergrown with the feldspar.
6. The shear zone is fine grained and contains fragmental remnants of pyroxene, plagioclase and calcite, the latter having a high modal abundance.

CHAPTER IV

GEOCHEMISTRY

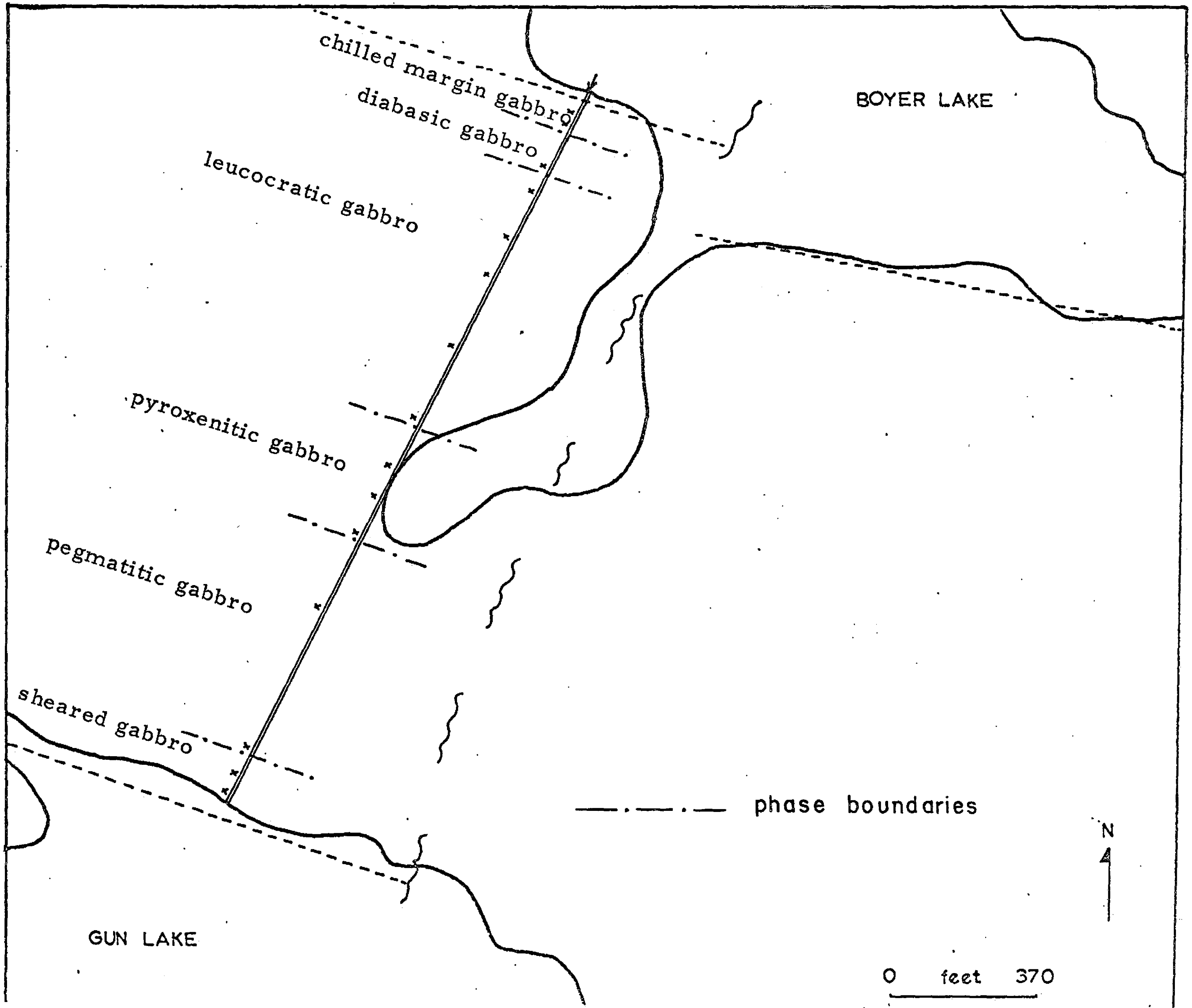
i) Analytical Methods

Whole rock analyses of samples from the sill were obtained using X-ray fluorescence. The samples were collected along a traverse across the sill at a bearing of 205°, roughly perpendicular to the strike of the intrusion (see Figure 22). Specimens were taken at fifteen meter intervals and at contacts of the mappable units. The total length of the traverse was seven hundred meters. Thirty-eight samples were taken.

Fifteen of these samples were crushed to -200 mesh using a Spex Industries shatter box with tungsten carbide rings. Care was taken to remove all weathered surfaces before crushing. Pressed discs of each sample were made following the procedure outlined by Marchand (1973). These discs with boric acid backing were analysed on a Philips Model 1450 AHP automatic sequential spectrometer housed in the Geology Department, at McMaster University. The method of data analysis and data handling followed that of Brown (1973). The results were satisfactory excepting Mg and Al. For these two errors may be up to ten percent. The major elements analysed were: Si, Al, total Fe, Mg, Ca, Na, K, Ti, Mn and P. A Cr X-ray tube was used throughout. One sample remained in the spectrometer at all times serving as a drift monitor. The results as well as a discussion on the errors are in Appendix B.

Location of Geochemical Traverse

Figure 22



CIPW norms were calculated using a computer program by Mathison (1973). The total Fe content was separated into Fe_2O_3 and FeO components based on Irving and Baragar's (1971) correction: % Fe_2O_3 = % TiO_2 + 1.5. The results are tabulated in Appendix B.

ii) The Results

The results are presented in Table IV and Figures 23 a - e and 24 a - f. The abscissa represents the stratigraphic position of the samples, from the base.

The following trends are observed:

1. An increase upwards in: Fe, Mn, Ti, and P_2O_5 and the normative minerals, magnetite and ilmenite. Both the oxides and normative minerals are low in the leucocratic phase and high in the pyroxenitic phase.
2. A decrease upwards in: Al, Mg and the normative mineral olivine. They are high in the leucocratic phase and low in the pyroxenitic phase.
3. A general increase towards the top in Si and the Fe/Fe+Mg ratio of the mafic minerals and in the percentage of hypersthene in the norm.
4. A general decrease upwards in Ca, with a corresponding increase in Na. The Ca/Na ratio of the plagioclase components accounts for most of this trend.
5. The An/Ab+An ratio remains relatively constant from bottom to top.
6. A reversal in trends of Mg, Fe, Mn to those similar of the initial chilled margin at the base.

7. The leucocratic phase has both maxima and minima concentration separating it as a major geochemical division within the sill.
8. Some constituents show sharp concentration in the sill. The pyroxenitic phase is typified by a very high mafic content. Fe, P_2O_5, and Ti reach their respective maxima. These variations are reflected by the norms as well, as seen in the anomalous abundance of ilmenite, apatite and magnetite.
9. In the pyroxenitic phase the Si content abruptly changes its trend from a negative to positive increase. The absolute minimum and maximum concentrations of Si are found within this phase.
10. A decrease upwards in the Fe/Mg ratios of the normative minerals:

    Fo/Fa of olivine from 2:1 to 0

    En/Fs of diopside from 2.2:1 to 1:2.2

    En/Fs of hypersthene from 2:1 to 1:2.2
11. Quartz and orthoclase show enrichment in the pegmatitic phase.
12. In most cases variations in the chemistry and norms reflect the units mapped in the field.
13. All variations are smooth and reflect the gradational nature of the phase boundaries.

