ORIGIN OF THE BAND OF QUARTZO-FELDSPATHIC ROCKS ALONG THE NORTH SHORE OF FALCON LAKE, MANITOBA

A Thesis Presented to the Faculty of Graduate Studies and Research of the University of Manitoba in Partial Fulfillment of the Requirements for the Degree of Master of Science.

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ABSTRACT

Petrographic and chemical studies were made to determine the origin of a band of quartzo-feldspathic rocks enclosed in andesites, basalts and basic tuffs.

A primary origin is examined, in which the zone is considered to be acid to intermediate volcanic rocks which were deposited during a normal volcanic cycle; a secondary origin is also considered, in which pervasive alkali-silica metasomatism has replaced basic volcanic flows and tuffs along a shear zone.

Gradational features observed in the quartzo-feldspathic band indicate that at least a limited amount of metasomatic transfer of material has occurred. The mechanisms which could have given rise to such a zone include: hydrothermal solutions from a nearby igneous intrusion conducted along a shear zone in the lavas, solphateric alteration, autometamorphism including diagenesis, and dynamic and regional metamorphism.

CHAPTER 1

INTRODUCTION

Statement of the Problem

A zone of siliceous-feldspathic rocks approximately 2 miles long and 500 feet wide occurs in basic volcanic rocks in the Falcon Lake area of southeastern Manitoba.

Pillow structure, apparent bedding structure (possibly of tuffaceous origin) and massive-looking rock occur within this zone. Lensoid patches of basic volcanic rock showing altered borders grading into the siliceous-feldspathic rock are present at one locality in this zone. These patches are a few tens of feet long and two to four feet wide.

Much of the band in question resembles a rhyolite and acid tuff sequence in outcrop. Rhyolite pillows, although rare, have been reported from a few localities. Further, it is well known that rhyolites, dacites, and fragmental equivalents are abundant in the Kenora area to the east. Several features of the body, however, suggest that at least some metasomatism may have occurred.

The present work is a petrographic and chemical study of selected specimens from the band and adjacent rocks to try to determine whether metasomatism was an important process in the genesis of the quartzo-feldspathic rocks.

Location and Access

The area covered in this study lies within Township 9, Range 17, east of the Principal Meridian along the north shore of Falcon Lake in southeastern Manitoba between Pakaska Beach and a point approximately ½ mile west of Toniata Beach.

The general area is about 90 miles east of Winnipeg on the Trans-Canada Highway. The study area is readily accessible by boat from Falcon Lake Settlement at the west end of the lake or by car on good gravelled roads which service cottages along the lake shore.

Physiography

The topography is typical of most Canadian Shield areas. The country consists of rolling hills and ridges of partially drift-covered bedrock with scattered basin-like depressions occupied by lakes. The lowlands between hills and ridges are commonly filled with muskeg. Maximum relief is approximately 100 feet.

The area is heavily forested for the most part with a variety of evergreens, birch, poplar and oak. A sparse growth of spruce, tamarack and cedar is supported in the swamps and muskegs.

History of the Area

A cursory investigation of the Lake of the Woods area was conducted by R. Bell (1882), of the Geological Survey of Canada. He interpreted the volcanic-sedimentary belt in this area as being Huronian in age.

A. C. Lawson (1885) examined the geology of the Lake of the Woods country including the Falcon Lake area. His discovery that the Laurentian gneisses intruded the volcanic-sedimentary rocks proved that the latter is older than Huronian and he termed them Keewatin.

E. L. Bruce (1917, 1918), J. S. DeLury (1917, 1918, 1919, 1921 and 1921a) and J. R. Marshall (1917) investigated mineral deposits in the Falcon Lake-West Hawk Lake region.

G. M. Brownell (1941) made a petrographic study of the Falcon Lake Stock.

G. D. Springer (1952) mapped a large area including Falcon Lake at a scale of one inch to one mile for the Manitoba Mines Branch.

J. F. Davies (1954) mapped the geology of the West Hawk Lake-Falcon Lake area at a scale of one inch to 1000 feet.

The band of acid rocks, which is the subject of the present study, was outlined and described by Davies (1954). He concluded from field evidence and a limited number of thin sections that the zone is that of silicified basic lavas and tuff.

Davies' map was used for control in collecting specimens and an enlargement of the area of the acid rocks was prepared from the map.

Acknowledgements

The author is indebted to Dr. J. F. Davies who was, at the time, chief geologist of the Manitoba Mines Branch, for suggesting the problem.

Aid given by Dr. Davies, Dr. H. D. B. Wilson, and Professor W. C. Brisbin in arranging the field trip, selecting specimens and their valuable comments are gratefully acknowledged.

Thanks also go to many of the post-graduate students for their valuable suggestions during the course of the study.

CHAPTER 2

REGIONAL GEOLOGY

General Geology

The detailed geologic work done by J. F. Davies (1954) for the Manitoba Mines Branch made it unnecessary for the writer to spend time mapping the area. The following material in this chapter is extracted almost entirely from Davies' report.

The West Hawk Lake-Falcon Lake area is underlain for the most part by volcanic rocks and sedimentary strata of the Keewatin Series. The volcanic rocks are rhyolitic to basaltic in composition with some fragmental and tuffaceous horizons.

Sedimentary rocks in the area overlie the volcanic rocks with the exception of some interbedded slate which occurs in andesite at the south end of Lyons Lake. The sedimentary rocks appear to be conformable with the lavas.

Regarding the band of quartzo-feldspathic rocks along the north shore of Falcon Lake, Davies (1954, page 6) states:

> "Some of the rocks mapped as sedimentary show unmistakeable evidence of having been altered, with the introduction of silica. The degree of this alteration is not determinable but it is possible that many of the so-called quartzites and allied rocks are silicified basic tuffs. Along the north shore of Falcon Lake there is a band of thoroughly metasomatized volcanic rocks previously considered to be sedimentary."

The Falcon Lake Stock, consisting of a gabbro-diorite rim and a quartz-monzonite core (G. M. Brownell, 1941), intruded the volcanic rocks between Star Lake and Barren Lake. Its southern extremity lies approximately 3/4 mile north of the west end of the quartzo-feldspathic band.

An irregular sill-like intrusion of quartz-feldspar porphyry, trending in an easterly direction is located along the north shore of Falcon Lake at the east end.

Various granitic rocks underlie the borders of the map-area.

Structural Geology

Folding

The main folding in the area is in the form of an easterly trending anticline, the axis of which lies about 1/2 mile south of West Hawk Lake (see location plan, Fig. 2). The westerly extension of the fold appears to swing to the southwest. The study area is part of the South limb of this fold.

Shearing, Faulting, and Fracturing

Several east and northeast trending shear zones lie between West Hawk Lake and Falcon Lake. The shear zones are usually less than ten feet wide and all dip northward at 70 to 80 degrees. Slickensides on some of the shears plunge at angles of 50 to 70 degrees to the east and a relative upward movement of the south wall is indicated. Some of the shears are cemented with barren quartz. Most of the sulphide mineral showings in the area occur along short shear zones having this orientation.