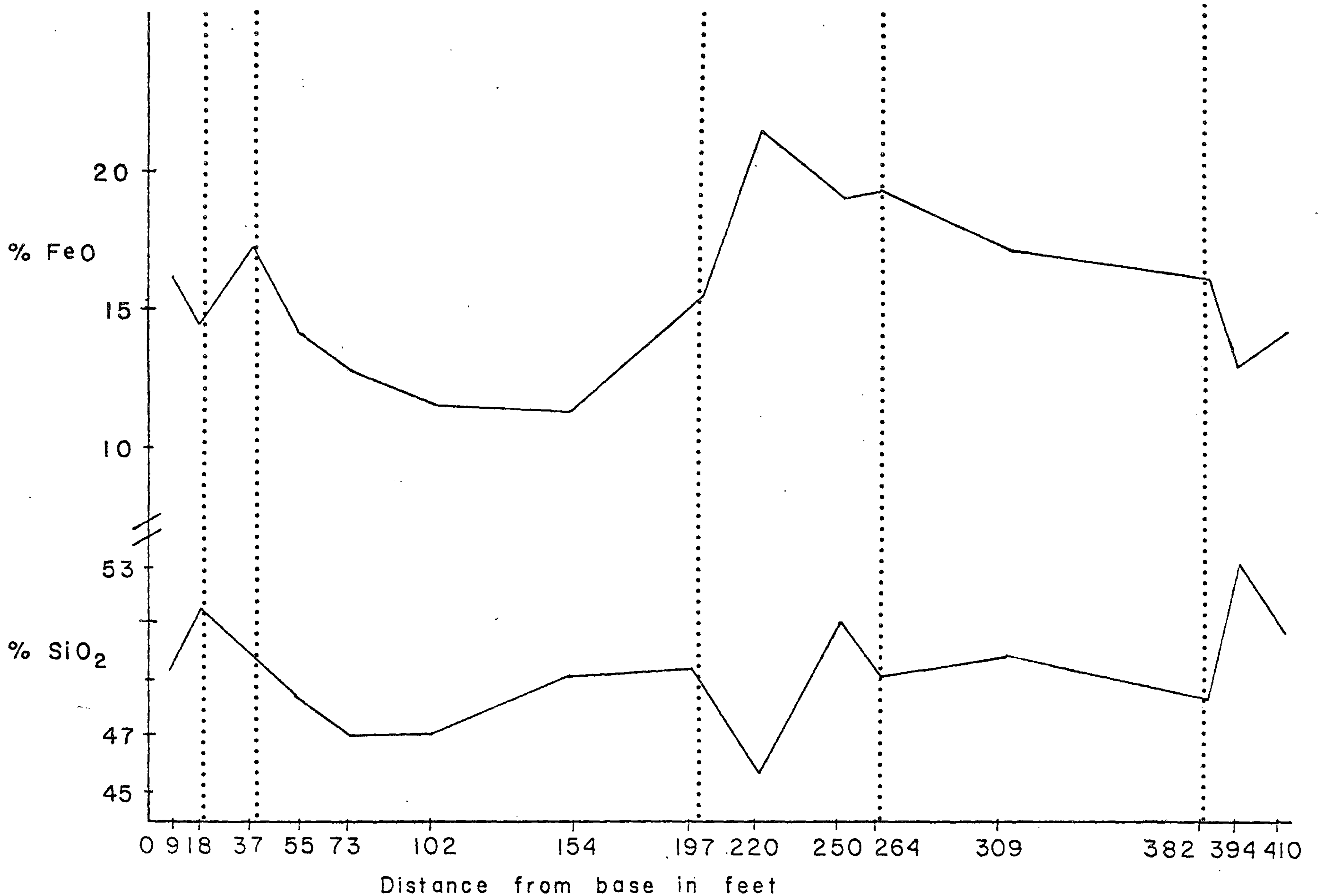


Figure 23 a Oxide vs. Height

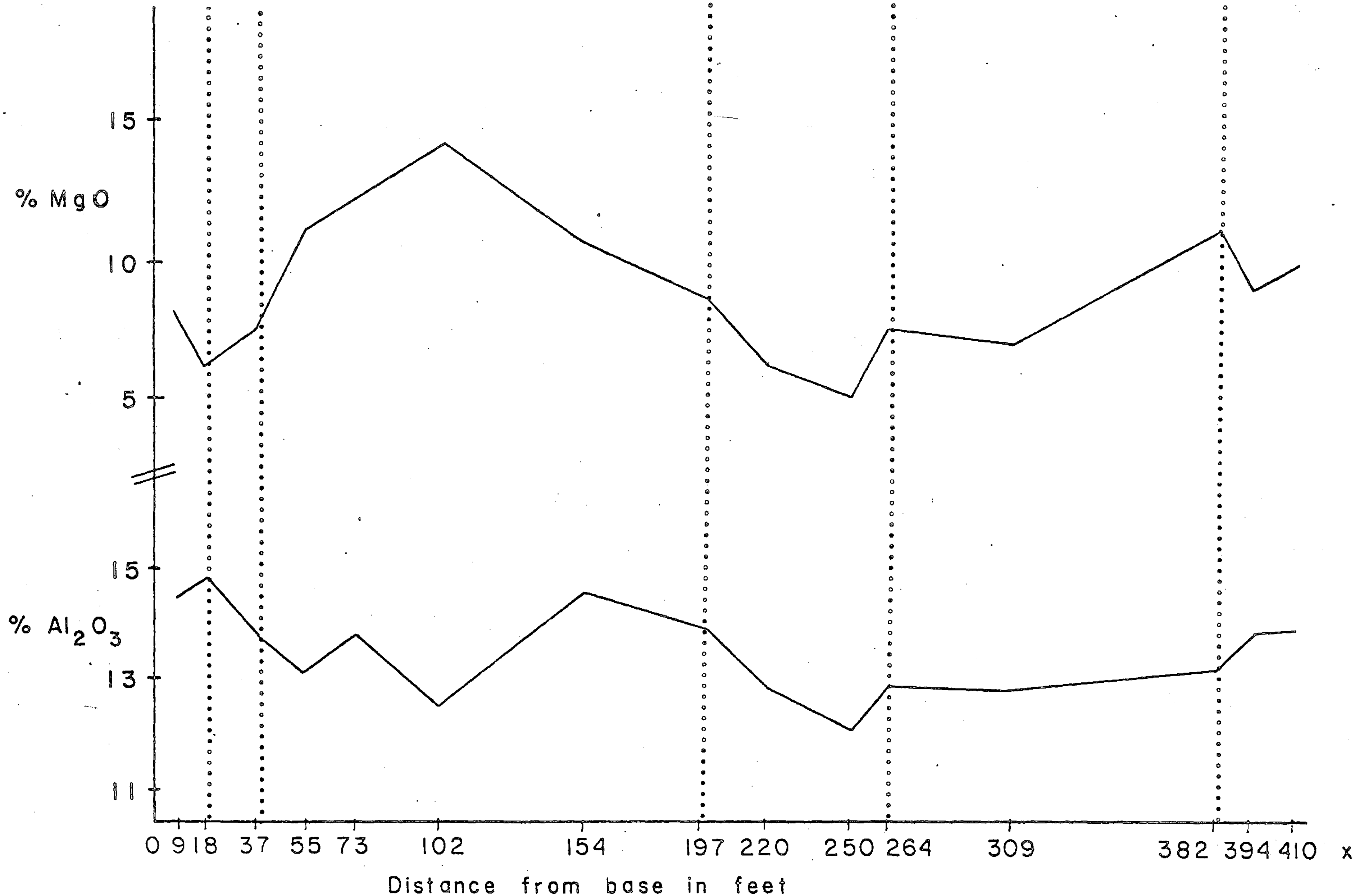


Figure 23 b Oxides vs. Height

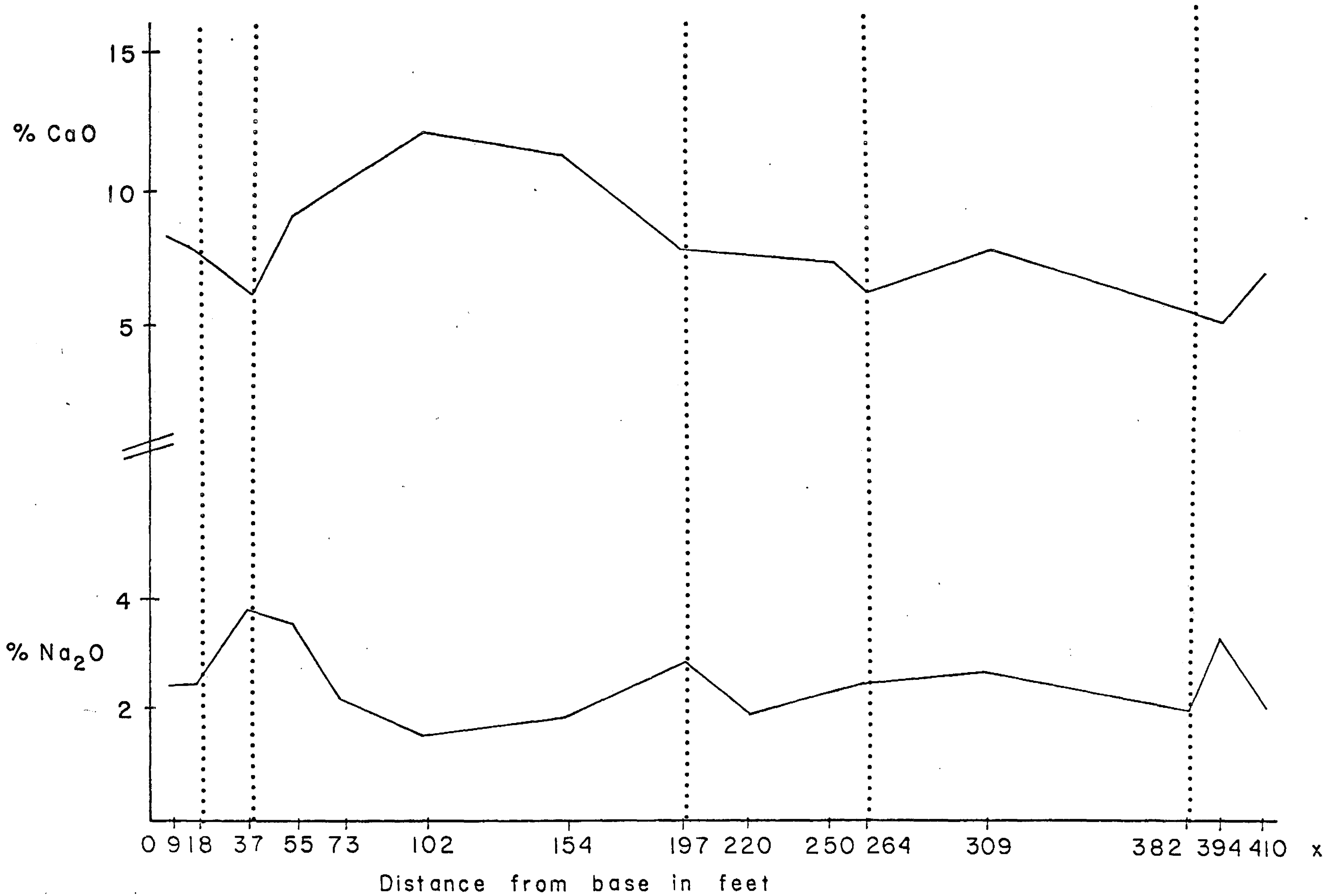


Figure 23 c Oxides vs. Height

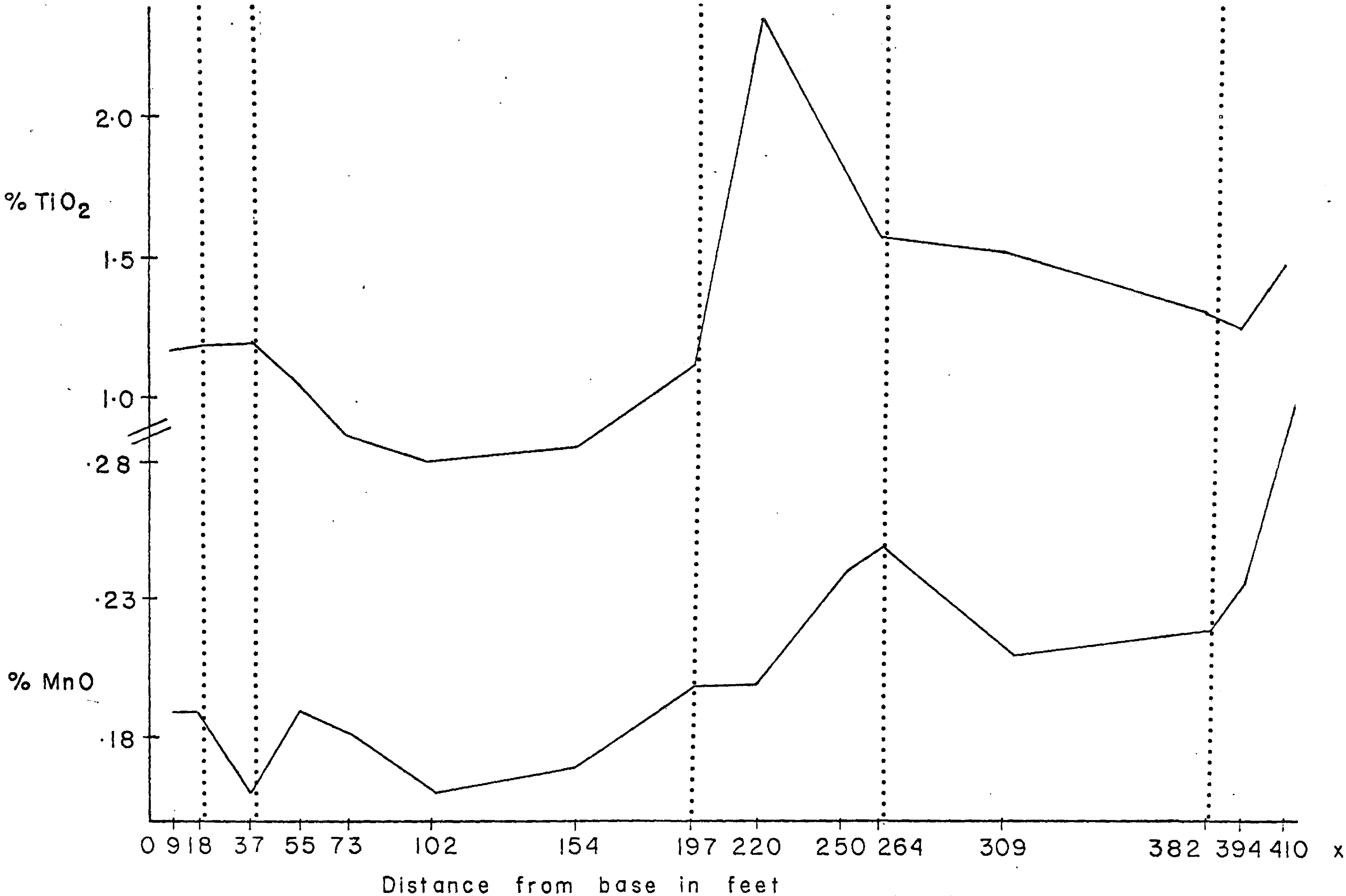


Figure 23 d Oxides vs. Height

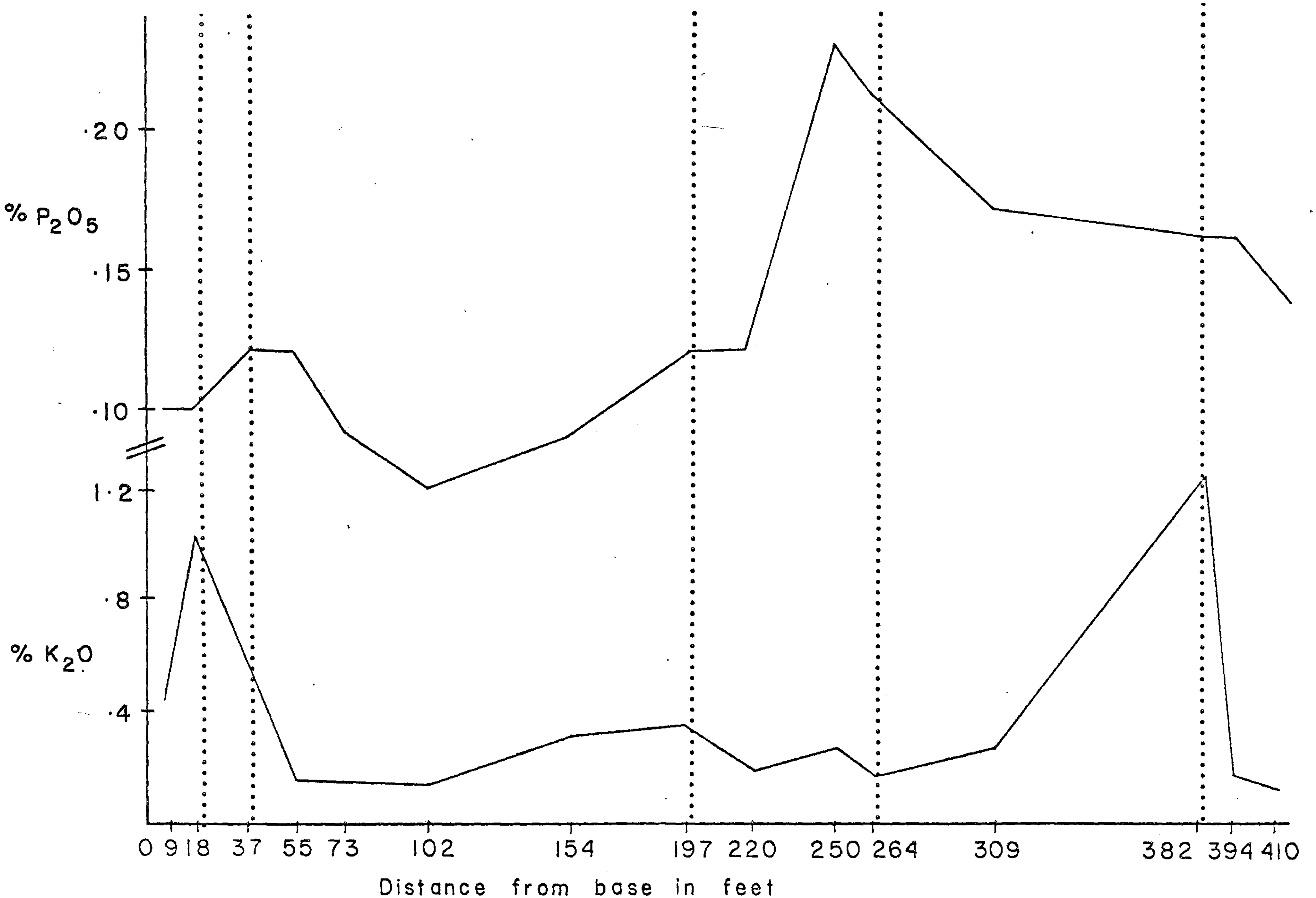


Figure 23 e Oxides vs. Height

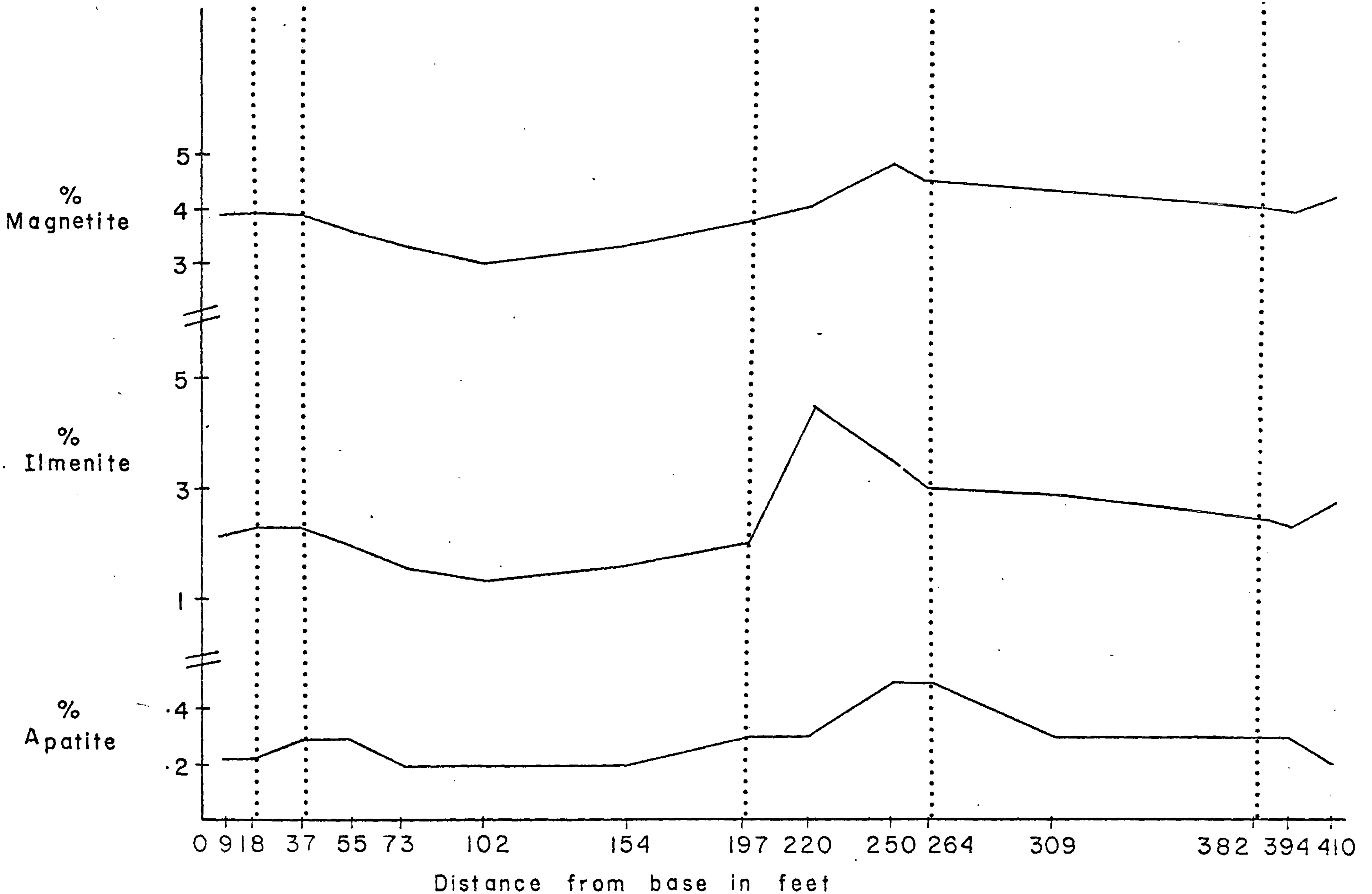


Figure 24 a Norms vs. Height

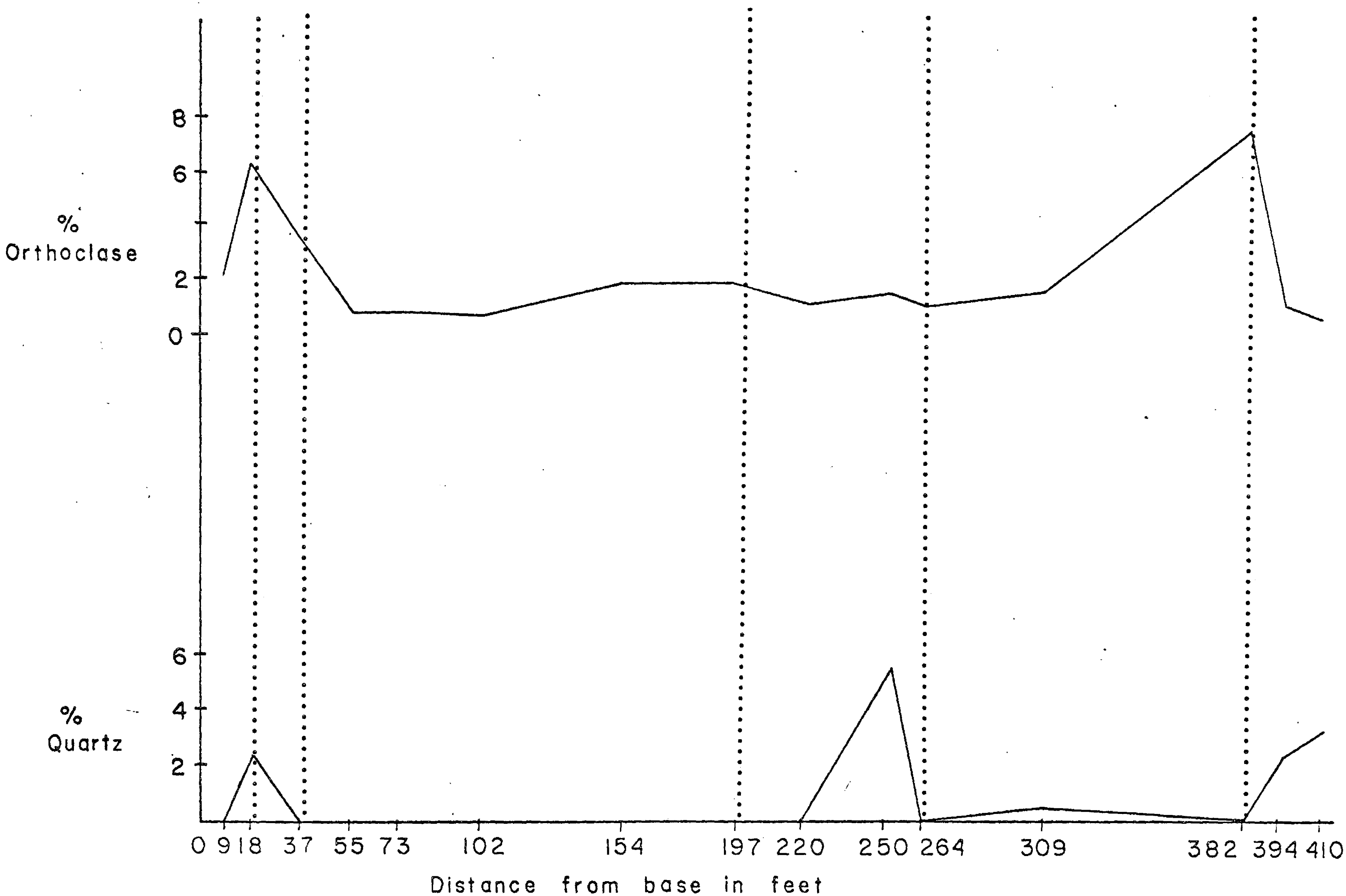


Figure 24 b Norms vs. Height

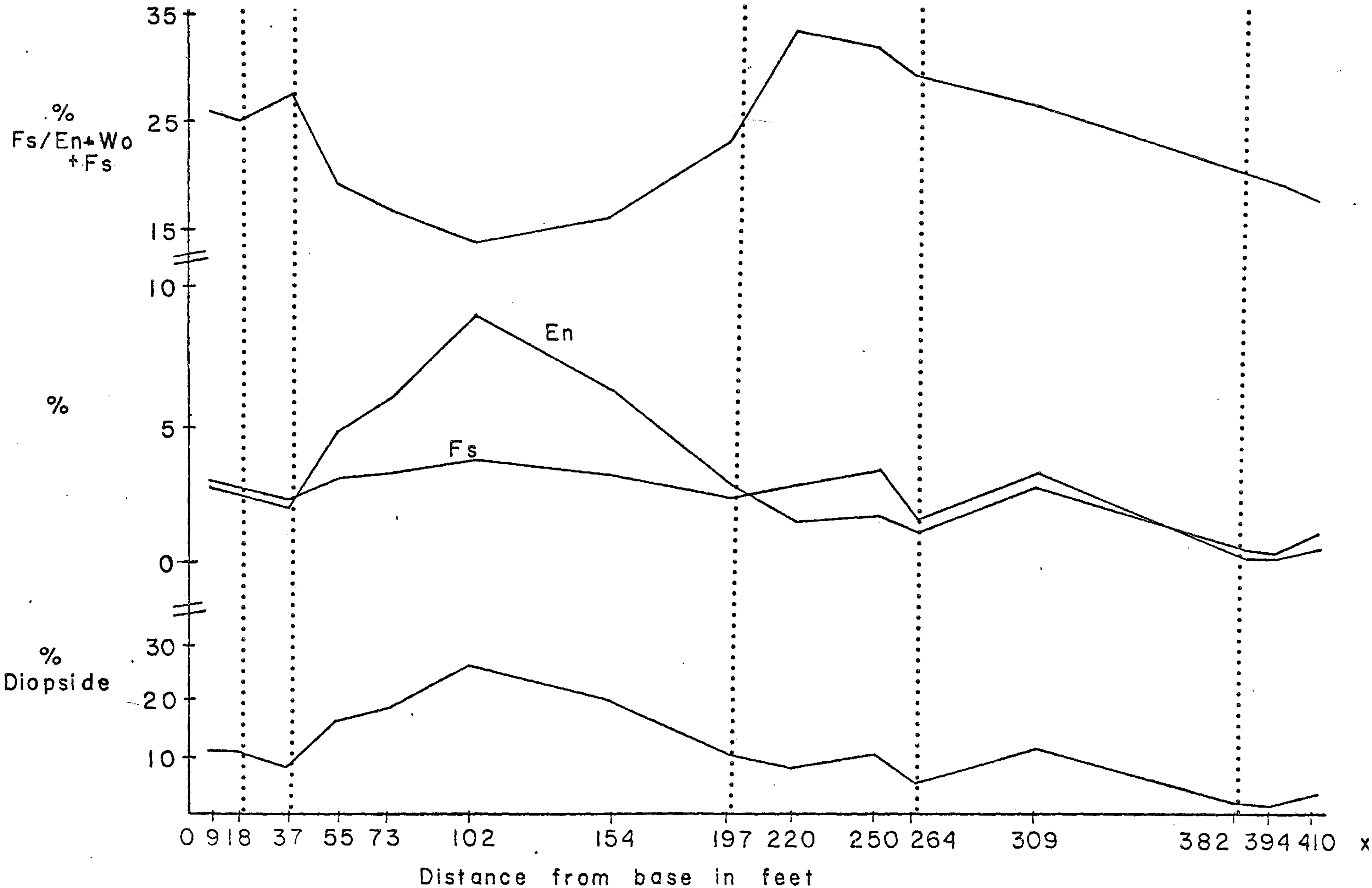


Figure 24 c Norms vs. Height

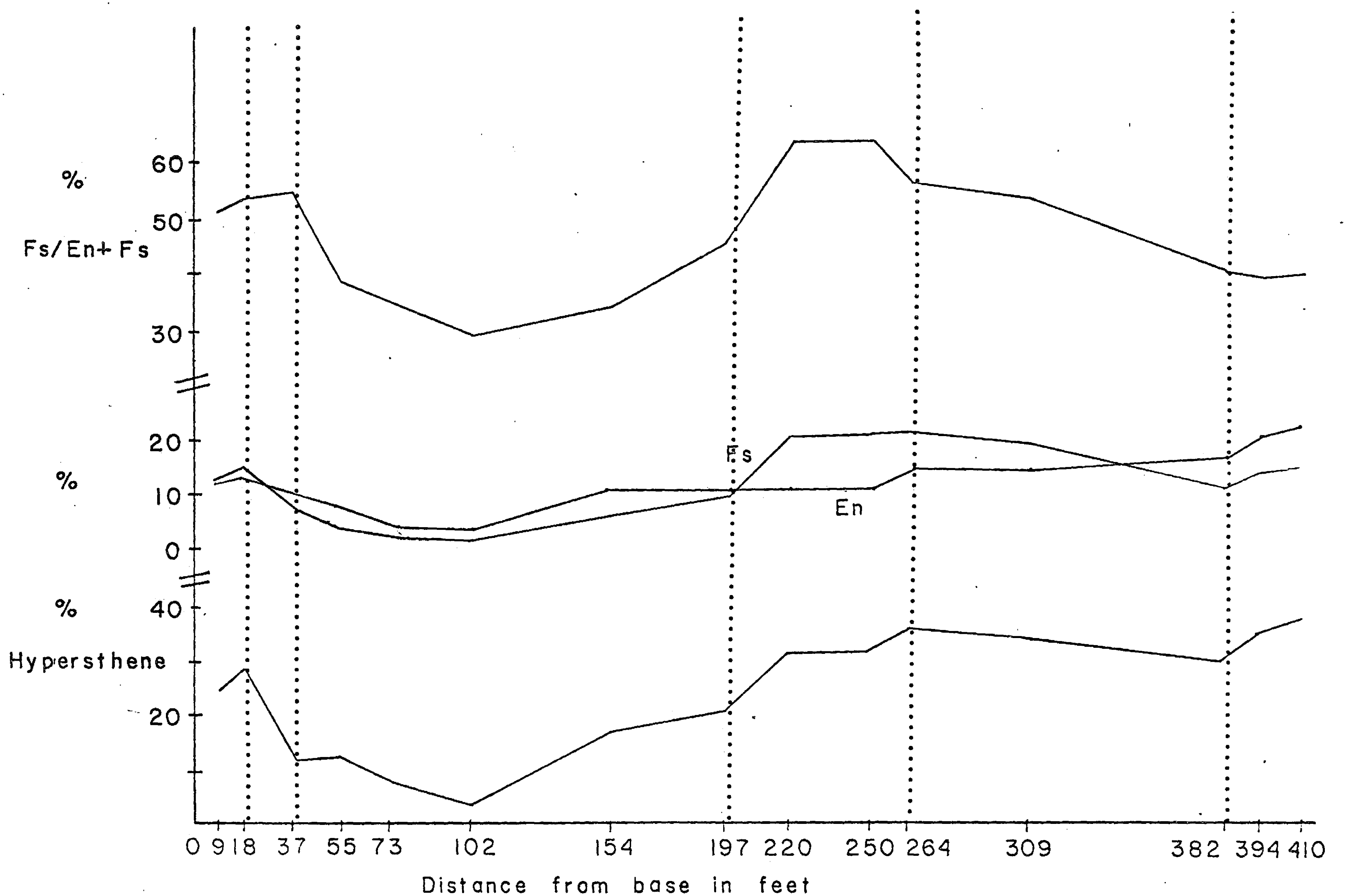


Figure 24 d Norms vs. Height

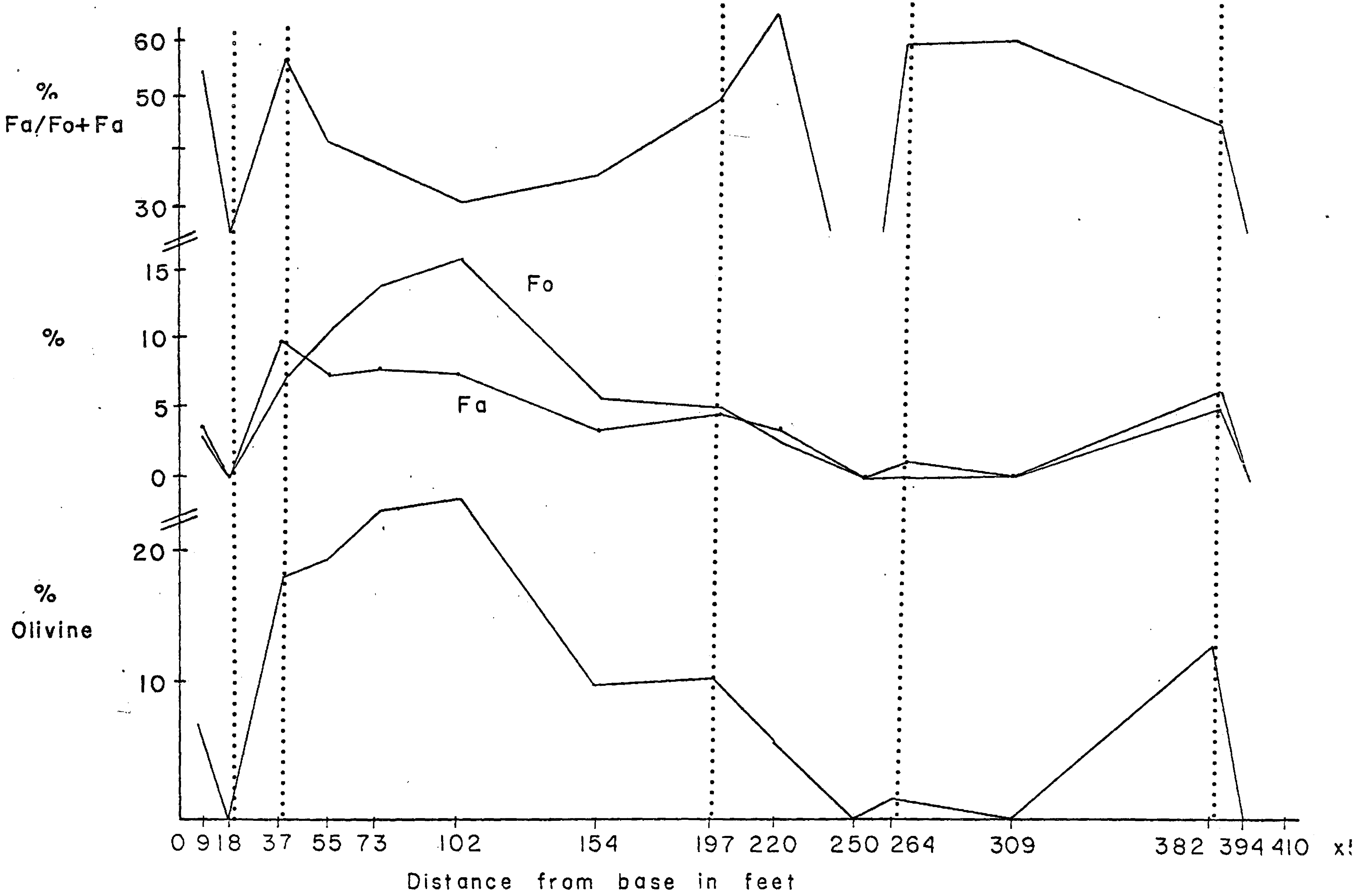
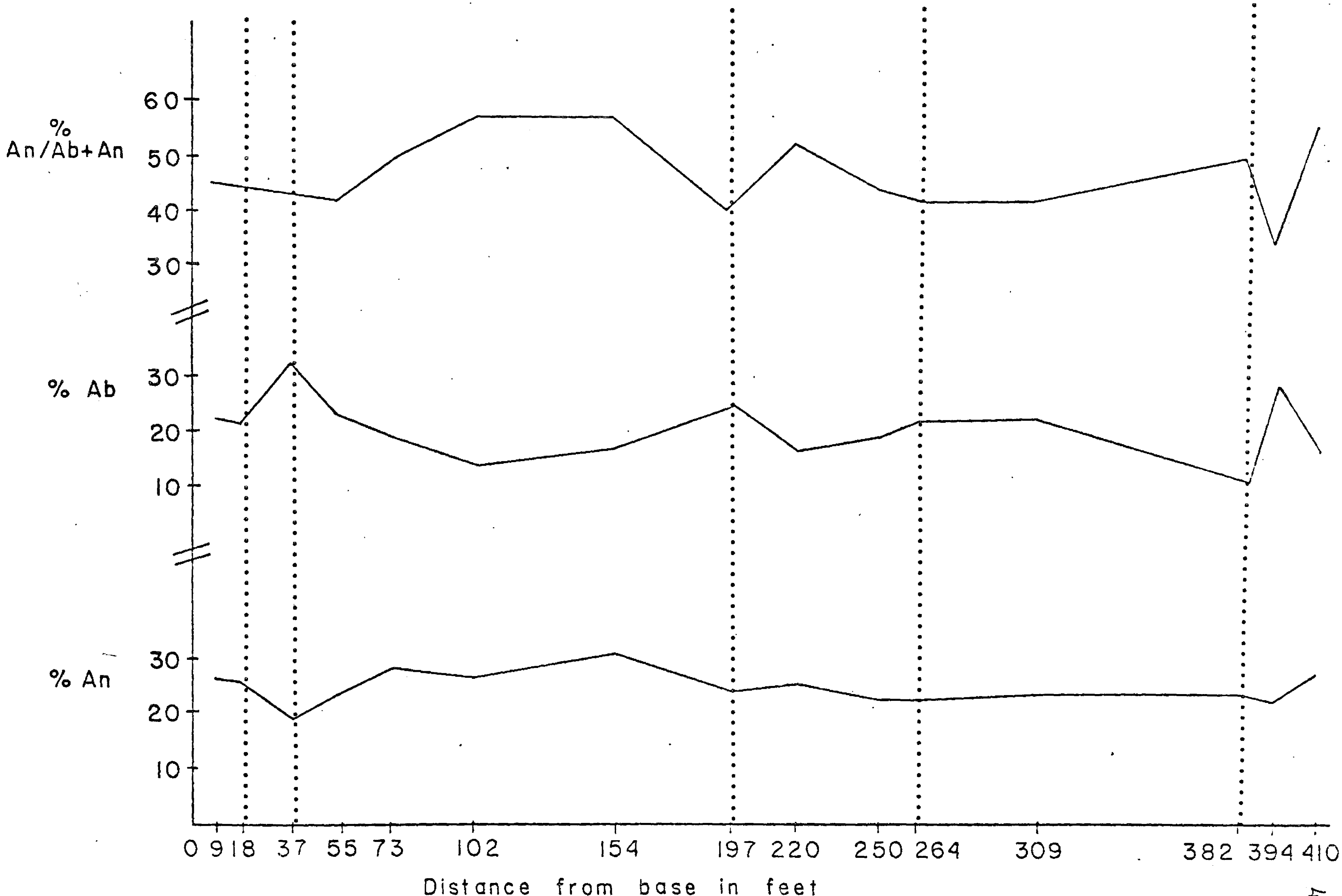
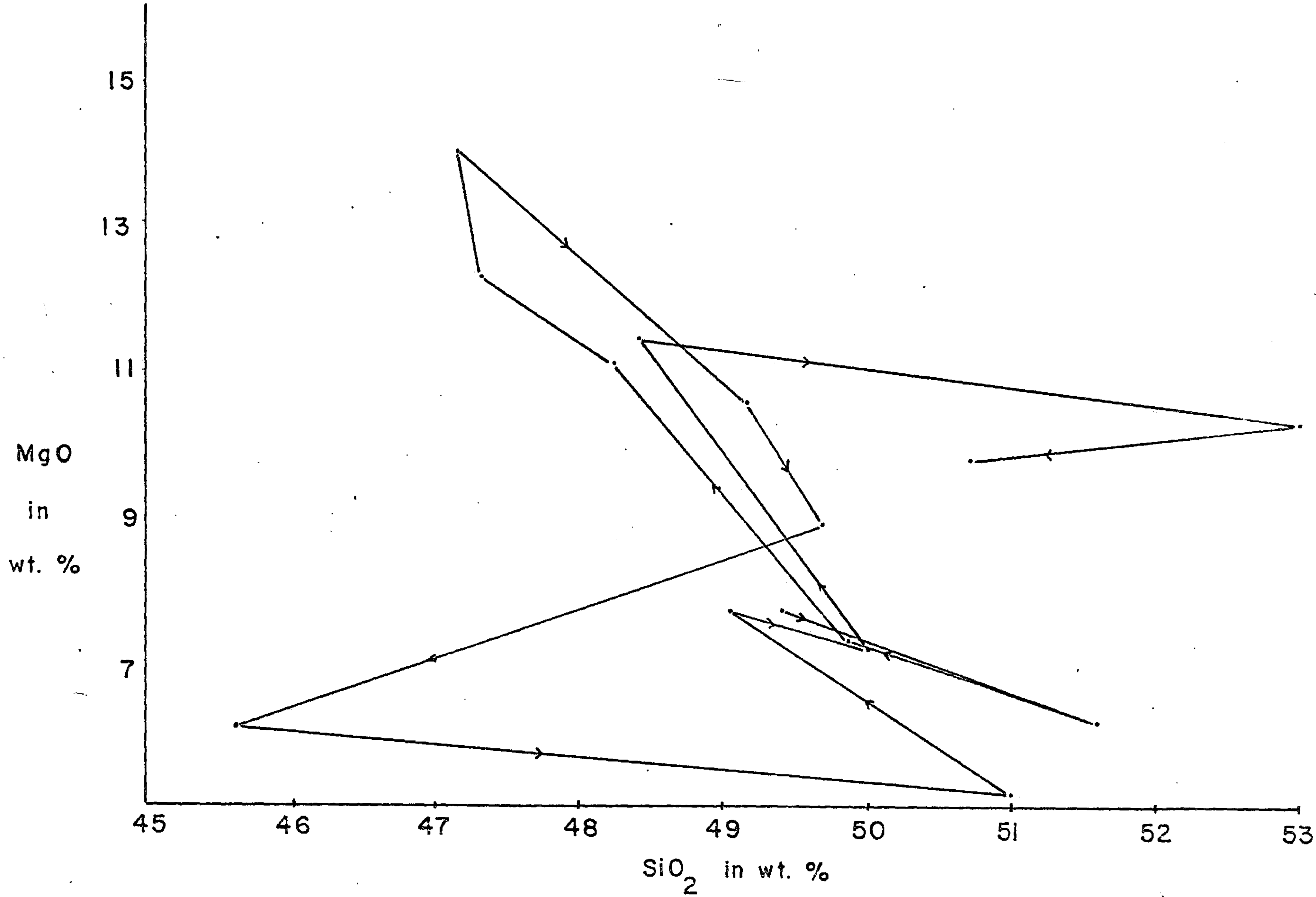


Figure 24 e Norms vs. Height



%
An/Ab+An
60
50
40
30
% Ab
30
20
10
% An
30
20
10
0
9
18
37
55
73
102
154
197
220
250
264
309
382
394
410
Distance from base in feet

47



SiO_2 Variation Diagram

Figure 25.

CHAPTER V

PETROGENESIS

In this chapter the petrogenesis of the sill will be considered. Various theories on the origin of layered intrusions will be discussed as they relate to the Gabbro Lake Sill.

i) Bulk Composition

It is essential in discussing the petrology of the sill that the original composition of the magma be determined. The chilled margin gabbro of the Gabbro Lake Sill, like the chilled marginal olivine gabbro of the Skaergaard Intrusion (Wager and Brown, 1967), and the marginal group of the Bushveld (Groeneveld, 1970), will be taken as the quenched initial magma. Thus where the sill comes in contact with the mafic volcanics along the northern margin, will be taken as a satisfactory representative of the composition of the original magma.

Table 1, lists chemical analyses for four well studied intrusions; Skaergaard, Palisades, Bushveld, Stillwater, and for comparison the olivine tholeiite of Hawaii. It can be seen that the chilled margin gabbro of the Gabbro Lake Sill is similar in composition to that of the Kilauea volcano. Compared to the other intrusions, it has a higher abundance of MgO, FeO and lower amounts of CaO and Al_2O_3.
In general the initial magma is basaltic with a relatively low content of silica and alkalis, high magnesia and iron, and moderate alumina contents. In this respect it would be termed an olivine tholeiite (Irvine and Baragar, 1971).

Table 1 Chemical Analyses of Chilled Margins

	1	2	3	4	5	6
SiO_2	48.08	51.82	50.68	50.55	49.16	47.33
Al_2O_3	17.22	14.76	17.64	15.23	13.33	13.30
FeO	9.76	10.46	10.14	11.11	11.02	14.78
MgO	8.62	7.32	7.71	8.30	10.41	12.15
CaO	11.38	10.02	10.47	11.30	10.93	8.45
Na_2O	2.37	2.06	1.87	2.24	2.15	2.07
K_2O	0.25	0.82	0.24	0.19	0.51	0.50
P_2O_5	0.08	0.12	0.09	0.12	0.16	0.11
MnO	0.16	0.12	0.15	0.23	0.16	0.18
TiO_2	1.17	1.34	0.45	0.66	2.29	0.94

1. Skaergaard chilled marginal gabbro (Wager and Brown, 1967)
2. Palisades Sill chilled margin (Walker, 1940)
3. Stillwater Complex chilled border zone (Hess, 1960)
4. Bushveld marginal group (Wager and Brown, 1967)
5. Kilauea Volcano olivine tholeiite (Yoder and Tilley, 1962)
6. Gabbro Lake Sill chilled margin gabbro (section C-51)

ii) Trends and Mechanisms

Most mafic layered intrusions are characterized by an overall mineralogical and chemical gradation from the bottom to top of the whole intrusion. This gradation, or phase layering (Wyllie, 1967), consists of two aspects:

1. certain minerals in turn begin and end crystallization, and other minerals belonging to solid-solution series (e.g. olivine, plagioclase, pyroxene) change composition continuously with progressive crystallization

2. the progressive chemical change is a result of gravitational settling of early formed grains. (Hyndman, 1972)

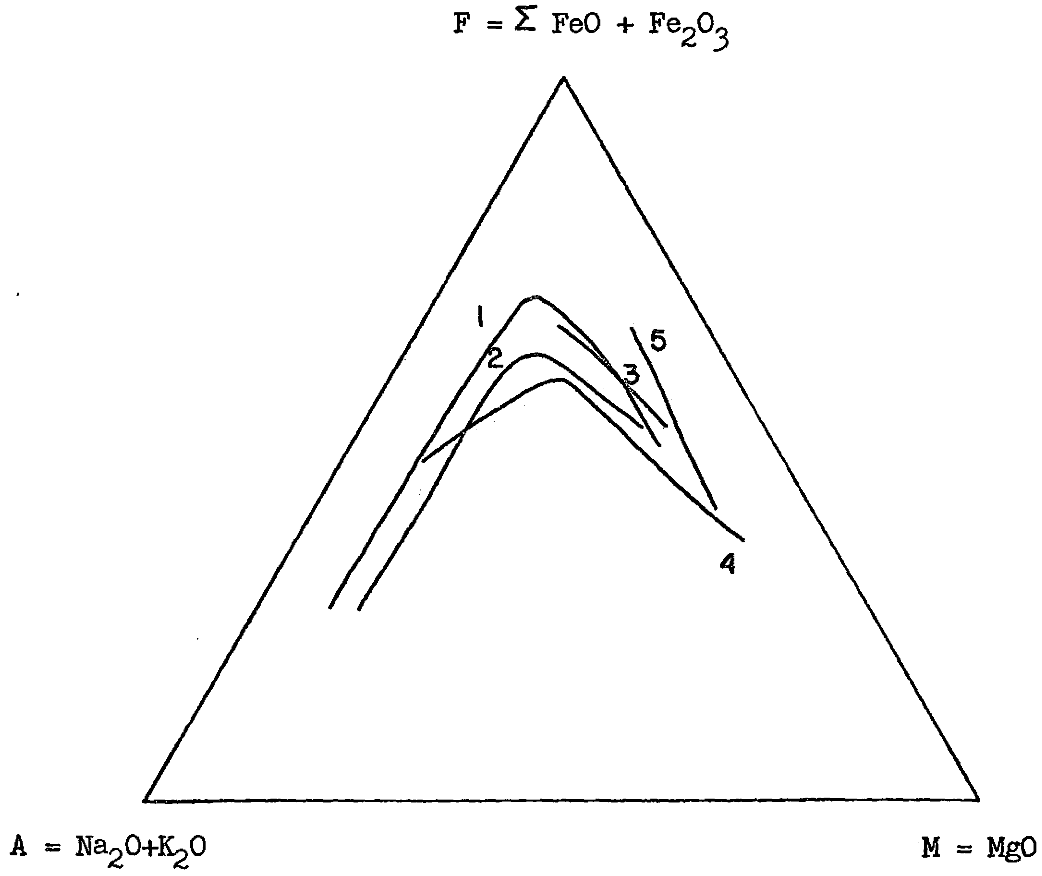
A characteristic feature of the Bushveld, Skaergaard, Stillwater, and others is the development of igneous lamination and rhythmic layering. It is produced because settling crystals will tend to accumulate with their longer axes parallel to the floor upon which sedimentation is occurring. This type of layering is absent from the Gabbro Lake Sill and many other dolerite sills (Hess, 1960). This has led many petrologists to suggest that differentiation processes in bodies less than three hundred meters in thickness do not involve crystal settling to an appreciable extent. Hess and others see the major process as crystallization inward from surfaces of cooling. "The initial magma is chilled against the floor and crystallized completely with a composition close to that of the original liquid. Above this crystals began to form along the solid-liquid contact. These would be the earliest crystals to separate from such a magma.