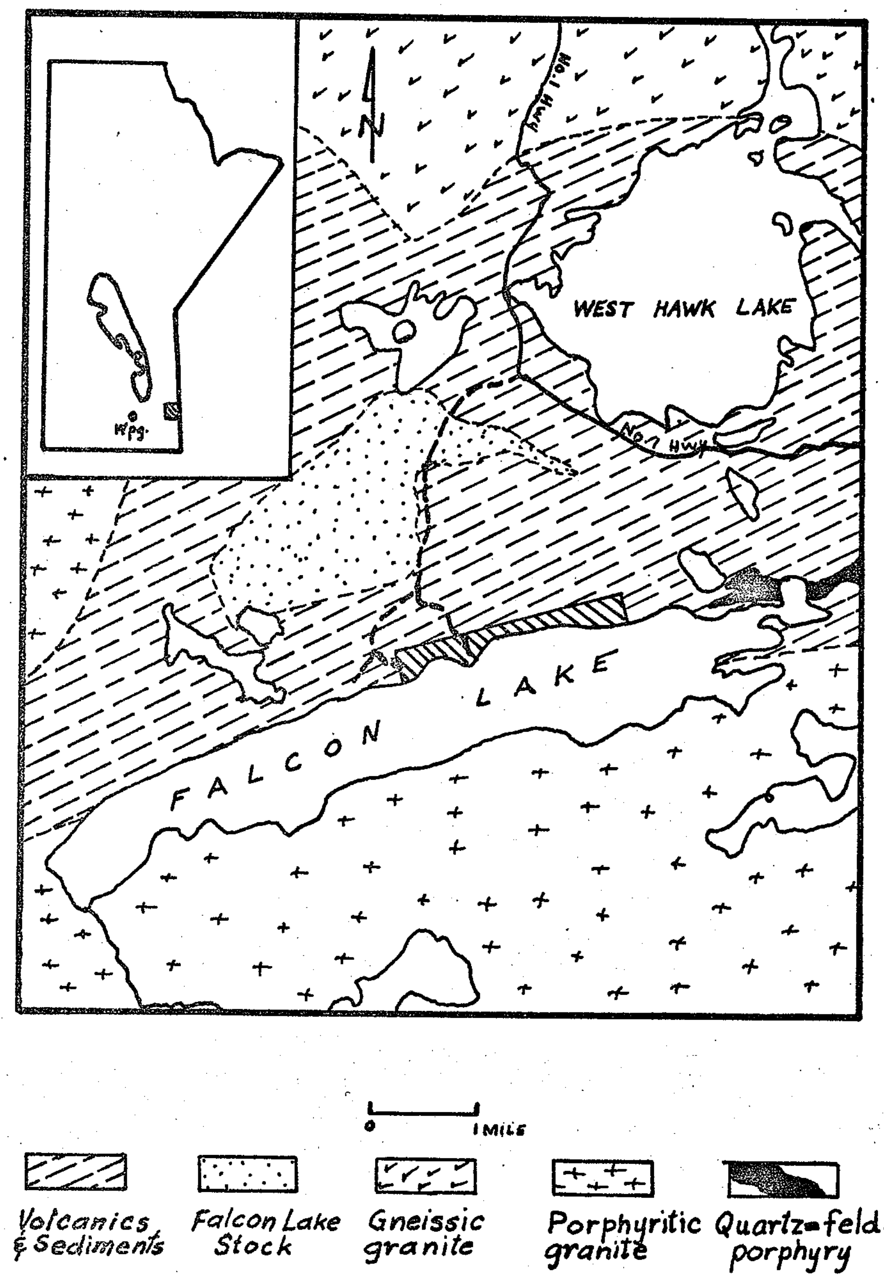

Figure 1: Location plan and general area. The area of detailed study is indicated by striping along the north shore of Falcon Lake.

Table 1

Table of Formations

(after Davies)

ARCHEAN or PROTEROZOIC		Quartz-feldspar porphyry.
		Pink porphyritic granite.
		Grey gneissic granite.
		Quartz monzonite.
	Falcon Lake Stock	Gabbro, diorite, granodiorite, syenodiorite.
	INTRUSIVE	CONTACT
ARCHEAN KEEWATIN		Mixed Keewatin rocks and pegmatites.
		Silicified andesite and tuffs.
		Clastic sedimentary and related rocks.
		Basic tuff.
		Basic agglomerate.
		Slate.
		Andesite, basalt.

Plate 1: Thinly laminated rock in the central zone, perhaps acid tuffs.

Plate 2: Oblong irregular inclusions of greenstone in rhyolitic rock. Note the gradational boundaries. Lenticular structure in the inclusion is due to stretched pillows.

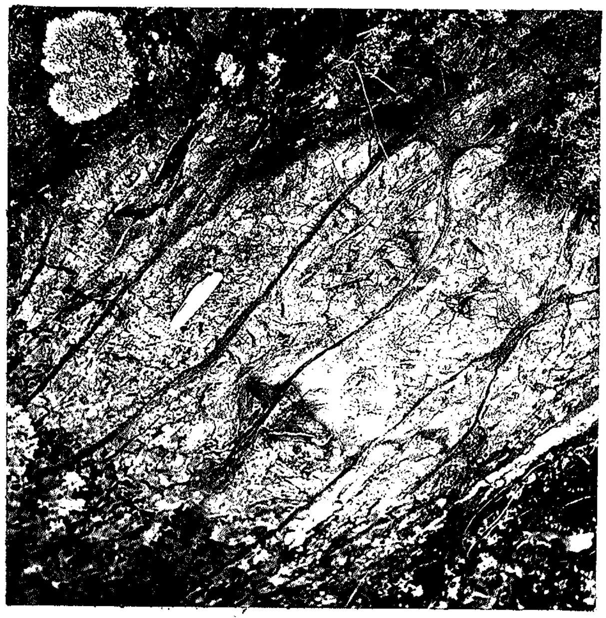

Plate 3: Ellipsoidal lava of rhyolitic composition at site D152

Plate 4: Partially altered pillow lava. Note dark amphibolitic center with light rimming alteration in the pillow top center. Petrography of four samples across such a pillow is described in Chapter 4, page 31. Tops face towards the top of the picture.

Plate 5: Fine agate-like banding in cherty rock in the central zone at site D9 (just above meter case).

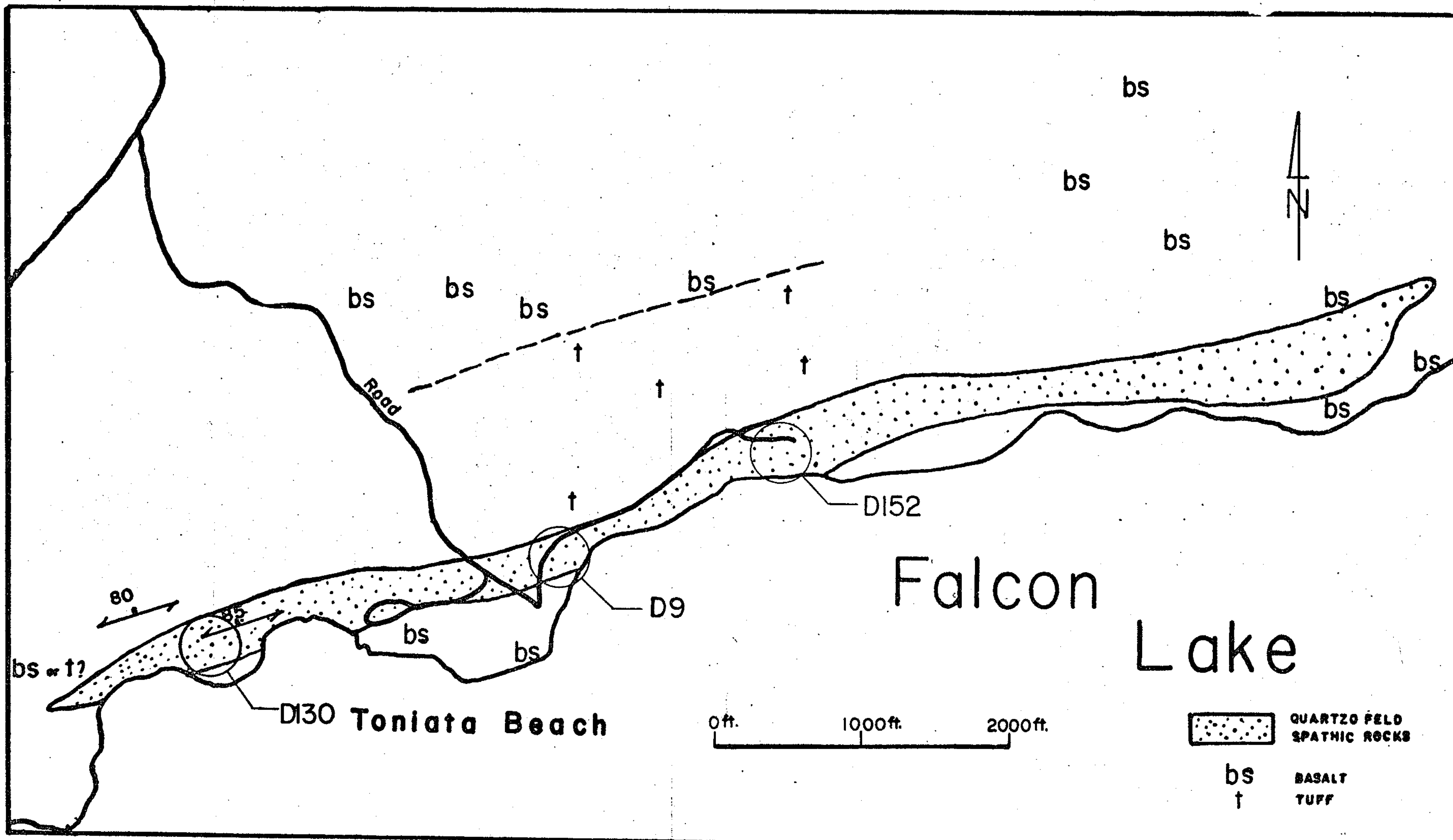

Fig. 1A: Geology of the study area showing the sampling localities D130, D152 and D9.

The basalts and tuffs shown are field identifications made by J. F. Davies (1954) and recorded on his aerial photographs.

CHAPTER 3

GEOLOGY OF THE STUDY AREA

Detailed field mapping of the study area was not done by the writer. However, from an examination of the geology at the sites visited, some general remarks can be made. The rocks are divided into four units for convenience in discussion:

a) Regionally metamorphosed andesites, basalts and tuffs.

b) Rocks of the quartzo-feldspathic band.

c) Falcon Lake Stock.

d) Quartz-feldspar porphyry.

a) Regionally metamorphosed andesites, basalts and tuffs

The rocks underlying the quartzo-feldspathic band (south contact of the band) are andesitic and basaltic flows. Massive, foliated and pillowed types are represented.

Davies (1954) recorded observations of basalts and basic tuffs on the aerial photographs of the area around the quartzo-feldspathic band although the two types were not distinguished on his map in this area. If the field recordings are correct, however, they indicate that the band is directly overlain by approximately 1000 feet of basic volcanic rocks which may be largely tuffs above the center of the band.

The rocks in the area are regionally metamorphosed to plagioclase (andesine) - amphibolite (garnet zone).

Fresh and weathered surfaces are dark green to dark grey in colour. The rocks are medium to fine grained.

b) Rocks of the quartzo-feldspathic band

Within the quartzo-feldspathic band the rocks contain varying amounts of quartz, plagioclase, potash feldspar, biotite, sericite and hornblende as major constituents. Hornblende is present only in the peripheral parts of the band, herein called the border zone, which varies between approximately 30 feet and 100 feet in width at the sites examined.

The rocks range from massive (pillowed in one case) to well foliated at the localities visited in the border zone, whereas in the central zone, intricately laminated, highly siliceous rocks are the most typical (Plate 1). An unusual rock with contorted agate-like banding occurs in the central zone at site D9 (plate 5). It is very fine grained and resembles chert.

Pillow lava outcrops at site D152 both in the southern margin of the quartzo-feldspathic band and in the underlying greenstone. An interesting sequence of rocks occurs at this site. Pillows of basaltic composition are overlain by pillows of dacitic to rhyolitic composition which in turn are overlain by a zone of very fine grained cherty rhyolite-like rock containing stretched amphibolitic inclusions two to four feet wide and a few tens of feet long (Plates 2, 3, and 4). The inclusions are aggregates of highly stretched pillows. The borders are shredded and appear to grade into the enclosing siliceous rock. Outcrops are plentiful at site D152 but not continuous enough to observe the contact relations of the sequence.

The rocks are light greenish grey to light brownish grey and weather to a very light cream or light grey. They are fine to very fine grained.

c) Falcon Lake Stock

The Falcon Lake Stock intrudes the greenstones and lies 3/4 mile north of the quartzo-feldspathic band. A detailed study by Brownell (1941) revealed that the stock consists of an outer margin of diorite and gabbro and a core of quartz monzonite. A ring of syenodiorite-granodiorite completely surrounds the quartz monzonite core and is gradational in composition into it such that no contact can be seen in the field.

Several gold and sulphide occurrences are distributed around the stock in silicified shear zones in the volcanic rocks and within the stock itself, indicating a close association between the stock and the mineralization.

d) Quartz-feldspar porphyry

An irregular sill-like body of quartz-feldspar porphyry outcrops at the east end of Falcon Lake along the north shore. The rock is made up of an abundance of stubby feldspar phenocrysts and small bluish quartz "eyes" set in a quartzo-feldspathic groundmass. The mass weathers a light buff to cream colour.

A very fine-grained, well-foliated, cream-coloured, felsic rock occurs at the margins of the intrusion. This may represent a fine border phase of the intrusion or a metasomatized contact rock.

The sill has intruded basic volcanic rocks and appears to have been controlled by fracturing and faulting. It lies approximately on strike with the siliceous band to the west which is the subject of the current study.

CHAPTER 4

PETROGRAPHY OF THE QUARTZO-FELDSPATHIC BAND

General Statement

Suites of specimens for petrographic examination were collected across the quartzo-feldspathic band and its contacts with the greenstone and across various features within the band which show mineralogical, chemical and textural variations. Some of the samples were selected from these for chemical analyses, the results of which are discussed in Chapter 5.

The regionally metamorphosed basic lavas enclosing the quartzo-feldspathic band are composed of hornblende (50 to 75 percent), andesine-labradorite, and less than 10 percent quartz, the latter constituent occurring commonly in the form of small veinlets.[1]

A border zone in the quartzo-feldspathic band as much as 100 feet wide is composed of varying amounts of hornblende (0 to 50 percent), plagioclase (15 to 25 percent), biotite (2 to 50 percent) associated with hornblende, quartz (10 to 20 percent) and accessory magnetite, calcite, chlorite and epidote.

A central zone 200 feet or more wide is composed of quartz (as much as 50 percent), muscovite and sericite (1 to 35 percent), biotite (2 to 30 percent) and potash feldspar which appears to have developed at the expense of biotite.

Some sections from the central zone contain minute crystals of blue tourmaline (schorlite) which have developed along foliation planes bearing biotite and sericite.

Site D130

Two suites of specimens were collected at site D130, approximately 700 feet west of Toniata Beach (see location plan, Fig. 1). One suite of five specimens was collected across the south contact and into the quartzo-feldspathic band. Specimen D130-A represents regionally metamorphosed basalt and specimens B, C, D, and E were taken across the border zone and into the central zone. These were chemically analyzed and are discussed in Chapter 5. A second suite of six specimens, D130-1 to D130-6, was collected across the quartzo-feldspathic body from north to south at approximate distances of 0, 30, 100, 200, 300 and 400 feet from the north contact of the band. These were examined under the petrographic microscope and grain counts were made (Table 1).