One might also expect from this process a similar differentiation from the roof downward, the amount of crystallization from the roof downward being about one-quarter of that from the floor upward. The roof section might be modified somewhat by upward streaming of late-stage volatile constituents." This type of process along with partial gravity settling, which accounts for the marked phase layering within the sill, is envisaged for the Gabbro Lake Sill.

Compositional variation within the main minerals reflects the chemistry of the intrusion. The primary differentiation trends are to increase SiO_2, K_2O, Na_2O and FeO, and decrease CaO and MgO. This is reflected in both the changing mineralogy and changing composition of individual minerals to higher levels. These trends may usefully be examined with the aid of the $Na_2O + K_2O$:FeO + Fe_2O_3:MgO ternary plot (AFM). In Fig. 26, the trends of Skaergaard, Stillwater, Palisades, and the Bushveld are included for comparison.

Early MgO enrichment is due to the high magnesium content of the early ferromagnesian minerals, especially olivine. During the middle stages, average rocks tend to lie near the iron apex because of the enrichment of the late ferromagnesian minerals in iron. Late-stage granophyric compositions, shift the line to the "A" apex, due to a marked alkali enrichment. The Gabbro Lake Sill shows an iron-enrichment trend with no late enrichment in alkalis. This could be explained if the alkalis are leached out, or if it did not differentiate to the same degree as the other intrusions.

AFM PLOT



1. Skaergaard Trend (Wager and Brown, 1967)
2. Bushveld Trend (Wager and Brown, 1967)
3. Stillwater Trend (Wager and Brown, 1967)
4. Palisades Trend (Carmichael et al., 1974)
5. Gabbro Lake Sill Trend

Figure 26

Variation diagrams with SiO_2 as the abscissa and other oxides as the ordinate, give a wide scatter of points, (see Fig. 25), and prove to be of little help in showing major trends. The main differentiation of the sill has been due to settling of a constituent (pyroxene) whose silica content is practically the same as that of the magma. The great majority of the specimens analysed, although showing a wide variation with respect to some oxides do not have much variation in SiO_2 (48% to 52%). This leads to quite an unintelligible distribution of points (Walker, 1940), on SiO_2 variation diagrams.

Chemically, most basic intrusions display four major trends, which will be compared with the Gabbro Lake Sill below.

1. A depletion in magnesium upwards. In the sill it decreases from 14% to 7%.

2. An enrichment in iron upwards. In the sill it increases from 12% to 17%.

3. An enrichment in silica upwards. This is not evident in the sill, it varies only slightly from 47% to 50%.

4. A depletion in calcium upwards. In the sill it decreases from 12% to 6%.

The major mineralogical trends in basic intrusions are listed below, and compared with the Gabbro Lake Sill.

1. The modal abundance of olivine decreases upwards. In the sill it shows a concentration in the lower levels, with none occurring above the pyroxenitic layer. Exact percentages are hard to estimate due to alteration of most primary minerals.

2. The amount of quartz increases upwards. Modally it increases from trace amounts in the diabasic phase to 18% in the pegmatitic phase. Normatively it shows a slight increase from 0 to 4%.

3. The An/Ab+An content in plagioclase decreases upwards. In the sill the leucocratic phase represents an early accumulation of material rich in An, with a ratio of 65. The ratio decreases to 50 in the pegmatitic phase.

4. The amount of alkali feldspar increases upwards. Modally it is concentrated in the pegmatitic phase of the sill. Normatively it increases from 1% in the diabasic phase to 7% in the pegmatitic phase.

5. An enrichment in normative iron in the ferromagnesian minerals:

(i) Fs/En+Fs of hypersthene increases from 30% in the leucocratic phase to 45% in the pegmatitic phase.