An examination of the thin sections indicates that specimen D130-6 was probably collected short of the south contact. Niggli's molecular norm calculations for D130-A, which was taken from regionally metamorphosed greenstone at the south contact, were made using the chemical analysis obtained for the specimen in order to complete the picture. The analysis of hornblende from D130-1 (Table 6) was used in the calculation as being representative of the hornblende molecule in the regionally metamorphosed greenstones. This assumption may not be entirely satisfactory for accurate results but the values obtained are probably close enough to show the gross trends of mineral variations beyond specimen D130-6.

Table 1

Modal Analyses for the D130-1 to 6 Suite

Specimen	Hb	Plag	Bio	Qtz	Musc	K-Feld	Mag	Other
D130-1	69.8	14.2	----	8.9	----	----	7.1	----
D130-2	21.3	24.6	28.6	19.6	----	----	2.1	Calcite 3.9
D130-3	----	15.3	2.1	42.7	34.6	5.4	----	----
D130-4	----	15.0	19.2	37.4	26.6	1.9	----	Tourm. tr.
D130-5	----	20.6	26.7	48.0	1.1	1.3	1.3	Tourm. tr.
D130-6	5.2	17.0	47.2	19.0	----	----	tr.	Epidote 11.7
D130-A*	70.0	15.0	4.0	7.6	----	----	0.9	----

*Values for D130-A were derived from the chemical analysis of this specimen using Niggli's Molecular Norm calculations.

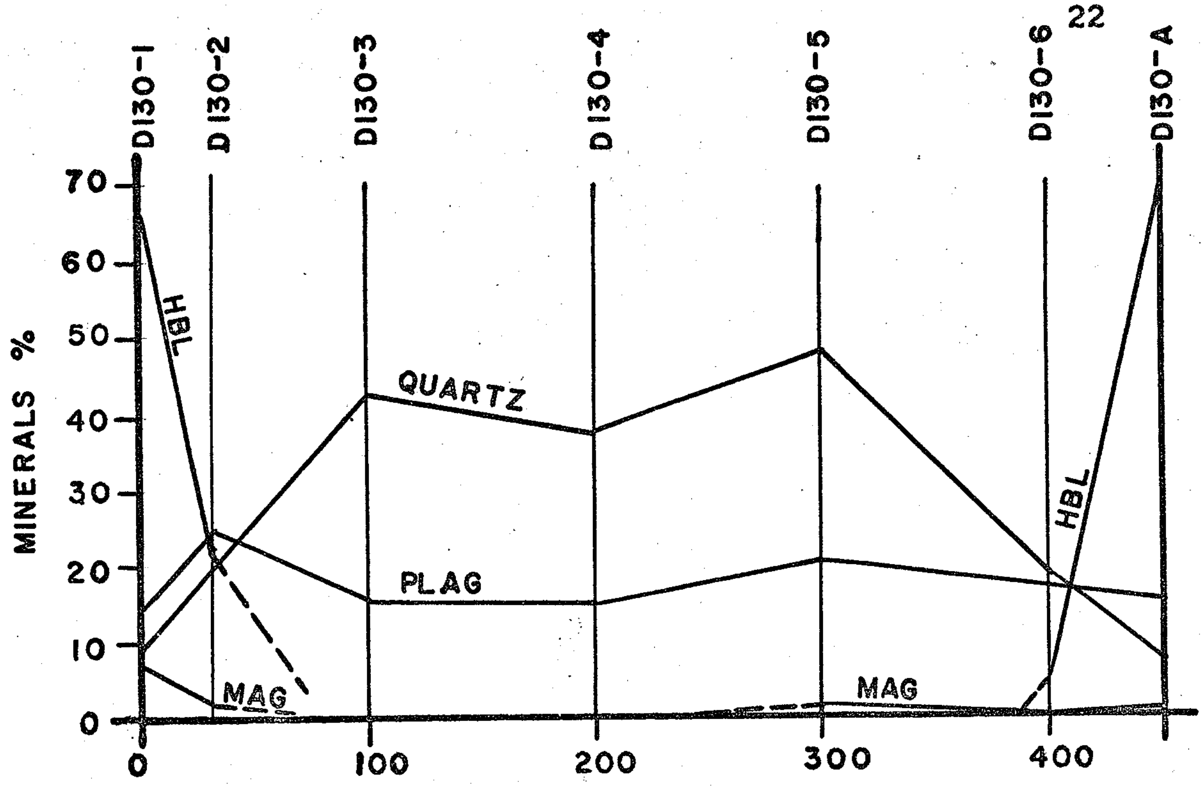

Figure 2: Mineral variation diagram showing the patterns of quartz, hornblende, plagioclase and magnetite across the quartzo-feldspathic band at site D130.

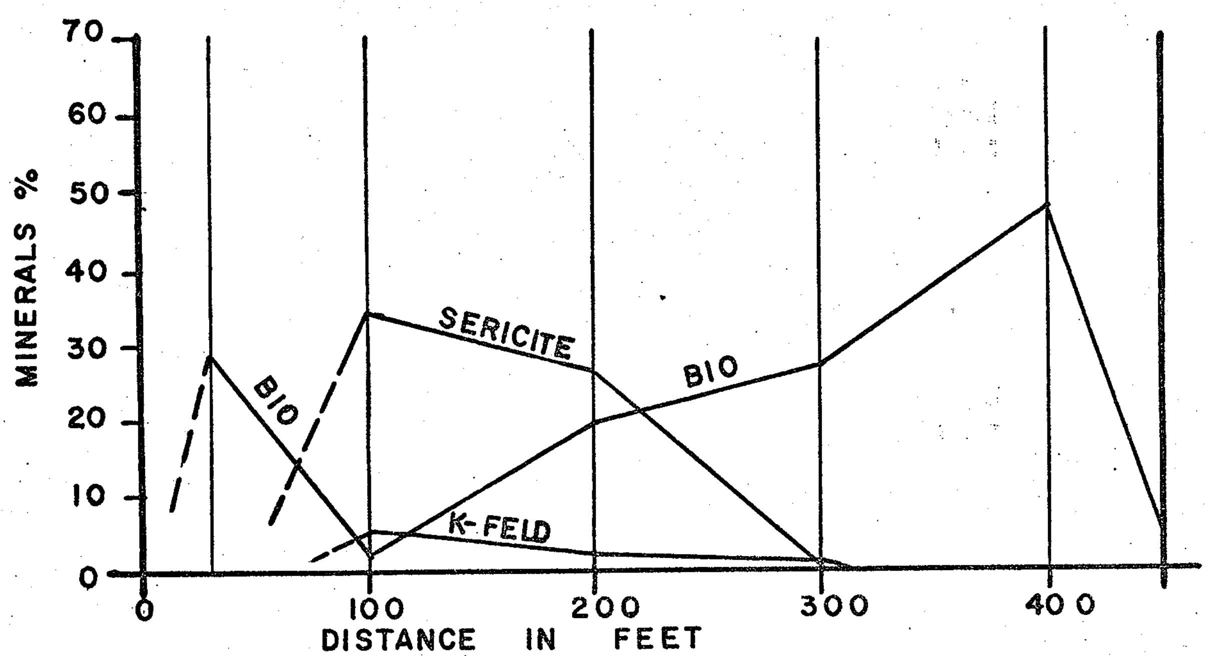

Figure 3: Mineral variation diagram showing relationships between biotite, sericite and potash feldspar across the quartzo-feldspathic band at site D130.