(ii) Fa/Fo+Fa of olivine increases from 30% in the leucocratic phase to 55% in the pegmatitic phase.

(iii) Fs/En+Fs of diopside increases from 15% in the leucocratic phase to 25% in the pegmatitic phase.

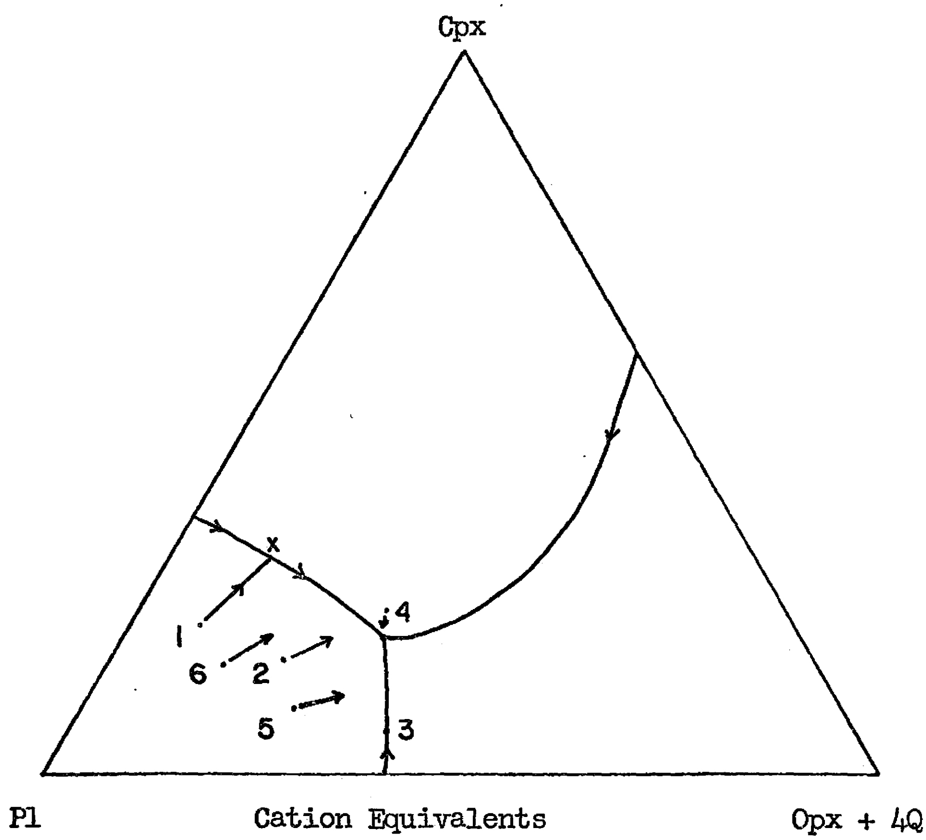
iii) Crystallization Sequences

The resulting mineral assemblage derived from the crystallization of a mafic magma depends on the initial overall chemical composition of the magma and the resulting crystallization sequences. According to Irvine (1970), the four major minerals; olivine (ol), clinopyroxene (cpx), orthopyroxene(opx) and plagioclase (pl), may have as many as thirty different orders in basaltic magmas, (i.e. ol-pl-cpx-opx; pl-ol-cpx-opx etc.), resulting in several different cumulate sequences, depending on the exact paths of the magma. It is beyond the scope of this thesis to give the details of his models. Instead the resulting sequences for five intrusions are given and compared with this sill. Fig. 27 is the phase diagram pl-cpx-opx+4Q (Irvine, 1970) projected from the olivine apex and shows the compositions of six initial magmas. Crystallization from these results in the following crystallization sequences:

Skaergaard	pl-ol-cpx-opx
Muskox	ol-opx-cpx-pl
Bushveld	pl-opx-ol-cpx
Keweenawan	pl-ol-cpx-opx
Palisades	ol-pl-opx-cpx
Gabbro Lake Sill	pl-ol-cpx-opx

Given the initial composition of the Skaergaard magma, at point 1, the following sequence would develop (assuming normal fractional crystallization). It would first crystallize out ol + pl and with continued cooling would move along line 1-x until it reached the cotectic boundary at x, where cpx would be coprecipitated. The liquid would follow the boundary curve until it reached the invariant point, where opx would begin to crystallize. Thus the resulting cumulate sequence would be: pl; ol+pl; ol+pl+cpx; pl+cpx+opx.

The Diagram Plagioclase-Clinopyroxene-
Orthopyroxene + 4 Quartz
(Irvine, 1970)



1. Skaergaard
2. Keweenawan
3. Bushveld
4. Muskox
5. Palisades
6. Gabbro Lake Sill

Figure 27

iv) Crystallization in Situ

The intrusion of the initial magma into the mafic volcanic pile resulted in quenching along the margins. The absence of large phenocrysts in the chilled layer suggests that the magma was nearly one hundred percent liquid when injected. Both margins begin to cool rapidly, but crystallization from the roof downward is considerably slower than the floor upwards. Two reasons have been suggested by Hess (1960):

1. the increase in pressure downward slightly favours crystallization at the floor.
2. convection circulation of the magma tends to keep the hottest portion directly below the roof so that crystallization along the roof contact may be slowed.

The chilled margin gabbro is thus typically a fine grained gabbro with equal amounts of plagioclase and pyroxene forming together. The crystallization of the lower chilled phase and early formed gabbro resulted in medium grain size and equigranular textures. The diabasic phase contains roughly equal amounts of plagioclase and pyroxene and may represent crystallization along the cotectic between pl-cpx (see Fig. 27). The continued cooling of the magma was at a slightly slower rate so that larger crystals might form. It differs chemically and mineralogically from the chilled phase and may mark the change from Hess' inward cooling model to one of partial gravity settling, envisaged by this author. Thus the diabasic phase may represent the initial differentiate of the magma. Crystallization resulted first in the separation of olivine and the settling and accumulation of olivine in the upward solidifying diabasic phase. As the magma continued to cool a layer of forsterite olivine crystals accumulated in sufficient numbers to exhibit signs of packing.

The concentration of plagioclase and olivine, about sixty meters above the base, is analogous to the Mandan Flow in the Lake Superior region (Cornwall, 1951). This flow has a high concentration of Mg-rich olivine. He attributes this to the early separation of olivine and the resulting crystal sorting by differential settling. In the Gabbro Lake Sill, MgO reaches a maximum of 15% in this phase and has 10% modal and 25% normative olivine. The leucocratic phase is troctolitic in nature, with subhedral plagioclase and interstitial pyroxene with scattered fractured olivine grains. This is similar in texture to the leucotroctolite layer of the Bushveld Complex (Grohler and Whitfield, 1970). The silica content of the troctolitic and olivine gabbro of the Bushveld is very low due to the abundance of silica poor olivine. A low oxygen fugacity would inhibit magnetite formation and allow iron as Fe^{+2} to concentrate in the residual magma. At the same time large quantities of plagioclase would crystallize out forming typically thick successions of leuconorite and leucogabbro. On the anorthite-forsterite-silica phase diagram (Fig. 28), the relative position of the original magma would plot near P. From the melt P, forsterite separates as the first solid phase

The Diagram Anorthite-Forsterite-Silica

(Turner & Verhoogen, 1960)

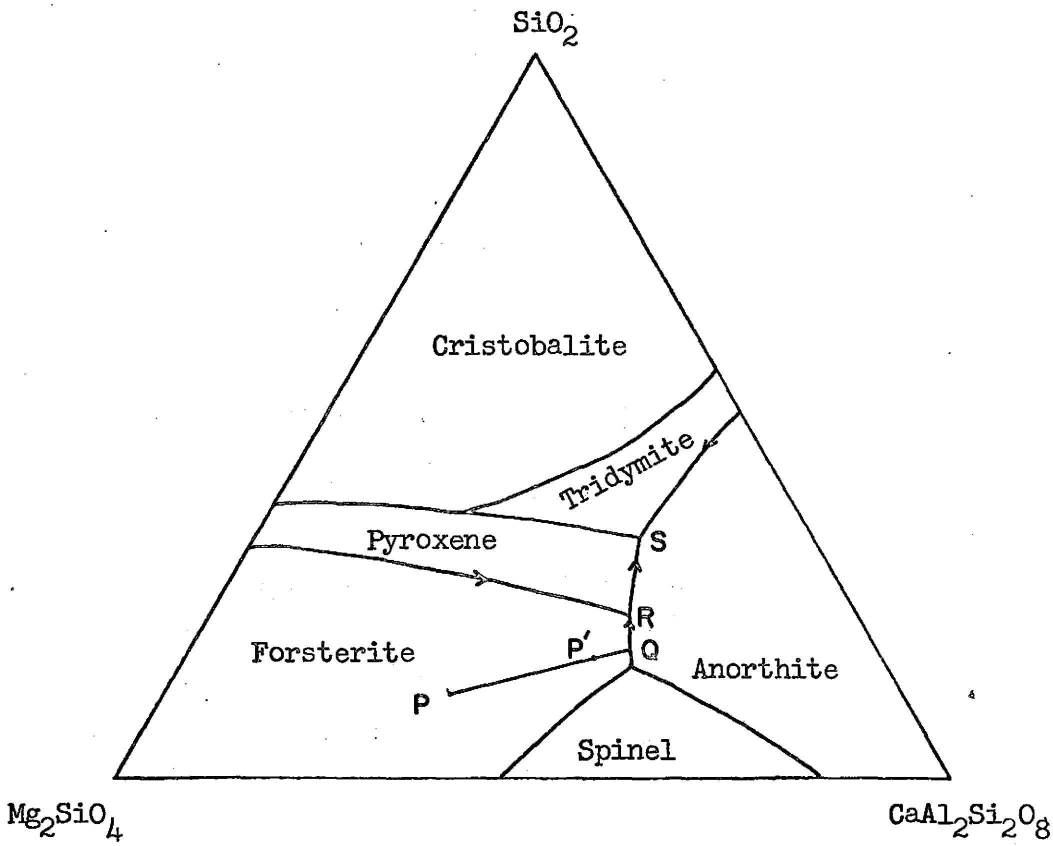


Figure 28

and the melt changes along PQ with falling temperature. At Q plagioclase crystallizes along with forsterite to give a troctolitic rock. The melt now follows the boundary QR, where at the reaction point R, olivine is consumed by the reaction;

$$\text{olivine + liquid} \longrightarrow \text{pyroxene}$$

$$Mg_2SiO_4 + SiO_2(l) \longrightarrow 2\ MgSiO_3$$

and anorthite and pyroxene separate out. The reaction ceases when the liquid phase is used up, the end product is a crystalline mixture of forsterite, pyroxene and anorthite; a gabbroic rock. If however the initial magma had composition P' then olivine instead of the liquid phase would be used up and the liquid would continue to cool up the curve to the Qtz-Px-An invariant point S, until the liquid phase is used up. The end product is a quartz gabbro. The above observations fit those of the Gabbro Lake Sill as well and thus similar processes are believed to be acting.

The pyroxenitic phase which is found gradationally above the leucocratic phase, poses problems as to why we have the high modal abundance of pyroxene (60%+) and the definite maxima exemplified by certain oxides such as TiO_2, FeO, P_2O_5 and MnO. Two hypotheses are suggested:

1. a fresh pulse of magma injected into the crystallizing sill
2. special conditions that caused mechanical concentration of the oxides and minerals

The first explanation was used by Upton (1970) to explain the intra-volcanic intrusions of Reunion. However, one would expect to see physical characteristics of a new intrusion in the field. There should be some evidence of shearing along the lower edge and the units should be petrologically distinct and separated by sharp junctions Upton (1970), but the phases above and below are gradational with the pyroxenitic phase.

The second mechanism involves special conditions producing the noted concentrations. The absence of olivine suggests cessation of olivine crystallization and a fall in MgO. The liquid has travelled beyond point R in the Fo-Qtz-Px phase diagram, Fig. 28. The high TiO_2 content of the pyroxenitic phase can be compared to that of the Losberg Intrusion (Donchin & Ferguson, 1970). Donchin and Ferguson point out that during differentiation, titanium enters the structure of pyroxenes and magnetite and generally tends to become enriched in the magma with progressive fractional crystallization. However, Ti easily forms the mineral, ilmenite, when its concentration in the magma is sufficiently high. The observed pattern is therefore one of steady enrichment, culminating in the precipitation of ilmenite and thereafter a gradual decrease in TiO_2. A similar concentration in P_2O_5 probably results in the abundant apatite forming. Irvine (1973) has pointed out that a contamination mechanism can produce concentrated deposits of magnetite, sulfides, chromite and other magmatic ores. For chromite he proposes that the addition of siliceous material to the liquids on the olivine - chromite cotectic will tend to shift their compositions into the chromite primary phase field, giving large concentrations of chromite similar to that seen in the Merensky Reef of the Bushveld. From the SiO_2 vs. height variation diagram, (see Fig. 23a), it can be seen that the SiO_2 content within the pyroxenitic phase abruptly changed direction from a negative to a positive slope and could be the type of contamination Irvine refers to. A check for chromite would be valuable and should be done at some future time. Thus the mechanism resulting in the formation of the pyroxenitic phase is a process allowing for the voluminous precipitation of pyroxene and enrichment of TiO_2, P_2O_5 and FeO resulting in the crystallization of unusual amounts of ilmenite, apatite and magnetite.

Subsequent cooling of the magma produces the final phase. This coarse grained rock is typical of many intrusions. It generally has its base near the middle of the intrusion and top at the base of the upper chill zone. Like the pegmatite of the Keweenawan lavas (Cornwall, 1951), the zone has low magnesia and alumina but relatively high FeO, P_2O_5, TiO_2, Na_2O and K_2O. Ridler (1966) regards the pegmatitic schlieren of the Kakagi Lake Sills as representing the segregation of volatile-rich interprecipitating fluids. Walker (1953) in his discussion of pegmatitic differentiates describes them petrographically as having long bladed pyroxenes that show marked curvature, and idiomorphic laths of plagioclase that are graphically intergrown with quartz. All these features are found in the pegmatitic phase, (Chapter III). As shown on the AFM plot, iron enrichment reaches its maximum in this phase. The high percentage of K_2O in this phase is represented by potassium feldspar, which is myrmekitically and graphically intergrown with quartz. These type of intergrowths are typical of granophyric differentiates near tops of intrusions Hotz (1953), and point to the fact that the pegmatitic phase is the final one.

The top contact of this layer is gradational with the bottom of the upper chilled margin of the sill. However it has a high modal abundance of calcite suggesting either the concentration of volatiles near the top or later metamorphism. Volatile streaming or percolation of volatiles upward in general is taken to indicate the proximity to an original roof (Ridler, 1966; Bridgewater, 1970 Hyndman, 1972). General upward trends in the oxides and minerals are reversed, that is increased MgO, CaO, and a decrease in FeO and SiO_2. This may be the result of initial cooling from the roof reflecting basal trends. The upper zone is fragmental in nature. All constituents, primary and secondary, show brecciation. This suggests post crystallization deformation. The simple folding of the area, with a synclinal axis running parallel and just to the south of the intrusion suggests that the shearing is related and/or restricted to axial plane shearing of the fold.

v) Summary

The Gabbro Lake Sill was injected into a mafic volcanic pile, basaltic in composition and subsequently underwent fractional crystallization and differentiation. It exhibits gross phase layering parallel to the walls of the intrusion and is analogous in many aspects to other intrusions.

The sequence of events that produced these features was:

1. intrusion of an olivine tholeiitic magma
2. rapid cooling of both margins
3. initial accumulation of a diabasic phase on top of a chilled floor
4. gravity settling of early formed dense olivine crystals resulting in an accumulation of an olivine rich troctolitic leucogabbro phase
5. a process (contamination, supersaturation etc.) that produced a magma rich in TiO_2, FeO and P_2O_5 and resulted in the crystallization of a pyroxene rich layer with relatively high abundances of ilmenite, magnetite and apatite.
6. continued cooling and crystallization with iron enrichment of the magma resulting in the formation of a coarse grained pegmatitic phase
7. no silica enrichment upwards until the final interstitial granophyric association in the pegmatitic phase
8. volatile streaming and the resulting concentration of carbonate near the top of the sill
9. metamorphism; uralitization and saussuritization
10. subsequent folding and axial plane shearing of the syncline affecting the upper layer(s) of the sill.

REFERENCES

Abbey, S. (1973). Studies on Standard Samples of Silicate Rocks and Minerals Part 3: Extension and Revision of Usable Values. G.S.C. Paper 73 - 36.

Bhattacharji, S. (1964). Flowage Differentiation. Science, 145, pp. 150 - 153.

Blackburn, C. E. (1975). Boyer Lake Area, District of Kenora, Ontario Division of Mines, Preliminary Map, scale 1 inch to $\frac{1}{4}$ mile.

Bridgwater, D. (1969). The role of stoping in the enplacement of the giant dykes of Isortoq, South Greenland, in Mechanisms of Igneous Intrusions, pp. 67 - 77.

Brown, G. C., Hughes, D. J. and Esson, J. (1973). New X.R.F. Data Retrieval Techniques and Their Application to U.S.G.S. Standard Rocks. Chemical Geology, Vol. 11, pp. 223 - 229.

Carmichael, I. S., Turner, F. J. and Verhoogen, J. (1974). Igneous Petrology. McGraw-Hill, New York.

Cornwall, H. R. (1951). Differentiation in Lavas of the Keweenawan Series and the Origin of the Copper Deposits of Michigan. G. S. A., Bull., vol. 62, pp. 159 - 202.

Donchin, R. V. and Ferguson, J. (1970). The Geochemistry of the Losberg Intrusion, Fochville, Transvaal, in Symposium on the Bushveld, pp. 689 - 714.

Fahrig, W. F. (1962). Petrology and Geochemistry of the Griffis Lake Intrusive Body, Ontario, Canada. U.G.S.A., Bull., vol. 68, pp. 1531 - 1564.

Goodwin, A. M. (1972). The Superior Province, in Variations in Tectonic Styles in Canada. G.S.C. Special Paper, No. 11, pp. 528 - 623.

Grobler, N. J. and Whitfield, G. G. (1970). The olivine-apatite magnetitites and related rocks in the Villa Nora occurrence of the Bushveld Igneous Complex, in Symposium on the Bushveld, pp. 208 - 227.

Hess, H. H. (1960). Stillwater Igneous Complex, Montana. G.S.A. Mem. #80.

Hotz, P. E. (1953). Petrology of a gronophyre in diabase near Dillsburg, Penn. G.S.A. Bull., vol. 64, pp. 675 - 704.

Hurst, M. E. (1932). Geology of the Sioux Lookout Area. O.D.M. Annual Report, vol. XLI, pt. 6.

Hyndman, D. W. (1972). Petrology of Igneous and Metamorphic Rocks. McGraw-Hill, New York.

Irvine, T. N. (1970). Crystallization sequences in the Muskox Intrusion and other layered intrusions, in Symposium on the Bushveld, pp. 441 - 476.

Irvine, T. N. (1973). Simple and Multiple Oxides in Magmatic Rock Systems. Carnegie Institute Geophysical Laboratory, 1973 - 74, pp. 300 - 316.

Irvine, T. N. and Baragar, W. R. A. (1971). A Guide to the Chemical Classification of the Common Volvanic Rocks. C.J.E.S., vol. 8, pp. 523 - 548.

Kerr, P. G. (1959). Optical Mineralogy, 3rd Edition. McGraw-Hill, New York.

Marchand, M. (1973). Determination of Rb, Sr and Rb/Sr by X.R.F. Tech. Memo 73 - 2, Dept. of Geology, McMaster University, Hamilton, Ontario, Canada.

Newell, G. and Rast, N. editors (1970). Mechanisms of Igneous Intrusions. Liverpool Letterpress Ltd., Liverpool.

Ridler, R. H. (1966). Petrographic Study of a Crow Lake Ultrabasic Sill, Keewatin Volcanic Belt, Northwestern Ontario. Unpub. M.Sc. thesis, Univ. of Toronto, Ontario.

Simpson, E. S. W. (1954). On the Graphical Representation of Differentiation Trends in Igneous Rocks. Geol. Mag. 91, pp. 238 - 244.

Thomson, J. E. (1934). Geology of the Manitou-Stormy Lakes Area. O.D.M. Annual Report, vol. LXII, part IV, pp. 1 - 40.

Turner, F. J. and Verhoogen, J. (1960). Igneous and Metamorphic Petrology. McGraw-Hill, New York.

Upton, B. G. J. and Woodsworth, W. J. (1969). Intra-volcanic intrusions of Reunion in Mechanisms of Igneous Intrusions, pp. 141 - 156.

Visser, D. J. L. and Van Grwenewaldt, G. editors (1970). Symposium on the Bushveld Igneous Complex and other Layered Intrusions. G.S. South Africa, Spec. Pub. #1, 763 p.

Wager, L. R. and Brown, G. M. (1967). Layered Igneous Rocks. W. H. Freeman and Co., San Francisco, 588 p.

Walker, F. (1940). Differentiation of the Palisade Diabase, New Jersey. G.S.A. Bull., vol. 51, pp. 1059 - 1106.

Walker, F. (1953). The Pegmatitic Differentiation of Basic Sheets. Am. Jour. of Science, vol. 251, pp. 41 - 60.

Williams, H., Turner, F. J. and Gilbert, C. M. (1954). Petrography, An Introduction to the Study of Rocks in Thin Sections. W. H. Freeman and Co., San Francisco.

Winkler, H. G. F. (1974). Petrogenesis of Metamorphic Rocks. 3rd Ed., Springer-Verlag, New York.

Wyllie, P. J. editor (1967). Ultramafic and Related Rocks. Wiley, New York.

Yoder, H. S. and Tilley, C. E. (1962). Origin of basalt magmas: an experimental study of natural and synthetic rock systems. Jour. Petrology, vol. 3, pp. 342 - 532.

Zoltai, S. C. (1961). Glacial History of Part of N.W. Ontario. Proc. G.S.C., vol. 13, pp. 61 - 83.

APPENDIX A

PETROGRAPHIC DESCRIPTIONS

AND

SKETCHES

Appendix A

Accuracy of the Results

Modal abundances were based on five hundred point counts per section. It was found that by tabulating the percentages of components after a series of one hundred counts, that the average of five hundred counts gave reliable data. The following example exemplifies this point.

Sample 1046-1

Run	Sauss.* Plag.	Ural. Py.	Carb.	Matrix	No. Counts
1	68	29	1	2	100
2	136	56	5	3	200
Av.	68	28	4.5	1.5	
3	203	88	6	3	300
Av.	67.6	29.3	2.0	1.0	
4	271	117	8	4	400
Av.	67.5	29.2	2.0	1.0	
5	338	144	12	6	500
Av.	67.6	28.8	2.5	1.2	
Error	±1%	±1%	±2%	±1%	

* In making the point counts, the author attempted to approximate the original mineralogy.

MODAL ABUNDANCES

Average Modes for each Unit

Zone	Sample No.	Sauss. Plag.	Ural. Pyrox.	Qtz.	Carb.	K-spar	Opaques	Olivine	Chlorite	Matrix
	C-46	21		2	15		3	6		52
Basalt	C-48	18		10	14		12	1		45
	Av.	20		6	15		7	3		49
Chilled	C-50	34	56	3			2			5
Margin	C-52	41	14	4	26		4			11
Gabbro	C-54	42	19	11	13		11			5
	Av.	39	27	6	13		6			7
Diabasic	1041-2	46	39		3		7			3
Gabbro	M-79	44	46		2		3			5
	M-93	41	45	2			3		3	3
	1037-1	50	43				5			2
	Av.	45	43	tr.	1		5		1	3
Leucocratic	3060-1	65	19	7	3		6			
Gabbro	M-29	65	20	2			3	10		
	1046-1	68	19		3			10		1
	Av.	66	19	3	2		3	7		tr.
Pyroxanitic	1107-2		61	2	2	2	4			29
Gabbro	1106-1	5	59	2	4	3	7			19
	Av.	2	60	2	3	2	5			24
Pegmatitic	G-220	39	29	26			6			2
Gabbro	M-1040	37	31	14			6			12
	M-98	35	28	11	2		7		7	10
	Av.	37	29	17	1		6		2	8
Sheared	M-100	6	7	17	39		4			26
Gabbro	M-103	6	8	14	45		3			24
	Av.	6	7	16	42		3			25

Sample: C-50 ODM Coordinates: 11150 Easting
82600 Northing

Classification: Chilled Margin Gabbro

Modal Abundances: Uralitized Pyroxene 56%
Saussuritized Plagioclase 34%
Matrix 5%
Quartz 3%
Opaques 2%

Textures:

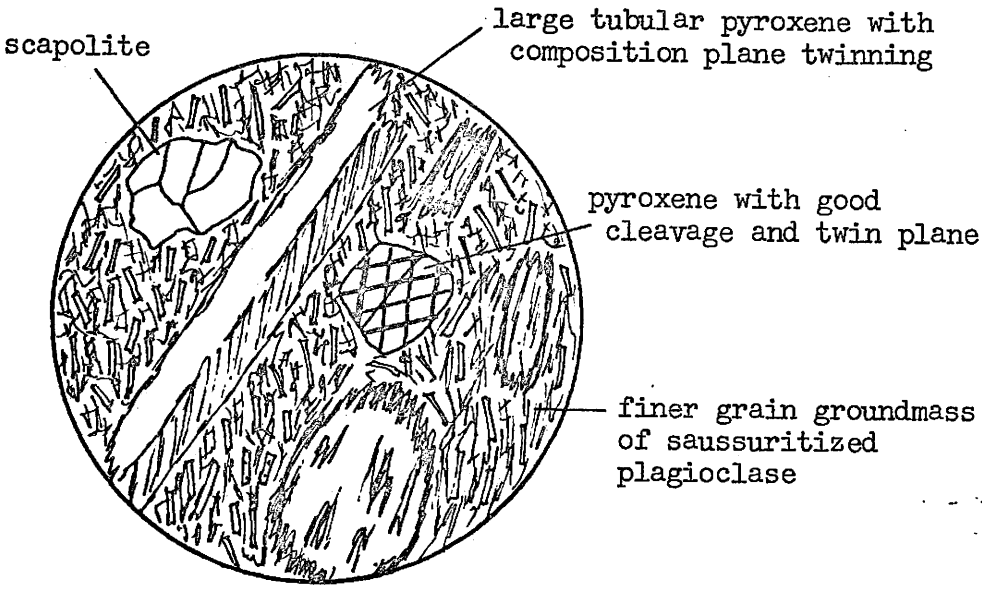
This section of medium to fine grain gabbro has no carbonate in it. It has a high percentage of uralitized pyroxene that surrounds a polygonized mass of clinozoisite that seems to be an alteration product of the plagioclase.

The pyroxene displays twinning with [100] as the twin-plane, and the actinolite amphibole alteration product is poorly terminated with very ragged ends. Actinolite in diamond-shaped cross-sections with good amphibole cleavage, also replaces the pyroxene. Maximum grain size is 0.5 mm.

Interstitial to the pyroxene lies the saussuritized product of the plagioclase. The gray mass consists of idiomorphic granular grains of clinozoisite. No relict twins or grain boundaries of the laths remain. Scapolite occurs in trace amounts. It has high birefringence, gives a uniaxial negative figure and is not cleaved.

It characteristically is a high temperature alteration product of plagioclase.

The matrix is made up of fine grain feldspar, quartz, actinolite and irregular masses of leucoxene.



Cross Nicols
Diameter 2 mm

Sample C-50

Sample: C-52 ODM Coordinates: 11150 Easting

82600 Northing

Classification: Chilled Margin Gabbro

Modal Abundances: Saussuritized Plagioclase 41%

Carbonate 76%

Uralitized Pyroxene 14%

Matrix 11%

Quartz 4%

Opaques 4%

Textures:

This slide is comprised of fine grained altered crystals of plagioclase and pyroxene in a very fine grained aphanitic matrix. Carbonate occurs as hypidiomorphic crystals disseminated throughout the slide. These textures are typical of a chilled intrusive margin.

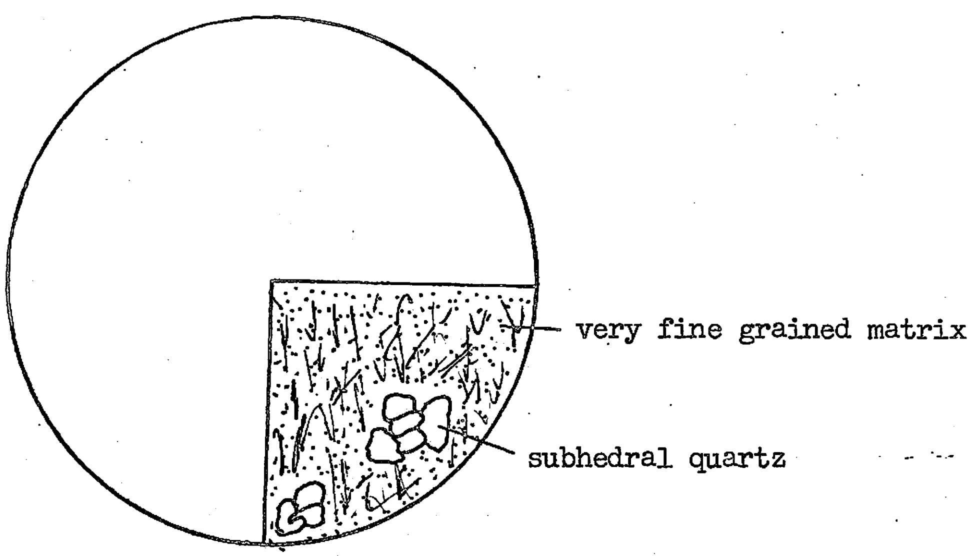
The plagioclase laths are very indistinct, with a maximum grain size of 2 mm. The plagioclase has been totally resorbed and saussuritized giving it a groundmass type appearance, only one remnant twin was seen.

The high carbonate content, typical of both margins of the intrusive body, is less abundant in the chilled zone. It occurs as subhedral crystals with no visible cleavage. It forms at the expense of both plagioclase and pyroxene. Carbonate also occurs in small veins that cut across the section.

The pyroxene shows alteration to chlorite and amphibole. Dark blue penninite and light green actinolite grow on the irregular grains of pyroxene. The pyroxenes are found interstitial to the plagioclase and are fine grained, less than 1 mm in size.

Quartz occurs as small allotriomorphic grains that are shattered and broken. Quartz also occurs as a matrix mineral. The matrix is hypocrystalline with fine grained pieces of broken pyroxene and plagioclase and very small crystals of calcite and quartz. The matrix is very fine grained and nearly basaltic in textural nature.

The opaque mineral is an alteration product of ilmenite, leucoxene. It occurs within the matrix and is fine grained.



Plane Light
Diameter 8 mm

Sample C-52

Sample:	C-54	ODM Coordinates:	11150	Easting
			82600	Northing

Classification: Chilled Margin Gabbro

Modal Abundances:
- Saussuritized Plagioclase 42%
- Uralitized Pyroxene 19%
- Carbonate 13%
- Quartz 11%
- Opaques 11%
- Matrix 5%

Textures:

This slide is intensely veined. The veins contain coarse grained minerals while the rest of the section is very fine grained. The carbonate content is high but characteristic of rocks of the chilled margin.

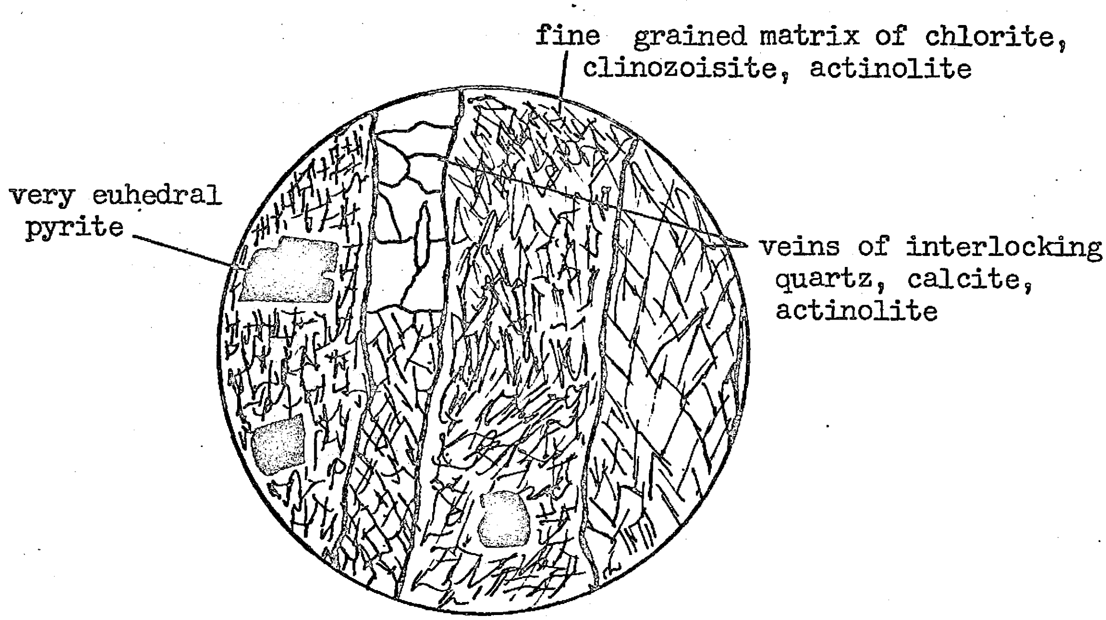
Both plagioclase and pyroxene have altered to 'saussurite' and actinolite respectively. No relict textures are visible in either of the secondary replacement minerals. They both occur as small anhedral grains and as part of the groundmass matrix.

The matrix consists of broken products of plagioclase and pyroxene, quartz, carbonate and opaques. Quartz also occurs as small grains, of 0.5 mm in size, within the matrix and is anhedral.

Euhedral dark brown to black pyrite with sharp boundaries, along with fine grain leucoxene, is desseminated throughout the slide.

Chloritic alteration affects about half of the section.

The vein material consists of large grains of quartz, carbonate, actinolite and pyroxene. Quartz grains up to 3 mm in size, actinolite needles 2 mm long, euhedral 1 mm carbonate crystals and pyroxene grains 2 mm in diameter are found in an interlocking configuration in the veins. The grains are anhedral and may be shattered parent rock that has been recrystallized.



Cross Nicols
Diameter 8 mm

Sample C-54

Sample:	1041-2	ODM Coordinates:	03400	Easting
			83450	Northing

Classification: Diabasic Gabbro

Modal Abundances:
- Saussuritized Plagioclase 46%
- Uralitized Pyroxene 39%
- Opaques 7%
- Carbonate 3%
- Matrix 3%

Textures:

This idiomorphic granular gabbro has a diabasic texture. It consists of well crystallized laths of plagioclase that subophitically enclose pseudomorphs of pyroxene.

The plagioclase crystals are poikiloblastic and are sieved by inclusions of the iron-free epidote clinozoisite, carbonate and chlorite. These saussuritized grains are 0.8 mm to 1.4 mm in size and Michel-Levy tests on relict twins give compositions in the range An_{60}-An_{80}, labrodorite to bytownite. These euhedral laths are intimately intergrown and as the degree of saussuritization increases the twins become obliterated.

The pyroxene is irregularly fractured and replaced by fibrous amphibole.

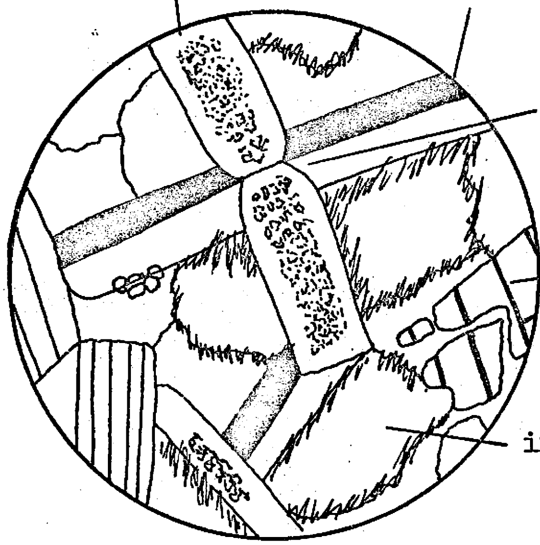
The degree of alteration of the pyroxene is greater than that of the plagioclase. The remnant pyroxene is enclosed by plagioclase laths and is irregularly terminated. The maximum grain size is 2 mm.

Clinozoisite occurs as inclusions in the plagioclase and also is formed at the expense of the plagioclase. Carbonate also occurs as very fine grained inclusions within the feldspar.

The matrix consists of fine grained fibres of chlorite, carbonate and clinozoisite grains.

The opaque mineral is found as masses 1 mm to 1.5 mm in diameter and has a skeleton of the black oxide, ilmenite. The ilmenite has been altered to a gray-brown leucoxene. The leucoxene occurs as irregular anhedral grains that have been highly fractured.

The entire rock has been chloritized and in some places amphibole alteration occurs as a secondary product. Fibrous actinolite is predominantly found replacing pyroxene but some crystals were seen included in the feldspars.



Cross Nicols
Diameter 4 mm

Sample 1041-2

Sample: M-79 ODM Coordinates: 04550 Easting

84700 Northing

Classification: Diabasic Gabbro

Modal Abundances: Uralitized Pyroxene 46%

Saussuritized Plagioclase 44%

Matrix 5%

Opaques 3%

Carbonate 2%

Textures:

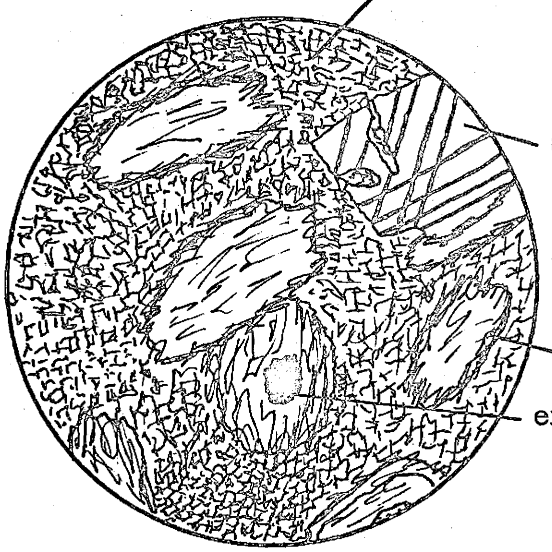
This idiomorphic granular gabbro has altered plagioclase enclosing pyroxene in a subophitic texture. The matrix consists of fine grain antigorite, and the odd patch of fine cryptocrystalline quartz and carbonate. The diabasic texture has been poorly preserved.

The primary pyroxene, which displays twin seams typical of augite, has been eaten up and resorbed. The irregular fractures have been replaced by fibrous pleochroic needles of actinolite. The pyroxene, primarily uralitized by amphibole, may be partially replaced by antigorite. Grains are 0.4 mm to 1 mm in size. Some show weak zoning.

The enclosing plagioclase laths have been replaced completely by polygonized clinozoisite. No relict twins are seen. Carbonate replaces the plagioclase and occurs as random clumps of crystals. The grains are similar in size to pyroxene, 0.5 mm to 1 mm.

A fine grain needle matrix of fibrolomellar antigorite occurs as pseudomorphs after pyroxene. Cryptocrystalline quartz and feldspar are also found in the matrix.

Siderite is the iron rich mineral present. Chlorite alteration has affected a quarter of the section.



Cross Nicols
Diameter 4 mm

Sample M-79

Sample: M-93 ODM Coordinates: 05600 Easting

83650 Northing

Classification: Diabasic Gabbro

Modal Abundances: Uralitized Pyroxene 45%

Saussuritized Plagioclase 41%

Chlorite Pseudomorphs 3%

Matrix 3%

Opaques 3%

Quartz 2%

Textures:

This sample contains altered pyroxene and plagioclase intergrown in a diabasic nature. The entire slide is darke due to iron rich serpentine which may be pseudomorphous after olivine.

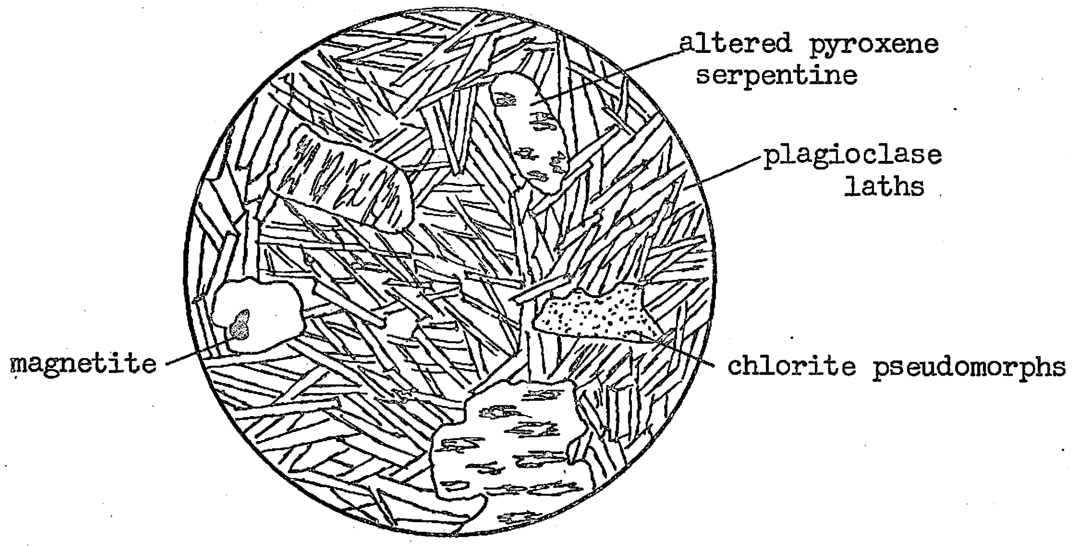
The pyroxene shows replacement to a fibrous amphibole, probably actinolite. These crystals are 1 mm to 2 mm in size and are untwinned. The pyroxene occurs as a interstitial material enclosed by laths of plagioclase. Uralitization of the pyroxene crystals is greater than the saussuritization of the plagioclase crystals.