Mineral variation diagrams (Figs. 2 and 3) were constructed from the data in Table 1 with mineral percentages as the ordinate and the distance in feet (approximate) from the north contact of the quartzo-feldspathic band as the abscissa. Several interesting relationships are evident from Table 1 and Figures 2 and 3:

Quartz. This mineral increases with some fluctuations from 8.9 percent in the greenstone at the north contact to a maximum of 47.2 percent in the central zone of the quartzo-feldspathic body and then decreases to 7.6 percent at the south contact. Quartz occurs as disseminated fine grains (0.02 to 0.04 mm.) and corrosive embayments in hornblende and plagioclase crystals in the greenstone and border zone rocks. It occurs in an equigranular mosaic with feldspar in the central zone. Thin veinlets are common in all the rock types.

Hornblende. Subhedral prismatic crystals of green hornblende constitute as much as 70 percent of the regionally metamorphosed basic volcanic rocks which surround the quartzo-feldspathic band. Splintery aggregates of hornblende (21.3 percent in D130-2) are closely associated with biotite flakes which appear to have replaced hornblende in the border zone. Hornblende is absent in specimens D130-3, D130-4 and D130-5 which were taken in the central zone.

Mica. Total mica content increases approximately in proportion with quartz and appears first as small flakes of biotite which in part have replaced hornblende in the border zone. Muscovite (sericite) appears in the central zone where it replaces biotite and only in the absence of hornblende. The inverse relationship between muscovite and biotite is well displayed in Figure 3. Muscovite is absent where biotite is a maximum and rises to a maximum as biotite decreases to a minimum on the diagram. The central zone is well foliated. This feature is accentuated by the fact that mica flakes are aligned and concentrated in bands (Plates 8 and 9).

Potash Feldspar. Potash feldspar in this suite seems to be present exclusively in conjunction with sericite-rich bands and occurs as euhedral to anhedral grains, patches and fracture fillings. Figure 3 illustrates the parallel relationship between sericite and potash feldspar. It is perhaps noteworthy that the maximum amount of potash feldspar observed in the suite was 5.4 percent in specimen D130-3, and is therefore only an accessory mineral even in the most acid rocks of the central zone.

Plagioclase. The percentage of plagioclase in the suite remains approximately constant with the exception of a prominent peak which occurs in the border zone close to the north contact (D130-2). The possible significance of this variation is discussed in Chapter 6. A variation in the composition of plagioclase in the suite was suspected from the development of zoning which was noted during the

Plate 6: Sample D130-1 from the north contact (X30). The rock is an amphibolite, perhaps originally a basic tuff.

Plate 7: Sample D130-2, 30 feet south of D130-1 (X30). Note development of biotite associated with hornblende.

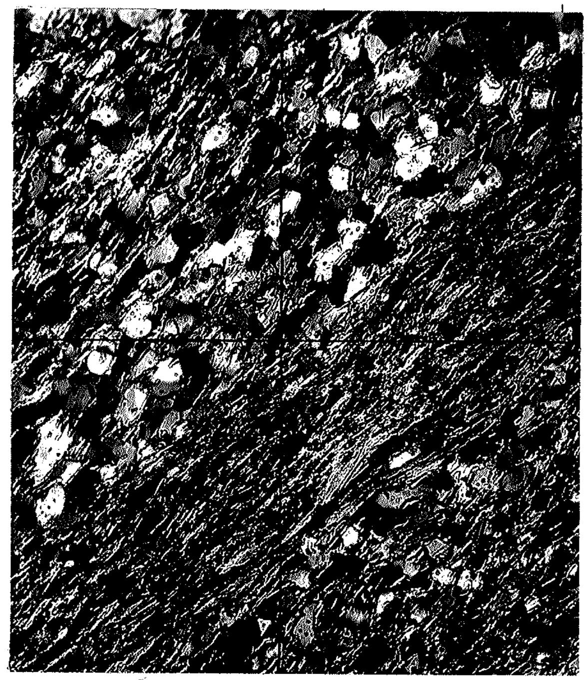

Plate 8: Sample D130-4 from the central zone of the quartzo-feldspathic band (crossed nicols, X30). The rock is an albite-quartz-sericite schist.

Plate 9: Sample D130-4, showing schorlite crystals (dark grains) associated with biotite (X55).

petrographic study. Chemical analyses of plagioclase in the D130A to E suite were obtained and are discussed in Chapter 5. Plagioclase in the greenstone specimen (D130-A) is andesine-labradorite, in the border zone specimen (D130-C) 15 feet from the contact is andesine and in the central zone specimen (D130-E) 40 feet from the contact is sodic albite.

Magnetite. This mineral occurs in association with hornblende and biotite. Magnetite is entirely absent in specimens D130-3 and D130-4 of the central zone where sericite and potash feldspar are a maximum and biotite percentages are low.

Tourmaline (schorlite). Trace quantities of soda-rich[1] schorlite (blue in colour) are present only in the central zone of the quartzo-feldspathic band in association with biotite seams.

Plate 6 (D130-1) represents regionally metamorphosed andesite (tuff?) at the north contact of the quartzo-feldspathic band. Quartz occurs as chains of grains which are parallel to the foliation. Other minerals are: hornblende, plagioclase and magnetite. Plate 7 (D130-2) shows the development of biotite within and around crystals of hornblende. This sample was collected at a distance of approximately 30 feet

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[1] According to Harker (1932, third ed. Page 117) blue tourmaline is probably related to a noteworthy content of soda.

from the north contact. Plate 8 (D130-4) illustrates the texture and structure of the well-laminated rock which occurs at several localities in the central zone of the quartzo-feldspathic band. Layers up to 1 mm. in width predominantly composed of aligned sericite laths (some biotite) alternate with bands consisting of a mosaic of equigranular quartz and albite grains. Plate 9 (D130-4) shows the development of schorlite crystals associated with biotite.

Site D152

Pillow structure occurs at site D152 in the basic lavas at the south contact and in what is herein called the border zone of the quartzo-feldspathic band. The acid pillows of the border zone approach rhyolite in composition. These stratigraphically overlie the basic lavas. At the north contact of the band the greenstone is well foliated and pillow structure is absent.

Several suites of specimens were collected at this site in order to investigate variations in mineralogy, chemistry and texture. Specimens D152-1A, 1B and 1C were taken across a small quartzo-feldspathic band 1½feet wide which appears to have been a shear zone in the greenstone at the north contact of the acid body which has been silicified.

Specimens D152-4-1, 2, 3, and 4 were collected across one of several pillows which in outcrop appear to have marked variations in composition (see Plate 4, page 12). Specimens D152-4-C and E were collected from the center and edge respectively of another similar pillow at the same locality. These were examined petrographically and chemical analyses were made.

Seven thin sections from J. F. Davies' collection, which were taken across a lenticular patch of greenstone in the border zone of the quartzo-feldspathic band were examined by the writer (FL-1 to 7). Several similar bodies observed by the writer are undoubtedly highly stretched pillow lavas.

Suite D152-1A, 1B and 1C

A band of silicic rock about 1½ feet wide and parallel to the main body occurs at the north contact of the quartzo-feldspathic body at site D152. It is bounded on the north and south sides by well foliated greenstone.

Specimen D152-1A was collected on the north side of the narrow band. The rock is well foliated regionally metamorphosed greenstone, perhaps tuffaceous in origin. It is composed of approximately 50 percent fine-grained green hornblende in anhedral, blocky and splintery aggregates. Fine-grained laths of zoned plagioclase and disseminated equigranular quartz grains make up most of the remainder. Some lenticular seams of quartz showing strain shadows occur. Adjacent to the quartz seams, hornblende has been smeared and chlorite developed. Accessory minerals are: calcite occurring as anhedral intergranular patches, magnetite, and shreddy chlorite.

Specimen D152-1B was taken from the silicic band. The foliation has a corrugated structure which is delineated by thin arcuate seams of shredded hornblende. This mineral constitutes about 20 percent of the rock. A groundmass of a mixture of splintery feldspar laths with faded boundaries and prominent zoning and equidimensional fine-grained quartz makes up approximately 75 percent of the rock. Lenses of granular quartz showing strain shadows are also present. Chlorite and biotite flakes are disseminated throughout the specimen. Accessory magnetite and some small garnets are present.