The plagioclase crystals are saussuritized by clinizoisite. Relict twins, on which Michel-Levy tests could be applied, give compositions in the range An_{54-62}, labradorite. These idiomorphic laths, 1 mm to 2 mm in size, subophitically enclose the pyroxene crystals. Alteration of the plagioclase is less than that of the pyroxene.

Chlorite pseudomorphs and matrix material have formed at the expense of the two primary minerals. Serpentine is found replacing actinolite as well as chlorite.

The gray-brown opaque mineral is siderite. It contains no small carbonate crystals between the definite rectangular cleavage and the partings are not replaced by oxide material.

Equal amounts of olivine and serpentine, approximately thirty percent, is seen. The iron rich serpentine overprint gives it a darker colour in thin section and hand specimen.



Plane Light
Diameter 8 mm

Sample M-93

Sample: 1037-1 ODM Coordinates: 04000 Easting
84700 Northing

Classification: Diabasic Gabbro

Modal Abundances: Saussuritized Plagioclase 50%
Uralitized Pyroxene 43%
Opaques 5%
Matrix 2%

Textures:

This section is composed of equidimensional grains intergrown diabasically. Altered plagioclase subophitically encloses altered pyroxene. This section has no quartz and only minor amounts of matrix and opaques.

The plagioclase crystals are untwinned and saussuritized by clinozoisite. The clinozoisite occurs as small, less than 0.1 mm, euhedral crystals irregularly distributed in the laths. The plagioclase is poorly bounded and the saussurite occurs more as a groundmass. The plagioclase is irregularly fractured and the maximum grain size is 1 mm to 1.5 mm.

The interstitial pyroxene has been replaced by fibrous actinolite. Relict grains of pyroxene, 0.5 mm to 1 mm in size, also display twinning, typical of the clinopyroxene augite. The borders of the altered pyroxene crystals are jagged as a result of the fibrous amphibole replacement, which occur preferentially along the edges. The actinolite in places has been altered to an epidote mineral, zoisite(?).

The matrix comprises fine grained chlorite, feldspar and clinozoisite. It was hard to distinguish some of the 'saussurite' from the matrix material.

The opaque is dark brown and randomly distributed throughout the slide. It has definite orthogonal cleavage and may be leucoxene or siderite.

Cross Nicols
Diameter 4 mm

Sample 1037-1

Sample:	3060-1	ODM Coordinates:	11250	Easting
			82250	Northing

Classification: Leucocratic Gabbro

Modal Abundances: Saussuritized Plagioclase 65%
Chloritized Pyroxene 19%
Quartz 7.0%
Opaques 6.0%
Carbonate 3.0%

Textures:

This coarsely crystalline leucogabbro is comprised of predominantly euhedral to subhedral plagioclase laths with interstitial chlorite, opaques and chloritized pyroxene grains.

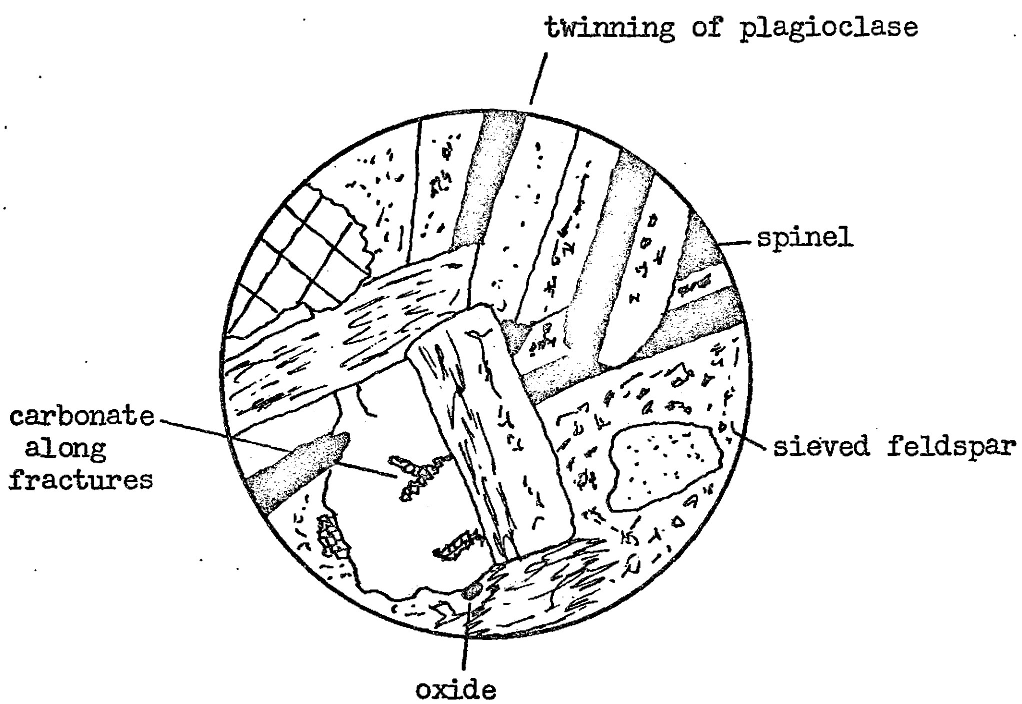
The plagioclase is riddled by inclusions of chlorite and carbonate. The carbonate seems to be an exsolution feature of the plagioclase. The laths are 1 mm to 1.6 mm in size and still show relict twins. Michel-Levy tests suggest that it was labradorite, An_{58-68}. These idiomorphic grains were poorly terminated with sutured ends.

The pyroxene has been altered to chlorite and irregular fractures that cut the grains have been infilled with penninite, distinguished by its anomalous blue interference colour. The grains of pyroxene were very massive, 2 mm to 4 mm in diameter, and have been replaced partially by an opaque mineral, probably pyrite. Relict cleavage, at close to right angles, is typical of pyroxenes.

The quartz is irregularly fractured and occurs as anhedral grains 1 mm to 2 mm in size. They contain few inclusions and do not exhibit undulatory extinction. Carbonate was seen to be exsolving along the fractures in the grains.

Carbonate was found as an exsolved mineral from plagioclase and quartz, and also as an interstitial mineral to plagioclase and chlorite.

Chlorite alteration affects three-quarters of the constituent minerals and occurs as both scaly masses of prochlorite and small euhedral tabular crystals of anomalous blue penninite.



Cross Nicols
Diameter 4 mm

Sample 3060-1

Sample:	M-29	ODM Coordinates	05650	Easting
			83950	Northing

Classification: Leucocratic Gabbro

Modal Abundances:
Saussuritized Plagioclase 65%
Uralitized Pyroxene 20%
Altered Olivine 10%
Opaques 3%
Quartz 2%

Textures:

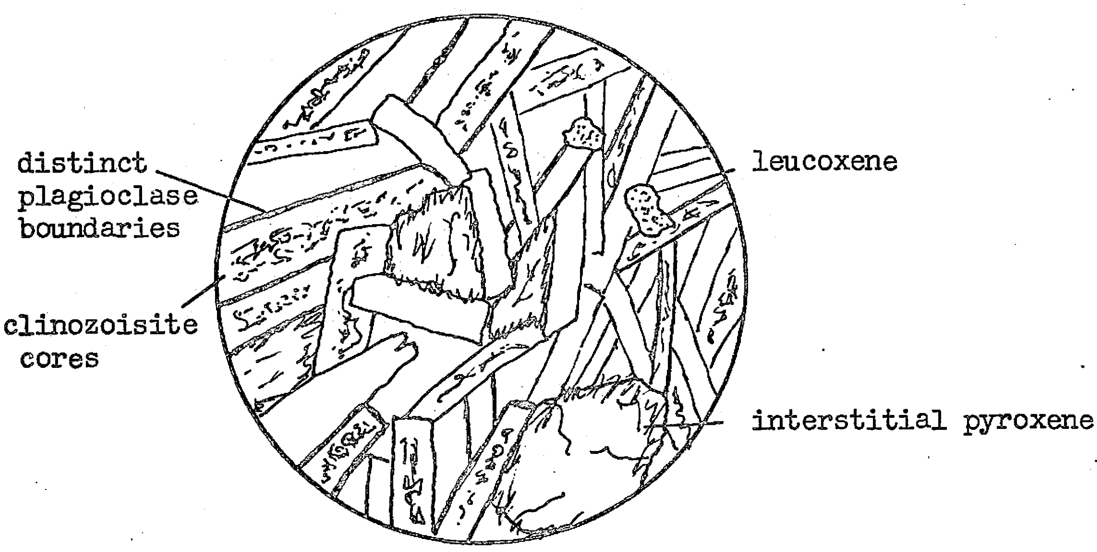
This section is typical of the leucocratic gabbros. It has a high percentage of altered plagioclase and minor amounts of altered pyroxene and olivine.

The plagioclase laths still exhibit relict twins, but these could not be used to determine the original An content. The plagioclase is eaten internally and replaced by clinozoisite polygons, with minor inclusions of chlorite, quartz and carbonate (?). The edges are very distinct; saussuritization has had its greatest affect on the centres of the crystals. The grains are 1 mm to 2 mm in size.

Olivine occurs as phenocrysts that are irregularly fractured and pseudomorphed by pyroxene. No unaltered crystals of olivine are present.

The pyroxenes are subophitic, found between plagioclase laths. Remnant twins from clinopyroxene still persist. The pyroxene has been resorbed and the lath like tabular crystals, replaced by amphibole, are poorly terminated with comb-like ends. These laths are 1 mm to 2 mm in size. Larger phenocrysts, pseudomorphous after olivine are 2 mm to 2.5 mm in size.

Quartz occurs as small anhedral grains with very sharp boundaries. Chlorite occurs as aggregates replacing thirty-five percent of the slide. The opaque mineral is brownish-gray and probably leucoxene.



Cross Nicols
Diameter 4 mm

Sample M-29

Sample: 1046-1 ODM Coordinates: 05650 Easting

83900 Northing

Classification: Leucocratic Gabbro

Modal Abundances: Saussuritized Plagioclase 68%

Uralitized Pyroxene 19%

Altered Olivine 10%

Carbonate 3%

Matrix 1%

Textures:

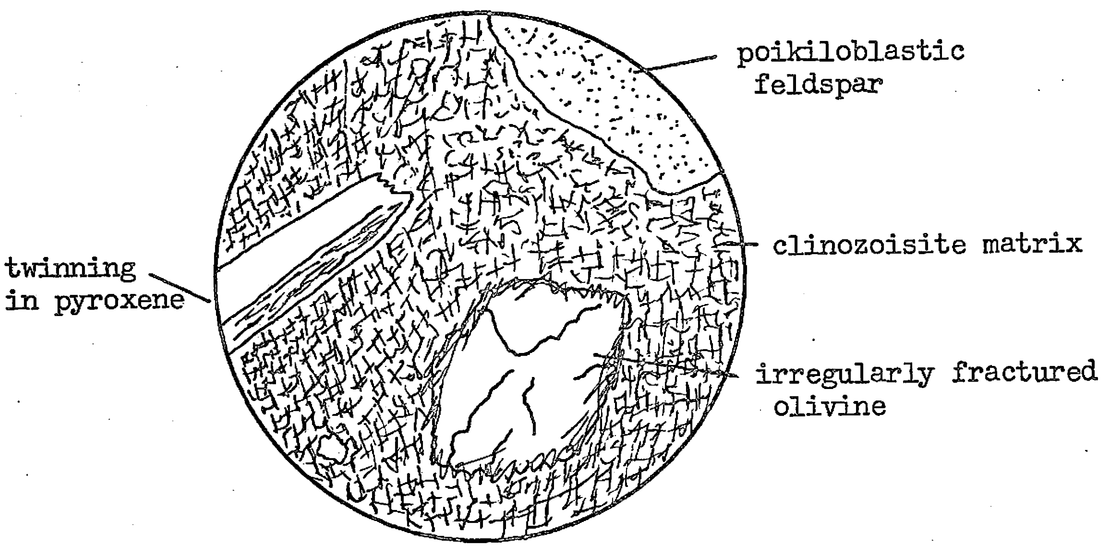
This medium grained leucocratic gabbro consists of a subophitic intergrowth of latered plagioclase and pyroxene with a minor carbonate and chloritic matrix.

The plagioclase is poikiloblastic with almost complete saussuritization to clinozoisite. One or two albite twins have been seen, but in general they have been resorbed. This altered plagioclase makes up most of the groundmass of the slide. Boundaries between individual laths are observed; thus crystals seemed to merge into each other. Measurements were rather inexact, with maximum grain sizes of 1 mm to 1.5 mm.

Good relict porphyroblasts of pyroxene, pseudomorphic after olivine, 1 mm to 2.5 mm in diameter are common. These are irregularly fractured and the rims show the greatest amount of uralitization. Other pyroxenes occur as prismatic crystals that exhibit good twins. These poorly terminated tabular crystals are replaced by actinolite and grain sizes were 0.5 mm to 1 mm.

The carbonate occurs as irregular masses and is found in association with polygonized clinozoisite grains.

No quartz was seen in this specimen. The matrix is made of fibrous acicular crystals of chlorite, minor apatite and sphere.



Cross Nicols
Diameter 4 mm

Sample 1046-1

Sample:	1107-2	ODM Coordinates:	97600	Easting
			83200	Northing

Classification: Pyroxenitic Gabbro

Modal Abundances:
Uralitized Pyroxene 61%
Matrix 29%
Opaques 4%
Quartz 2%
K-spar 2%
Carbonate 2%

Textures:

This fine grained pyroxene rich gabbro consists mainly of uralitized pyroxene and matrix.

The pyroxene displays good relict cleavage at 89° and 91°. It is irregularly fractured and along these fractures and the edges of the crystals, amphibole replaces the pyroxene. The amphibole is prismatic to fibrous actinolite. In some crystals the pyroxene is zoned with a calcium rich core of green diopside.

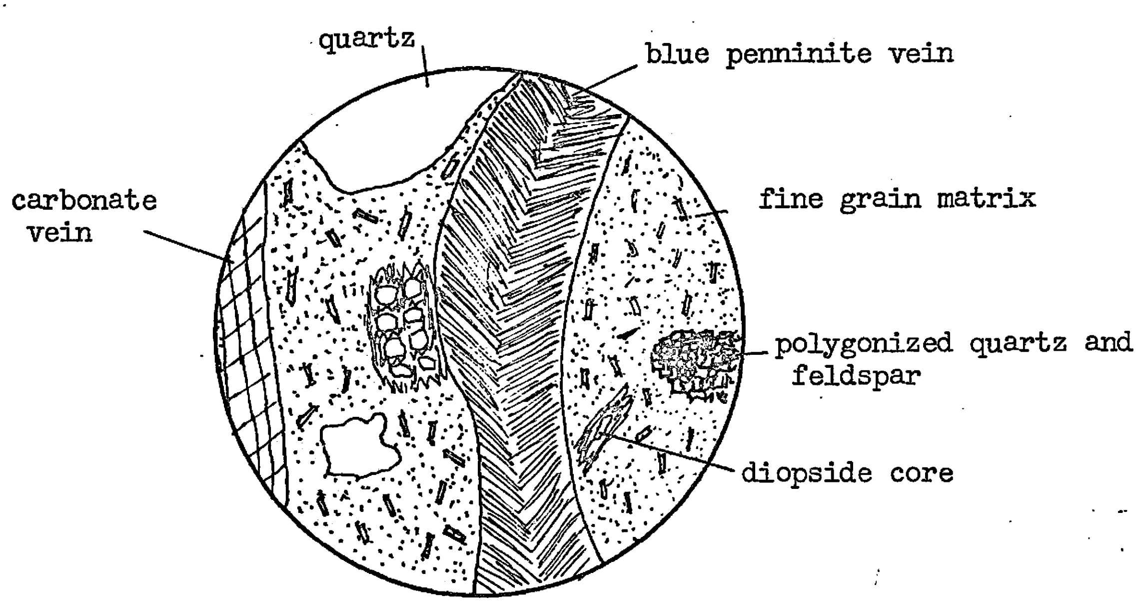
The matrix consists predominantly of fine grain chlorite, carbonate, opaques and possibly plagioclase and quartz. The matrix is aphanitic with some larger phenocrysts of feldspar and cross-sections of actinolite irregularly dispersed. Irregular patches of polygonized quartz and feldspar also occur in the matrix.

Two types of feldspar are prevalent. Plagioclase phenocrysts of a maximum grain size of 1.8 mm but characteristically much smaller, less than 0.1 mm, are saussuritized so that the weak twins are useless for Michel-Levy tests. Some of the feldspars exhibit normal zoning with calcium rich cores. Most of the plagioclase is included as matrix material. The orthoclase is slightly sieved and is subhedral to anhedral in form.

Carbonate is a very minor constituent, and is produced during saussuritization. It also occurs as vein filling material.

Chlorite, with its anomalous blue interference colours, fills fractures and veins. The slide is cut by one distinct seam that is filled by this blue penninite. Chlorite also occurs as a dark black intercumulus matrix material.

The opaque mineral has a black isotropic core with a gray-brown leucoxene (?) overgrowth.



Cross Nicols
Diameter 4 mm

Sample 1107-2

Sample: 1106-1 ODM Coordinates: 98150 Easting
83100 Northing

Classification: Pyroxenitic Gabbro

Modal Abundances: Uralitized Pyroxene 59%
Matrix 19%
Opaques 7%
Feldspar Plagioclase 5%
K-spar 3%
Carbonate 4%
Quartz 2%

Textures:

This section is comprised of uralitized crystals of pyroxene in a medium to fine grain matrix of feldspars, carbonate and quartz.

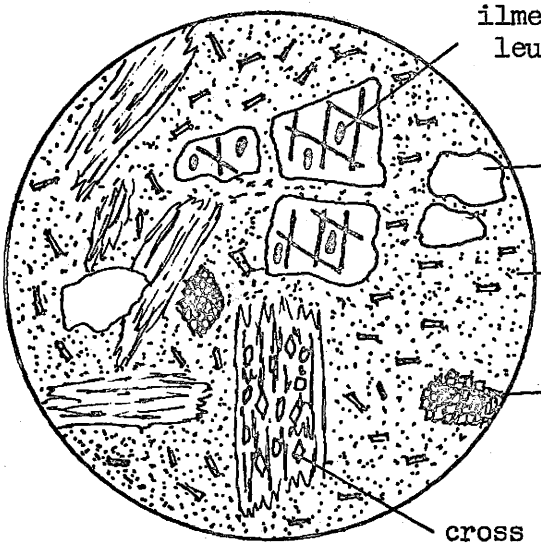
The pyroxene has been altered to chlorite followed by later amphibole growth along cleavage and fracture surfaces. More than one period of growth may be evident in that some long prisms of actinolite are seen to intersect each other at right angles. Diamond-shaped cross-sections of actinolite are common, many being deformed and stretched. The grains were 1 mm to 2.5 mm in size.

The matrix consists of quartz, carbonate and feldspars. Saussuritized plagioclase, having no relict twins, is fine grained and has been found with the matrix. The matrix has been altered to chlorite. Patches of fine grained polygonized feldspar and quartz are found throughout the slide, forming around feldspar crystals and along fractures.

Both orthoclase and quartz occur as large, 1 mm to 2 mm, anhedral grains. The orthoclase is sieved slightly.

Carbonate exsolved from plagioclase and also is seen as veinlets introduced as carbonate-oxide pseudomorphs.

The brown stained, transluscent to opaque mineral exhibits definite orthogonal cleavage. Blebs of black oxide occur within it. Between the cleavage traces fine euhedral crystals of carbonate are visible. This mineral may be siderite.



Cross Nicols
Diameter 4 mm

Sample 1106-1

Sample: M-1040 ODM Coordinates: 03300 Easting
83600 Northing

Classification: Pegmatitic Gabbro

Modal Abundances: Saussuritized Plagioclase 37%
Uralitized Pyroxene 31%
Quartz 14%
Matrix 12%
Opaques 6%

Textures:

This section is very coarse grained and contains approximately equal amounts of altered plagioclase and pyroxene with a relatively large amount of quartz.

The plagioclase has been saussuritized and replaced by idiomorphic cubes and polygons of clinozoisite. Some relict twins are still visible but no twin tests could be applied. Grains are 2mm to 4 mm in size. The grain boundaries are poorly preserved and not always apparent.

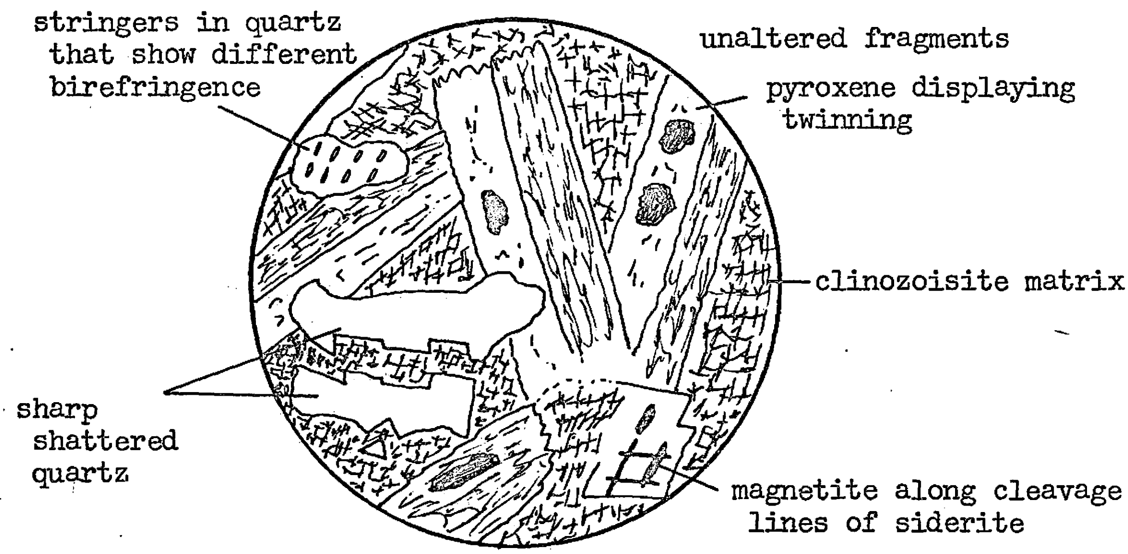
The pyroxene exhibits definite twin seams indicative of augite. However the tabular crystals have been totally resorbed and altered to chlorite, biotite and amphibole. Actinolite, seen in diamond-shaped cross-sections, has partially replaced the chloritized pyroxene. The columnar crystals are very large, 2 mm to 4 mm in size and help to give this rock its pegmatitic nature.

The quartz also is very coarse grained with hypidiomorphic to allotriomorphic crystals, 2 mm in size. The quartz is surrounded by chlorite and contains inclusion of chlorite. The quartz is irregularly fractured, and these fractures are filled with fine grained clinozoisite. Exsolution within the quartz is visible. Stringers of lenses or pods that show different birefringence, and display a weak but visible planar alighment are found in some quartz crystals. The quartz has been shattered and broken crystals show sharp breakage surfaces. Fine grained quartz and clinozoisite fill the zone of separation between fragments. The sharpness of the break has been preserved; if rejoined the crystal fragments would interlock almost perfectly.

Bluish penninite occurs as pseudomorphs and as cavity filling material. The franoblastic matrix consists of plagioclase, quartz, clinozoisite and carbonate.

The translucent mineral is siderite. It has perfect rhombohedral cleavage, and the entire crystal has a rough hexagonal form. It is highly altered and a definite magnetite association along the cleavage partings is seen.

Chloritic alteration affects one-quarter of the section and serpentine rosettes are found irregularly dispersed in the slide.



Cross Nicols
Diameter 4 mm

Sample M-1040

Sample: M-98 ODM Coordinates 07000 Easting
83000 Northing

Classification: Pegmatitic Gabbro

Modal Abundances: Saussuritized Plagioclase 35%
Uralitized Pyroxene 28%
Matrix 10%
Quartz 11%
Opaques 7%
Carbonate 2%
Chlorite Pseudomorphs 7%

Textures:

This section is very coarse grained with equal amounts of altered plagioclase and pyroxene. Grain sizes 4 mm to 5 mm are common and account for the pegmatitic classification.

The plagioclase exhibits relict twins and has been replaced by euhedral grains of chlinozoisite and carbonate. Grains are smaller than the pyroxenes, 2 mm to 2.5 mm in size.

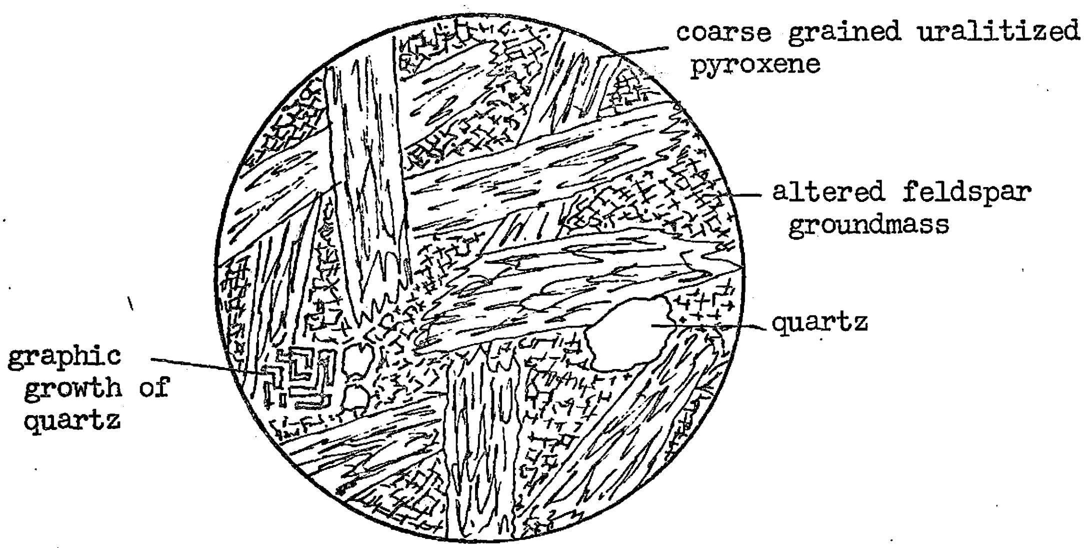
The pyroxene occurs as phenocrysts, 2 mm to 5mm in diameter. The pyroxene has been replaced by actinolite. This amphibole is fibrous and crystals are poorly terminated. Twin seams, a relict texture from the clinopyroxene, are preserved in the uralitized pyroxene.

The quartz occurs in two forms. The first is as an interstitial mineral to the plagioclase laths. These grains, 1 mm to 1.5 mm in length are irregularly fractured and shattered. The breaks are very angular and well preserved. The voids between shattered sections are filled by chlorite and clinozoisite. Quartz also occurs graphically intergrown with feldspar. The quartz grains are very regular and cuneiform in character.

Carbonate rims the tabular actinolite crystals replacing chlorite and is also found as inclusions within the actinolite.

Serpentine, three to five percent in abundance, occurs as irregular flakes. Chlorite alters over a quarter of the slide.

The opaque mineral is a iron-carbonate, probably siderite. It has good rhombohedral cleavage and a rough hexagonal form.



Cross Nicols
Diameter 4 mm

Sample M-98

Sample: G-220 ODM Coordinates: 13400 Easting
80650 Northing

Classification: Pegmatitic Gabbro (Granophyric)

Modal Abundances: Saussuratized Plagioclase 39%
Chloritized Pyroxene 29%
Quartz 26%
Opaques 4%
Epidote 2%

Textures:

This section is very coarse grained with chloritized pyroxene grains interstitial to saussuritized plagioclase laths. An iron-rich serpentine overprint gives the rock the dark appearance in the hand specimen.

The idiomorphic laths of plagioclase with a range of 2 mm to 4 mm in size have been replaced and are a cloudy gray in plane light. Relict twins are still seen but no tests could be applied to them. The grain boundaries are well defined.

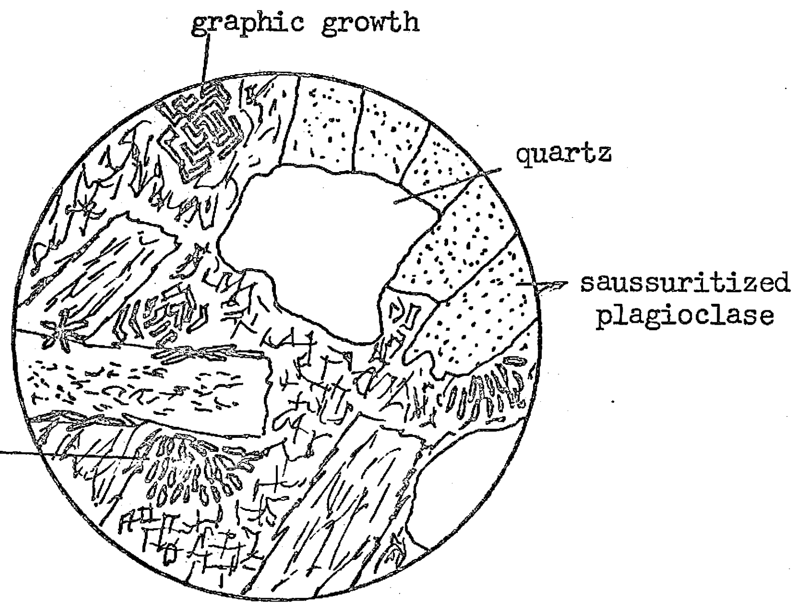
The pyroxene has been completely chloritized, obliterating any relict textures. The chlorite replacement is a fine feathery penninite. The pyroxenes are found interstitial to the plagioclase laths. Grain size determinations were impossible because of the irregular nature of the grains.

The quartz content is very high, over twenty-five percent, and three different types of growth are visible. The most striking is the graphic intergrowth with feldspar. Large anhedral grains seemed to grow within the boundaries of plagioclase laths and display this unique cuneiform texture. Other quartz grains occur as allotriomorphic crystals, 1 mm in diameter, randomly dispersed throughout the slide. They occur in interlocking clusters that had rims replaced by biotite. Deformation may have produced the third type, which has a strong undulatory extinction.

Another striking feature of the rock is the "worm-like" myrmekite intergrowth of feldspar and quartz. This type of growth is typical of late granophyric stages of differentiated intrusions.

The oxide mineral is an alteration product of ilmenite. Leucoxene, with weak cleavage partings, is pseudomorphic after blebs of ilmenite. The iron poor epidote, with high birefringence and upper second order interference colours occurs as fine grain crystals.

Iron rich serpentine gives the hand specimen a dark weathered appearance and has replaced forty percent of the slide.



Cross Nicols
Diameter 8 mm

Sample G-220

Sample: M-103 ODM Coordinates: 05600 Easting
83100 Northing

Classification: Sheared Gabbro

Modal Abundances:
Carbonate 45%
Matrix 24%
Quartz 14%
Uralitized Pyroxene 8%
Saussuritized Plagioclase 6%
Opaques 3%

Textures:

This section is comprised of fine grain carbonate and a fine cryptocrystalline matrix of quartz and feldspar. The hand specimen has been sheared but no tectonic fabric is visible in the thin section.

The feldspar is very fine grained and is replaced both by clinozoisite and by matrix material. No twins or good laths remain from the primary mineral.

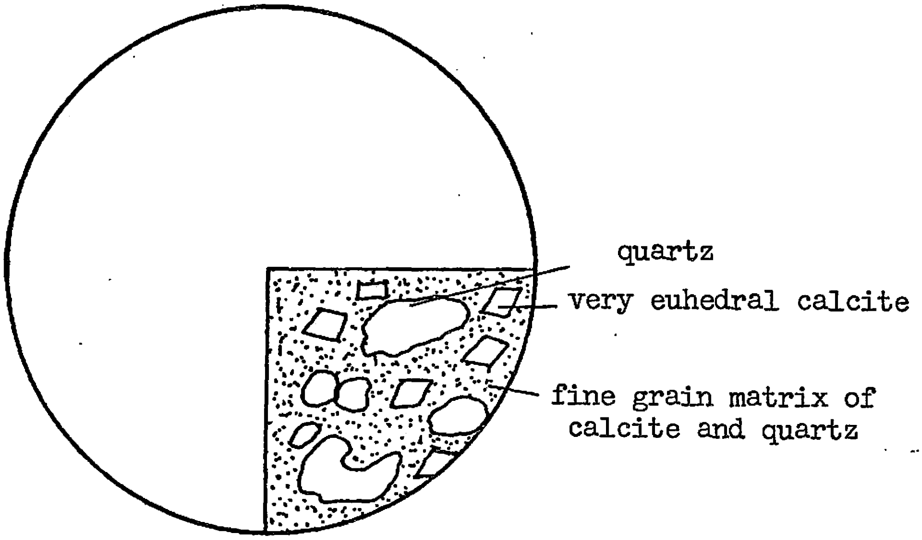
The pyroxene as well, is very fine grained. The actinolite needles are very small and are broken up. This may indicate a period of deformation after metamorphism. Most of the minerals in the section, including pyroxene, seem to be fractured or brecciated.

The carbonate displays good rhombohedral cleavage and good idiomorphic outlines. It is also riddled by inclusions. Carbonate is also found in the matrix.

The matrix is a fine grain aggregation of quartz, feldspar and chlorite. The quartz and feldspar are found graphically intergrown within the matrix.

Rhombohedral cleavage also occurs in the translucent siderite. It too has been broken up.

The fragmental nature of many of the constituents suggests that this rock underwent a period of mechanical deformation after metamorphism. This may have been a weak fault or shear zone.



Plane Light
Diameter 2 mm

Sample M-103

Sample:	M-100	ODM Coordinates:	05650 Easting
			83100 Northing

Classification: Sheared Gabbro

Modal Abundances:

- Carbonate 39%
- Matrix 26%
- Quartz 17%
- Uralitized Pyroxene 7%
- Saussuritized Plagioclase 6%
- Opaques 4%

Textures:

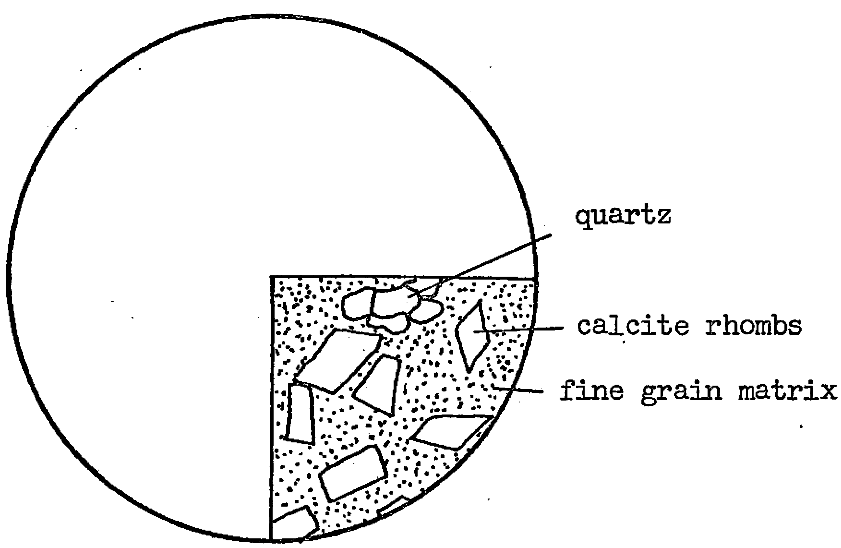
This section is of a fine grained rock with a modest tectonic fabric overprinted on it. Results of minor shearing can be seen in the hand specimen. The extremely high carbonate content and fine grain nature has led to its classification as a sheared gabbro.

The small plagioclase grains are cloudy gray and the relict twins, though visible, have been nearly obliterated by matrix material. Saussuritization is present but minor. Most of the plagioclase has been replaced by fine grain quartz and feldspar.

The pyroxene, also fine grained, and the resulting alteration product, actinolite, occur as very fine needles. Minor chlorite alteration of pyroxene takes the form of fine shards.

By far the most important constituent is the carbonate. Idiomorphic rhombs of calcite with good rhombohedral cleavage are clustered together through the entire slide. The carbonate appeared to have formed at the expense of both plagioclase and pyroxene.

Areas of granular interlocking quartz that are overlain by finer broken quartz fragments, indicate a subsequent period of deformation. The quartz is also graphically intergrown with feldspar. The matrix is dominantly a microcrystalline aggregate of quartz, calcite and feldspar. Siderite is the iron rich mineral present. Chloritization has affected ten percent of the slide.



Plane Light
Diameter 2 mm

Sample M-100

Sample:	C-46	ODM Coordinates:	11150	Easting
			82600	Northing

Classification: Basalt

Modal Abundances:

- Matrix 52%
- Altered Plagioclase 21%
- Carbonate 15%
- Altered Olivine 6%
- Opaques 3%
- Quartz 2%

Textures:

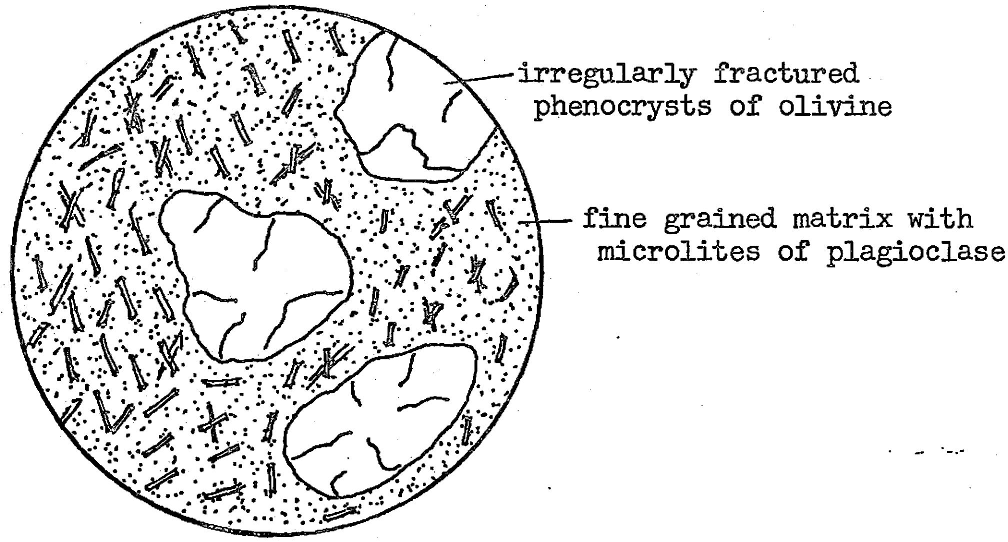
This hypocrystalline assemblage of porphyritic basalt (andesite), contains phenocrysts of olivine in a fine grain devitrified matrix.

The matrix is halohyline in nature. It consists of intergranular leucoxene, ilmenite, chlorite, calcite, feldspar and quartz.

Large porphyroblasts, 3 mm to 4 mm in diameter, of olivine are found in the above matrix. The olivine is irregularly fractured and has been replaced by fibrous actinolite.

Microlites of sericitized or albitized plagioclase, 0.2 mm to 0.3 mm in length are found in the vesicular matrix.

Carbonate occurs as a fine grain alteration product of the plagioclase and olivine (pyroxene).



Plane Light
Diameter 8 mm

Sample C-46

Sample:	C-48	ODM Coordinates:	11150	Easting
			82600	Northing

Classification: Basalt

Modal Abundances:
- Matrix 45%
- Altered Plagioclase 18%
- Carbonate 14%
- Opaques 12%
- Quartz 10%
- Altered Olivine

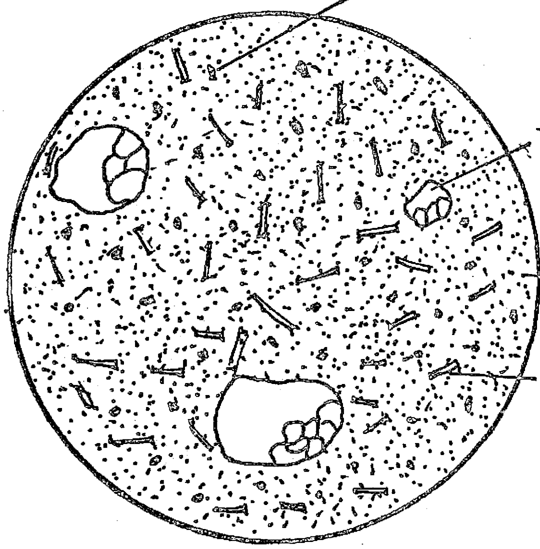
Textures:

This hypocrystalline amygdaloidal basalt contains no large porphyroblasts of relict olivine, but the vesicles have been filled.

The fine black glassy matrix of chlorite, calcite, plagioclase, leucoxene and ilmenite makes up about half of the slide. Small fine grained sericitized microlites of plagioclase are found imbedded in the matrix.

The vesicles have been filled by intergranular quartz of uniform size and extinction.

The fine grained olivine is a very minor constituent of the rock and has been chloritized. Veins of leucoxene are also visible and cut across the sample.



Plane Light
Diameter 8 mm

Sample C-48

Sample:	M-67	ODM Coordinates:	98150	Easting
			83100	Northing

Classification: Gabbro

Modal Abundances:
Uralitized Pyroxene 39%
Saussuritized Plagioclase 27%
Matrix 26%
Opaques 4%
Quartz 3%

Textures:

This rock is comprised of saussuritized plagioclase and uralitized pyroxene in a very fine grained aphanitic matrix. It is dissected by veins and many of the minerals display irregular fractures.

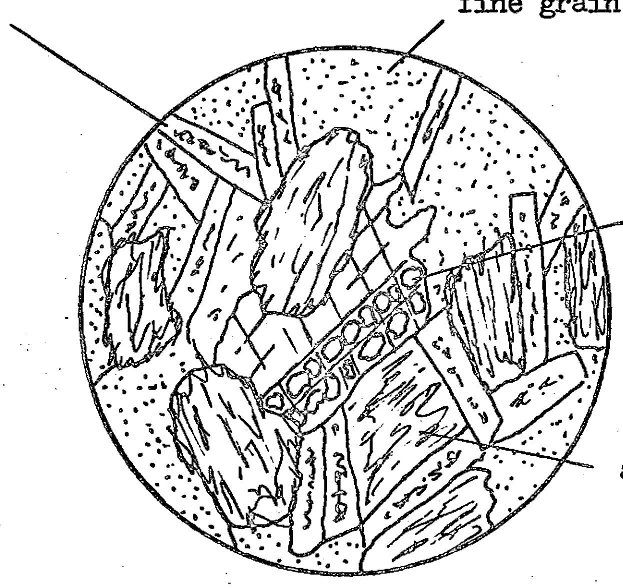
Good orthogonal cleavage in pyroxene is still visible and along with the well preserved twin seams, suggests that it was originally the clinopyroxene augite. Grain sizes range up to 1 mm, but exact lengths are difficult to estimate since the actinolite replacement is fibrous and poorly terminated. Bluish penninite is an alteration product of the pyroxene; serpentine was also found around the peripheries of many pyroxene crystals.