Specimen D152-1C was collected from the greenstone on the south side of the silicic band. It is composed of approximately 80 percent green hornblende. The foliation is pronounced and due to shearing such that layers of blocky hornblende crystals alternate with layers of shredded hornblende. Quartz occurs both in a mixture with fine zoned plagioclase laths in the interstices of the hornblende crystals and as thin granular lenses. Anhedral patches and lenses of calcite and minute grains of magnetite occur as accessories.

Suite D152-4-1, 2, 3 and 4

A sample profile was taken across an individual pillow near the south contact of the quartzo-feldspathic body at site D152. D152-4-1 was taken from the bottom quarter of the pillow, D152-4-2 above 4-1 in the second quarter, D152-4-3 above 4-2 in the third quarter and D152-4-4 from the top quarter of the pillow. Mineral percentages were determined from thin sections by the point count method and the results are given in Table 2. Chemical analyses were also obtained for this suite and are discussed in Chapter 5.

Table 2

Modal Analyses for the D152-4-1 to 4-4 Suite

Specimen	Hb	Plag	Qtz	Bio	Mag
D152-4-1	43.7	34.4	16.7	2.3	3.0
D152-4-2	32.7	47.8	11.1	3.0	5.3
D152-4-3	44.4	42.3	9.3	0.6	3.4
D152-4-4	22.6	47.3	19.4	6.0	4.4

The peripheral area of the pillow studied is well foliated and quartz occurs both as thin veinlets with some plagioclase and biotite transverse to the foliation in

Plate 10: Sample D152-4-1, (X30) from the peripheral part of an altered pillow. Note the foliation developed. The white transverse veinlets are quartz, the dark shredded mineral is hornblende, and the groundmass is plagioclase (dark grey because of staining) stippled with disseminated quartz (white flecks).

Plate 11: Sample D152-4-3, from the core of the altered pillow (X55). Note radiate pattern of plagioclase laths (stained). White mineral is quartz; hornblende is present--bottom center, left center and upper right hand corner of the photograph.

many cases and as fine disseminated equigranular grains (Plate 10). The central portion is massive for the most part and the original diabasic texture has been preserved. Hornblende is randomly oriented and plagioclase laths show a radiating pattern (Plate 11). Quartz occurs interstitially outlining plagioclase laths and as embayments in hornblende and plagioclase.

Quartz percentages (Table 2) show a consistent increase from the center of the pillow outwards but this variation is apparently unrelated to variations in the amounts of the other minerals. The higher quartz values in the peripheral part of the pillow, therefore, can be perhaps entirely attributed to open space deposition into marginal fractures which are a common feature of pillows.

Biotite and magnetite percentages are approximately inversely proportional to those of hornblende suggesting their development at the expense of hornblende.

Plagioclase percentages are the least variable and perhaps represent the original distribution.

<u>Specimens D152-4-C and E</u>

Specimens D152-4-C and E were taken from the center and edge respectively of a pillow a few tens of feet north of the previous suite. The textural variation in this pillow is similar to that observed in the first pillow; mineral percentages, by way of contrast, are much more variable (Table 3). Hornblende increases from 12.7 percent at the center

Table 3

Modal Analyses for Specimens D152-4-C and E

Specimen	Hb	Plag	Qtz	Bio	Mag	Other
D152-4-C	12.7	58.0	8.1	7.1	2.8	Chl. 11.1
D152-4-E	28.6	36.8	24.0	1.6	2.4	K-Feld 0.4

to 28.6 at the edge of the pillow. It should be noted that complementary amounts of biotite and chlorite are present in D152-4-C, however, and that no great change in composition is implied by the hornblende variation. The increase in quartz from 8.1 percent at the center to 24.0 at the edge is similarly attended by a considerable reduction in plagioclase thus offsetting an apparent increase in silica. Chemical analyses for these specimens (Table 9, page 53), which are discussed in Chapter 5, show that in fact silica is the same for both.

Biotite occurs both as replacement patches in hornblende and as fine flecks along fractures and lining the walls of quartz veinlets.

Chlorite occurs as an alteration of hornblende and in fine splintery grains in the matrix of the rock.

A few grains of potash feldspar associated with biotite and quartz occur in the peripheral part of the pillow.

Suite FL-1 to 7

A sample profile was taken across the width of a lensoid patch of greenstone in the border zone of the quartzo-feldspathic band at site D152 by J. F. Davies (1954). The patch is approximately three feet wide and ten feet long. The central core of the inclusion, represented by FL-3 and FL-4 is made up of dark green andesitic rock. The core is flanked by FL-1 and FL-2 on one side and FL-5, FL-6 and FL-7 on the other. This material is light grey with numerous dark green streaks representing the shredded borders of the patch. WHL-9 was collected from the rhyolitic rock which encloses the inclusions. Similar lensoid patches observed by the writer are aggregates of stretched pillows. A photograph of such a body is shown in Plate 2, on page 10.

Grain counts were made (Table 4) and a mineral variation diagram (Fig. 4) was plotted with mineral percentages as the ordinate and distance (arbitrary) as the abcissa.

The diagram shows a gross symmetry of mineral variation about specimen FL-3. Hornblende is a maximum of 38 percent in FL-3 and diminishes in both directions in the suite away from this specimen. The presence of 3.8 percent hornblende in specimen FL-7 perhaps reflects the irregular shredded nature of the borders of the body (Plate 2). Biotite is absent in FL-3 and FL-4 and increases in both directions away from the central part of the patch thus in an inverse relationship with hornblende. Plagioclase increases from FL-3 in both directions to maxima at FL-1 and FL-6. Quartz is less regular than the other minerals probably because of its tendency to occur as veinlets arising from open space deposition. It is perhaps noteworthy that minima on the quartz curve

Table 4

Modal Analyses for Specimen WHL-9 and the FL-1 to 7 Suite

Specimen	Hb	Plag	Qtz	Bio	Mag	Epid
WHL-9	----	35.0	40.0	1.0 + 20% sericite		
FL-1	1.4	60.0	11.4	21.4	5.7	0.0
FL-2	17.6	43.5	24.9	8.4	4.1	0.8
FL-3	38.0	40.6	16.9	0.0	4.6	0.0
FL-4	21.5	46.3	26.0	0.0	4.9	1.3
FL-5	14.0	46.1	24.0	9.7	4.5	0.3
FL-6	0.0	57.0	23.0	13.2	6.1	0.6
FL-7	3.8	42.7	35.2	12.1	6.3	0.0

Hb column includes minor chlorite alteration in HB.