The plagioclase has been completely saussuritized and is difficult to distinguish from the matrix material. No twins are seen. Grain boundaries are few and indistinct making grain size determination impossible.

The matrix consists of microlites of plagioclase and microcrystalline calcite, quartz and clinozoisite. Fine grained patches or lenses of polgonized quartz and feldspar are found interstitial to pyroxene plates. The entire slide has a felty antigorite "coating" or overprint. Antigorite has been found as both an alteration product of the primary pyroxene and the secondary actinolite.

Quartz grains, 0.5 mm in size have been fractured, resorbed and shattered. The fractures are filled by fibrous antigorite. Veins which cut through the slide are filled by antigorite, chlorite and clinozoisite in a textural habit similar to tiger's skin of chalcedony.

The opaque mineral is an iron clouded carbonate, siderite(?) The partings are filled by isotropic pyrite and magnetite(?) Between the partings small loosely packed idiomorphic grains of carbonate are visible and distinct.



Plane Light
Diameter 8 mm

Sample M-67

Sample : M-35 ODM Coordinates 05600 Easting

83250 Northing

Classification: Gabbro

Modal Abundances: Saussuritized Plagioclase 35%

Carbonate 29%

Altered Pyroxene 13%

Matrix 9%

Quartz 9%

Opaques 4%

K-spar 1%

Textures:

This section is comprised of altered plagioclase, carbonate and altered pyroxene intimately intergrown with quartz and a fine grain matrix.

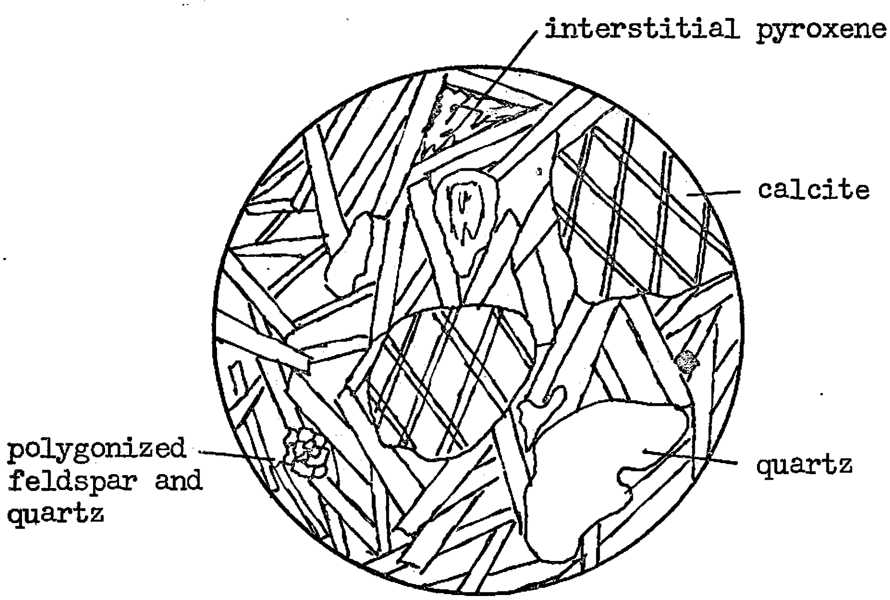
The plagioclase laths have been completely chloritized and replaced by carbonate and chlorite crystals. Relict twins were present but could not be used for a composition determination. Grain sizes range from 0.5 mm to 1 mm.

The carbonate occurs as small fine grain matrix material as well as large irregular crystals. The grain sizes range from 1 mm to 1.5 mm. The larger phenocrysts display good rhombic cleavage and partings typical of calcite. Calcite was also seen as vein material. The veins are composed of equant grains of fine carbonate. Carbonate is also found as an alteration product of the pyroxenes, fitting in irregular fractures in the pyroxene crystals.

The pyroxene has been chloritized but no amphibole alteration is present. The pyroxene grains are interstitial to the plagioclase laths. These grains are subhedral and dissected by irregular fractures filled by calcite.

The matrix consists of fine grain quartz, carbonate, feldspar and chlorite. The quartz exhibits graphic intergrowth with calcite and saussuritized plagioclase. Both microlitic plagioclase and K-spar are present in the matrix. In some instances the quartz grains has sizes of 1.0 mm to 1.5 mm and the K-spar, 1 mm.

The opaque isotropic mineral is probably pyrite.



Plane Light
Diameter 8 mm

Sample M-35

Sample: 3073-2 ODM Coordinates 10300 Easting
89200 Northing

Classification: Leucocratic Gabbro

Modal Abundances: Saussuritized Plagioclase 71%
Altered Pyroxene 20%
Quartz 4%
Opaques 3%
Matrix 2%

Textures:

This medium crystalline leucogabbro is comprised of hypidiomor crystals of plagioclase with interstitial chlorite, pyroxene and matrix.

The feldspar occurs in two forms. Relict plagioclase laths have been saussuritized and replaced by clinozoisite. These feldspars 1 mm to 1.5 mm in length, exhibit undulatory extinction indicating that they have suffered a period of deformation. Feldspar also occurs as recrystallized or polygonized grains along with quartz. They occur in pods and lenses.

The opaque minerals have exsolved from amphibolized pyroxenes along cleavage and fractures and form pseudomorphs of the now obliterated crystals.

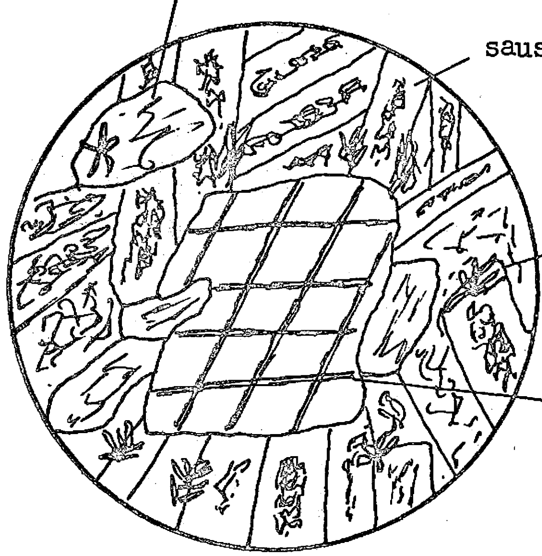
Quartz occurs as irregular grains, 0.2 mm to 0.4 mm in size, and are irregularly fractured and these fractures have been filled with chlorite.

Chlorite occurs as acicular platy crystals with undulatory extinction. They may have some relationship with the opaques but mainly are found with the polygonized masses of feldspar and quartz. Anomalous blue penninite also occurs; the primary mineral it alters from could not be distinguished. Chlorite is an alteration product for about 40% of the slide.

Serpentine occurs as matted prisms to aggregates of fibrous rosettes. Most of the serpentine occurs as an alteration of the fine grained feldspathic matrix.

Many holes or vesicles with corroded edges are visible. The oxide present is pyrite.

This section is from the sill on the north short of Boyer Lake.



Cross Nicols
Diameter 4 mm

Sample 3073-2

APPENDIX B

GEOCHEMICAL WHOLE ROCK DATA

Appendix B

i) Precision or Reproducibility

A check was made on the reproducibility of the pellet preparation procedure by running sample 309 in triplicate. The results as seen below are most satisfactory. The error is negligible.

Sample 309

				Average	Error
SiO_2	50.01	50.00	49.86	49.95	±0.06
TiO_2	1.54	1.54	1.55	1.54	-
Al_2O_3	12.91	12.93	12.94	12.93	±0.02
FeO	17.29	17.28	17.44	17.34	±0.11
MnO	0.21	0.21	0.21	0.21	-
MgO	7.23	7.24	7.14	7.20	-
CaO	7.88	7.87	7.94	7.89	±0.04
Na_2O	2.63	2.60	2.61	2.61	±0.02
K_2O	0.28	0.28	0.28	0.28	-
P_2O_5	0.17	0.17	0.17	0.17	-

The internal precision of the XRF unit can be seen by examining the results of the drift monitor (Table III). This sample was run, fourteen times over an eight hour period and the standard deviation from the average in all cases was minimal, and further strengthens the accepted precision of the results.

ii) Accuracy

In the XRF determination of weight percent of the oxides, for everything except Al_2O_3 and MgO, agreement with "accepted values" in standard rocks (Abbey, 1973) is satisfactory, i.e. within 5%. For MgO and Al_2O_3 there is a bias in the programme causing these values to consistently be low by 5 - 8% of the actual value.

TABLE III

WHOLE ROCK ANALYSES

IN

WEIGHT PERCENT OXIDES

CHECK ON ACCURACY OF DRIFT MONITOR (DM)

Sample	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
DM	56.87	15.53	10.84	1.20	4.21	6.65	1.43	1.33	0.28	0.30
	56.95	15.54	10.85	1.22	4.16	6.58	1.45	1.32	0.28	0.30
	56.93	15.59	10.73	1.22	4.16	6.66	1.46	1.32	0.27	0.30
	57.01	15.58	10.73	1.22	4.15	6.61	1.46	1.32	0.28	0.30
	56.99	15.59	10.83	1.20	4.18	6.54	1.44	1.32	0.28	0.30
	56.98	15.57	10.78	1.21	4.17	6.59	1.45	1.32	0.28	0.30
	57.00	15.59	10.77	1.21	4.16	6.59	1.44	1.32	0.28	0.30
	57.01	15.59	10.76	1.22	4.15	6.58	1.45	1.31	0.28	0.29
	57.03	15.60	10.74	1.22	4.15	6.58	1.46	1.32	0.28	0.30
	57.00	15.59	10.75	1.23	4.13	6.61	1.46	1.31	0.28	0.29
	57.05	15.62	10.75	1.23	4.14	6.54	1.46	1.31	0.28	0.30
	56.90	15.60	10.87	1.23	4.19	6.56	1.43	1.33	0.28	0.30
	56.91	15.65	10.81	1.22	4.17	6.60	1.43	1.31	0.28	0.29
	56.84	15.71	10.82	1.23	4.18	6.57	1.43	1.32	0.28	0.30
	56.89	15.68	10.81	1.22	4.18	6.56	1.43	1.32	0.28	0.30
Total 15	854.36	234.03	161.84	18.28	62.18	98.82	24.68	19.78	4.19	4.47
Average	56.95	15.60	10.78	1.22	4.14	6.58	1.44	1.32	0.28	0.29
Standard Deviation	.064	.047	.047	.010	.033	.035	.014	.006	.002	.004

TABLE IV

WHOLE ROCK ANALYSES IN WEIGHT PERCENT OXIDES

Samples	SiO_2	Al_2O_3	Fe_2O_3 (1)	FeO (2)	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Total
Series A												
G-9	49.42	14.47	2.68	13.30	7.64	8.15	2.60	0.42	1.18	0.19	0.10	100.15
G-18	51.58	14.87	2.69	11.85	6.10	7.94	2.56	1.03	1.19	0.19	0.10	100.10
G-37	49.85	13.88	2.71	14.28	7.28	6.03	3.91	0.54	1.21	0.16	0.13	99.98
G-55	48.23	13.16	2.58	11.69	11.14	9.00	2.62	0.15	1.08	0.19	0.12	99.96
G-73	47.31	13.77	2.36	10.59	12.31	10.21	2.19	0.16	0.86	0.18	0.09	100.03
G-102	47.17	12.55	2.22	9.45	14.05	12.12	1.64	0.14	0.72	0.16	0.07	100.29
G-154	49.17	14.62	2.33	9.08	10.57	11.27	1.92	0.31	0.83	0.17	0.09	100.36
G-197	49.64	13.96	2.63	12.60	8.66	7.74	2.94	0.34	1.13	0.20	0.12	99.96
G-220	45.64	12.87	2.86	18.71	6.15	7.52	1.92	0.19	2.36	0.20	0.12	98.54
G-250	50.98	12.24	3.35	15.82	5.18	7.34	2.33	0.27	1.85	0.24	0.23	99.83
G-264	49.25	12.92	3.10	16.38	7.42	6.23	2.62	0.17	1.60	0.25	0.21	100.15
G-309	50.01	12.19	3.04	14.25	7.23	7.88	2.63	0.28	1.54	0.21	0.17	100.15
G-382	48.41	13.27	2.82	13.34	11.47	5.56	1.92	1.25	1.32	0.22	0.16	99.74
G-394	53.07	13.83	2.77	10.30	9.02	5.13	3.39	0.17	1.27	0.24	0.16	99.35
G-410	50.69	13.88	3.00	11.42	9.77	7.11	1.86	0.12	1.50	0.30	0.14	99.79

1 $\%Fe_2O_3 = 1.5 + \%TiO_2$ Irvine + Baragar (1971)

2 $FeO = FeO_{Total} - Fe_2O_3$

Samples	SiO_2	Al_2O_3	Fe_2O_3(1)	FeO(2)	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Total
Series B												
G-9	49.34	14.47	2.67	13.41	7.62	8.15	2.59	0.42	1.17	0.19	0.09	100.12
G-18	51.60	14.84	2.69	11.83	6.17	7.91	2.57	1.03	1.19	0.19	0.10	100.12
G-37	49.76	13.88	2.69	14.36	7.41	6.06	3.76	0.54	1.19	0.16	0.12	99.93
G-55	48.04	13.19	2.59	11.69	11.18	9.02	2.61	0.15	1.09	0.19	0.12	99.87
G-73	47.07	13.80	2.36	10.63	12.37	10.25	2.18	0.16	0.86	0.18	0.09	99.95
G-102	46.94	12.55	2.22	9.50	14.23	12.04	1.66	0.14	0.72	0.17	0.07	100.24
G-154	49.16	14.61	2.33	9.07	10.61	11.23	1.93	0.31	0.83	0.17	0.09	100.34
G-197	49.49	13.97	2.64	12.66	8.59	7.84	2.91	0.34	1.14	0.20	0.12	99.90
G-220	45.56	12.84	2.88	18.71	8.26	7.60	1.93	0.18	2.38	0.20	0.11	100.65
G-250	51.04	12.23	3.35	15.69	5.67	7.30	2.34	0.27	1.85	0.24	0.24	100.22
G-264	49.11	12.96	3.11	16.41	7.50	6.22	2.57	0.17	1.61	0.25	0.21	100.12
G-309	50.00	12.93	3.04	14.24	7.24	7.87	2.60	0.28	1.54	0.21	0.17	100.12
G-382	48.48	13.27	2.83	13.44	11.23	5.60	1.98	1.23	1.33	0.22	0.16	99.77
G-394	53.14	13.85	2.77	10.28	9.02	5.11	3.35	0.18	1.27	0.24	0.16	99.37
G-410	50.43	13.93	3.00	11.50	9.82	7.15	1.86	0.11	1.50	0.30	0.14	99.74

Samples	SiO_2	Al_2O_3	Fe_2O_3 (1)	FeO (2)	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Total
Series C												
M-67(i)	48.05	15.24	2.57	12.77	10.37	5.81	2.74	0.86	1.07	0.24	0.11	99.83
(ii)	48.05	15.24	2.57	12.77	10.31	5.80	2.77	0.87	1.07	0.21	0.11	99.77
C-51(i)	47.33	13.30	2.44	12.34	12.15	8.45	2.07	0.50	0.94	0.18	0.11	99.81
(ii)	47.37	13.29	2.44	12.40	12.02	8.44	2.05	0.49	0.94	0.18	0.11	99.73
M-100(i)	50.13	15.26	3.13	10.56	6.60	8.52	3.27	0.66	1.63	0.24	0.13	100.13
(ii)	50.17	15.20	3.11	10.58	6.68	8.45	3.24	0.67	1.61	0.24	0.13	100.08

TABLE V CIPW NORMS

Sample	Q	or	ab	an	di	hy	ol	mt	il	ap	Total
Series A											
G-9		2.48	22.00	26.57	10.96	24.97	6.81	3.89	2.24	0.23	100.15
G-18	1.50	2.26	21.66	26.04	10.56	27.85		3.90	2.26	0.23	100.10
G-37		3.19	33.09	18.73	8.61	11.94	17.90	3.93	2.30	0.30	99.98
G-55		0.89	22.17	23.71	16.45	12.04	18.64	3.74	2.05	0.28	99.96
G-73		0.95	18.53	27.27	18.49	6.87	22.66	3.42	1.63	0.21	100.03
G-102		0.83	13.88	26.47	26.75	3.97	23.65	3.22	1.37	0.16	100.29
G-154		1.83	16.25	30.36	20.24	16.81	9.72	3.38	1.58	0.21	100.36
G-197		2.01	24.88	23.89	11.32	21.05	10.58	3.81	2.15	0.28	99.96
G-220		1.12	16.25	25.94	8.94	31.83	5.55	4.15	4.48	0.28	98.54
G-250	5.57	1.60	19.72	22.14	10.78	31.12		4.86	3.51	0.53	99.83
G-264		1.00	22.17	22.99	5.47	38.81	1.68	4.49	3.04	0.49	100.15
G-309		1.65	22.25	22.59	12.81	33.08	0.04	4.41	2.92	0.39	100.15
G-382		7.39	16.25	23.90	2.16	30.01	13.07	4.09	2.51	0.37	99.74
G-394	2.41	1.00	28.69	22.02	1.95	36.48		4.02	2.41	0.37	99.35
G-410	3.58	.71	15.74	29.17	4.24	38.83		4.35	2.85	0.32	99.79

Sample	Q	or	ab	an	di	hy	ol	mt	il	ap	Total
Series B											
G-9		2.48	21.92	26.62	10.98	24.67	7.15	3.87	2.22	0.21	100.12
G-18	1.43	6.09	21.75	25.92	10.54	28.01		3.90	2.26	0.23	100.12
G-37		3.19	31.82	19.40	8.23	13.85	17.01	3.90	2.26	0.28	99.93
G-55		0.89	22.08	23.83	16.42	11.29	19.25	3.75	2.07	0.28	99.87
G-73		0.95	18.45	27.40	18.55	5.70	23.65	3.42	1.63	0.21	99.95
G-102		0.83	14.05	26.38	26.50	2.65	25.09	3.22	1.37	0.16	100.24
G-154		1.83	16.33	30.29	20.13	16.72	9.87	3.38	1.58	0.21	100.34
G-197		2.01	24.62	24.05	11.60	20.61	10.74	3.83	2.16	0.28	99.90
G-220		1.06	16.33	25.84	9.32	24.23	14.91	4.18	4.52	0.25	100.65
G-250	5.02	1.60	19.80	22.07	10.59	32.22		4.86	3.51	0.56	100.22
G-264		1.00	21.75	23.33	5.15	39.03	1.81	4.51	3.06	0.49	100.12
G-309	0.11	1.65	22.00	22.78	12.61	33.23		4.41	2.92	0.39	100.12
G-382		7.27	16.75	23.69	2.50	29.69	12.87	4.10	2.53	0.37	99.77
G-394	2.67	1.06	28.35	22.22	1.70	36.57		4.02	2.41	0.37	99.37
G-410	3.14	0.65	15.74	29.34	4.27	39.09		4.35	2.85	0.32	99.74

Sample	Q	or	ab	an	di	hy	ol	mt	il	ap	Total
Series C											
M-67(i)		5.08	23.18	26.75	1.12	16.95	20.74	3.73	2.03	0.25	99.83
(ii)		5.14	23.44	26.58	1.21	16.50	20.88	3.73	2.03	0.25	99.77
C-51(i)		2.95	17.52	25.52	12.79	13.98	21.47	3.54	1.78	0.25	99.81
(ii)		2.90	17.35	25.62	12.68	15.00	20.61	3.54	1.78	0.25	99.73
M-100(i)		3.90	27.67	25.01	13.52	15.92	6.17	4.54	3.10	0.30	100.13
(ii)		3.96	27.42	24.95	13.28	16.73	5.88	4.51	3.06	0.30	100.08


GABBRO LAKE SILL
Gabbro Lake
Walmsley Lake
Boyer Lake
Gun Lake
Shongwashu Lake
Boyer Lake Area
miles
LEGEND
Mafic Volcanics
1a Massive Basalt
1c Pillowed Basalt
1d Porphyritic Basalt
1f Pillow Breccia
Intrusives
4a Quartz-Feldspar Porphyry
4e Quartz-Porphyry
5a Normal Gabbro
5b Leucocratic Gabbro
5c Chilled Margin Gabbro
5d Diabasic Gabbro
5p Pegmatitic Gabbro
5s Sheared Gabbro
5y Pyroxenitic Gabbro
Symbols
Contact
Fault
Joint
Pillow Tops
Sample Locations
Shearing
Gradational Phase Boundary
Scale: 1" = 440'
0 500'
GM-75