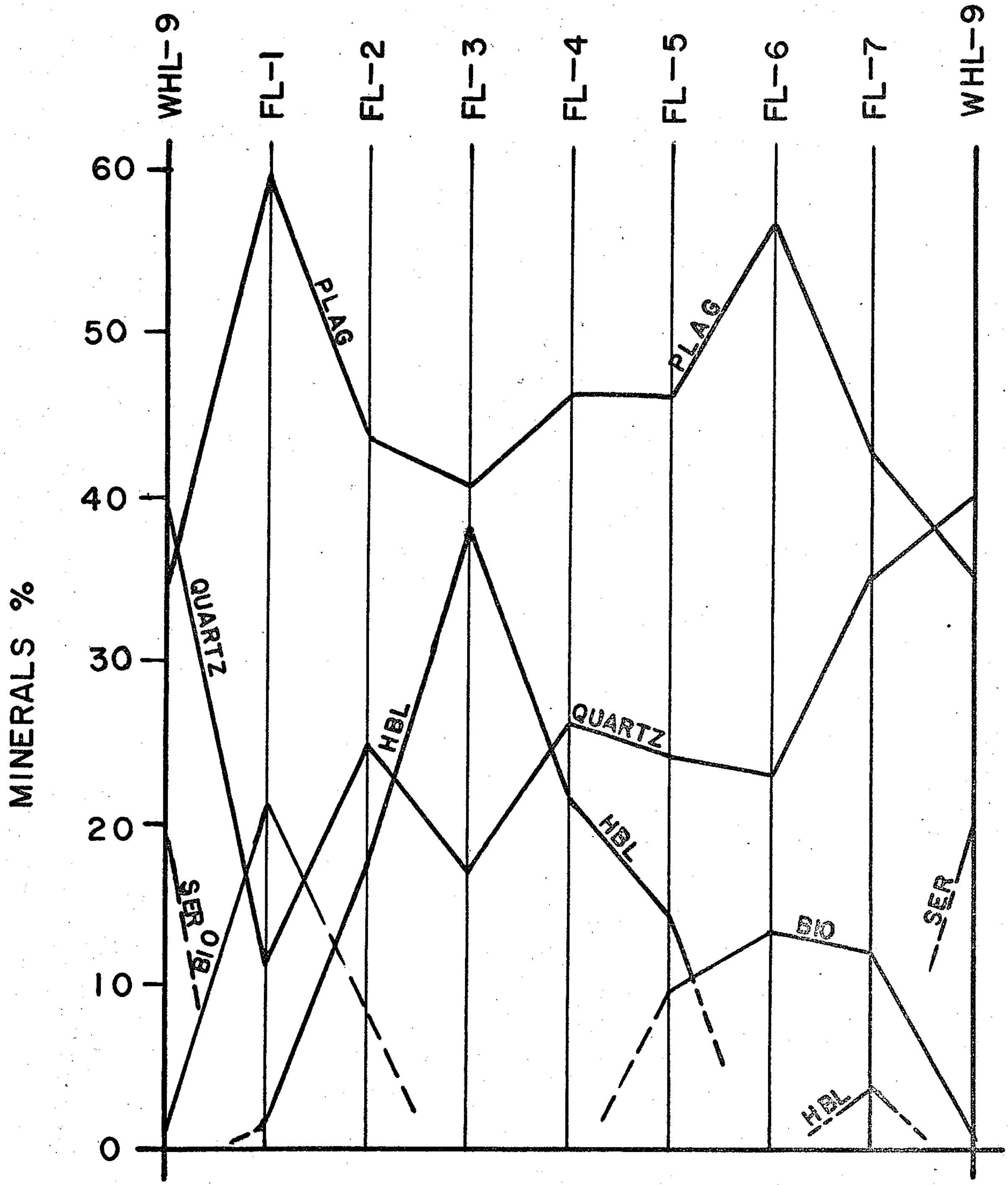

Figure 4: Mineral variation diagram showing the patterns of quartz, plagioclase, hornblende, biotite and sericite across a greenstone inclusion in rhyolitic rock near the south contact at site D152 (see Plate 2).

correspond with maximum hornblende in FL-3 and plagioclase maxima in FL-1 and FL-6. The behaviour of quartz and plagioclase in this suite may be due to the phenomenon of geochemical culmination and depression which is discussed in Chapter 6.

The FL-1 to 7 suite was collected entirely within the borders of the lenticular body. It may have been instructive if sampling had continued beyond the patch to investigate mineralogical variations in the enclosing quartzo-feldspathic rock. Specimen WHL-9 was collected by Davies from typical siliceous host rock in the same general area. The approximate mineral percentages from specimen WHL-9 are plotted as extensions in both directions to Figure 4 by dashed lines. Although this procedure incurs some uncertainty which arises from the fact that WHL-9 is not contiguous with FL-1 to 7 suite, from the similarity of the lenticular patches, their relatively symmetrical nature and the broad areas over which the siliceous rock represented by WHL-9 occurs, it is probable that the major trends indicated are approximately correct. If the foregoing is valid, plagioclase decreases to approximately 35 percent and quartz increases to approximately 40 percent in the enclosing siliceous rock. Biotite decreases to less than one percent and sericite is approximately 20 percent.

The textural description of the suite which follows is taken from Davies' report (1954, page 15):

> "....The specimen from the core of the inclusion consists of andesine-labradorite feldspar, hornblende, and quartz, with magnetite disseminated throughout. The andesine occurs as narrow laths, up to 0.2 mm. long, thoroughly intermingled with quartz which appears to have corroded the plagioclase to a small degree.......Average grain size of quartz in this specimen and in others of the series is 0.02 to 0.04 mm.
>
> Outward from the core the plagioclase in the rock becomes thoroughly riddled, cut up, and corroded by fine granular quartz... Still closer to the margins of the inclusions the feldspar becomes "slivery" and aligned. Lenses of coarse quartz are present. Abundant small biotite flakes or shreds appear, with the hornblende disappearing rather rapidly. Unlike the "slivery", apparently crushed and stretched feldspar, the quartz is more or less equidimensional and unstrained.
>
> There are some bands in the marginal sections consisting entirely of stretched plagioclase with abundant magnetite and no quartz. These may alternate with veinlets or quartz 0.5 mm. or less in width.
>
> The outermost sections, essentially the rhyolitic rock, contain 40 to 50 percent granular quartz, much of it in narrow veinlets, the rest mixed with andesine. There are also some quartz-free bands in these sections and the magnetite in the specimens is concentrated in these bands. Some tourmaline and clinozoisite are also present. Generally biotite in the section is very fine grained but that in the quartz veinlets is in fairly large, apparently recrystallized."

Some of what is called fine quartz in the above description was found to be plagioclase which is discernible only after staining of the thin section.

CHAPTER 5

CHEMICAL RELATIONSHIPS

General statement

Chemical analyses were obtained for a suite of five specimens at site D130 (D130A to E) taken across the south contact and into the quartzo-feldspathic body and for suites of specimens taken from the two individual pillows at site D152 which were examined petrographically (page 31). Oxide versus distance diagrams were plotted using the results of these analyses. Barth's standard cell calculations were made for the D152-4-1 to 4-4 suite (Table 10).

Portions of samples D130-1 and D130-2 which were examined petrographically (page 15) and of D130A, C, and E (above) were ground to -100, +200 mesh and clean hornblende and quartz-plagioclase concentrates respectively were prepared from these using the Franz isodynamic separator. Chemical analyses of these samples (two hornblende and three quartz-plagioclase) were obtained so that variations in compositions of these minerals could be investigated.

Variation Diagram for D130-A to E Suite

The D130-A to E specimens were collected 0, 12, 15, 30 and 40 feet consecutively from the south contact and into the quartzo-feldspathic band. D130-A is from the

greenstone underlying the siliceous rocks. It is a dark greenish grey, mildly foliated amphibolitic rock.
D130-B, C and D are very light grey to cream, fine-grained, foliated, intermediate to acid rocks from the border zone and D130-E is a cream to light brownish grey, well-foliated very fine-grained rock from the central zone of the quartzo-feldspathic body. Chemical analyses were obtained (Table 5) and an oxide versus distance plot was prepared (Figure 5).

The gross trends of the curves in Figure 5 show fairly systematic variations:

<u>Silica</u>. Silica increases from 51.0 percent in D130-A to 78.9 percent in D130-E over a distance of 40 feet. The value 78.9 percent appears to be a maximum for the silica content in the quartzo-feldspathic band.

<u>Alumina</u>. Alumina remains fairly constant in the suite (14.5 to 15.7 percent) until silica reaches a value near 70 percent and then drops off to 11.9 percent in specimen D130-E.

<u>Iron</u>. Total iron (oxides) decreases in the suite from 14.8 percent in D130-A to 1.5 percent in D130-E. FeO and Fe_2O_3 individually decrease overall in the suite but with some irregularities.

Magnesia. Magnesia decreases consistently from 5.27 percent in D130-A to 0.37 in D130-E.

Lime. Lime decreases in the suite from 10.7 to 0.7 percent in D130-A and D130-E respectively.

Soda. Soda increases consistently throughout the suite from 1.59 percent in D130-A to 5.40 percent in D130-E.

Potash. Potash rises from 0.47 percent in D130-A to a maximum of 3.15 percent in D130-D and then decreases to 0.85 in D130-E.

Titania. Titania values rise slightly from 0.82 in D130-A to 1.17 in D130-B and then decrease successively in the next three specimens to 0.22.

Manganese. This constituent decreases consistently from .24 to nil in the suite.

Phosphate. This constituent varies in a parallel relationship with titania, rising from 0.18 percent in D130-A to 0.43 in D130-B and then decreasing in successive specimens to 0.04 percent in D130-E.

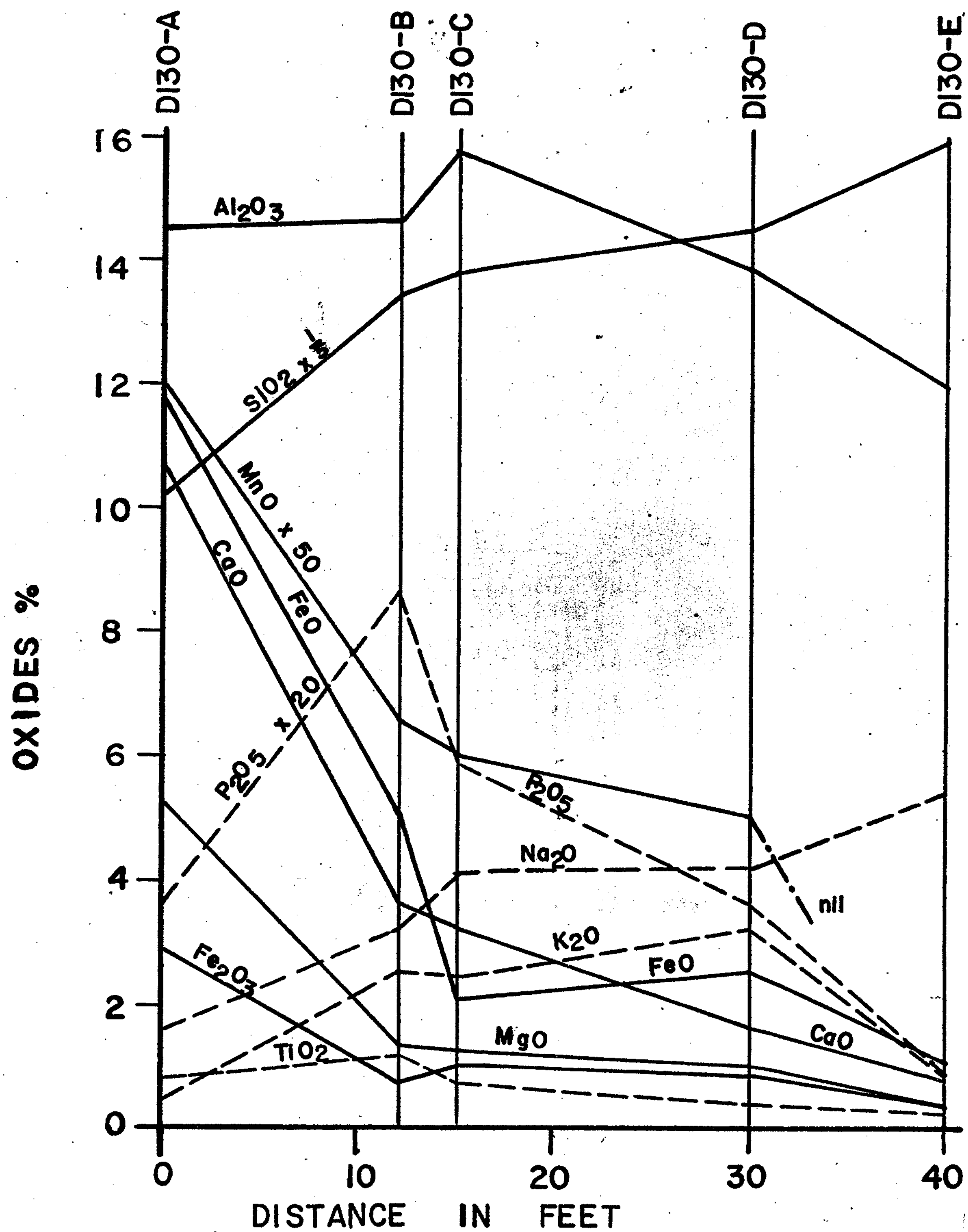

Figure 5: Oxide versus distance plot of chemical analyses of the D130 A to E suite collected from the southern border zone of the quartzo-feldspathic band at site D130.

Table 5

Chemical Analyses for the D130-A to E Suite

Oxides	D130-A	D130-B	D130-C	D130-D	D130-E
SiO_2	51.0	66.0	68.8	72.0	78.9
Al_2O_3	14.5	14.6	15.7	13.8	11.9
Fe_2O_3	2.9	0.72	1.0	0.84	0.30
FeO	11.72	5.04	2.04	2.48	1.04
MgO	5.27	1.34	1.21	0.98	0.37
CaO	10.69	3.61	3.20	1.65	0.74
Na_2O	1.59	3.25	4.14	4.16	5.40
K_2O	0.47	2.50	2.42	3.15	0.85
H_2O	0.22	0.18	nil	0.08	nil
CO_2	0.40	0.21	0.35	0.26	0.33
TiO_2	0.82	1.17	0.77	0.38	0.22
P_2O_5	0.18	0.43	0.29	0.18	0.04
MnO	0.24	0.13	0.12	0.10	nil

Soda-Lime Ratios for Plagioclase in D130-A, C, and E

Clean plagioclase-quartz concentrates of specimens D130-A, C and E, which were obtained by magnetic separation, were chemically analyzed (Table 6). Soda-lime ratios were determined from these analyses and were compared with ratios given for known plagioclase: albite--6.4 or greater, oligoclase--1.3 to 6.4 and andesine--0.6 to 1.3. The plagioclase therefore, is andesine-labradorite in D130-A, andesine in D130-C and sodic albite in D130-E.

Table 6

Chemical Analyses for Quartz-Plagioclase Concentrates

Oxides	D130-A	D130-C	D130-E
SiO_2	93.9	83.4	84.0
Al_2O_3	3.8	11.1	11.2
Fe_2O_3 FeO	0.2	0.1	----
MgO	Tr.	0.4	0.25
CaO	1.3	2.60	0.10
Na_2O	0.78	2.06	4.23
K_2O	0.08	0.4	0.24
$\frac{Na_2O}{CaO}$ =	0.60	0.79	42.3

Chemical Analyses of Hornblende in D130-1 and D30-2

Clean hornblende concentrates were prepared by magnetic separation from D130-1 and D130-2 and chemical analyses were obtained (Table 7). Only two samples could be analyzed as hornblende is absent in the remainder of the suite.

Table 7

Chemical Analyses for Hornblende Concentrates

Oxides	D130-1	D130-2
SiO_2	47.2	44.6
Al_2O_3	12.7	14.5
Fe_2O_3 FeO	19.9	23.0
MgO	6.6	6.0
CaO	11.7	9.5
Na_2O	1.60	0.86
K_2O	0.05	1.56

Total iron is expressed as Fe_2O_3

Variations in hornblende composition relative to that of D130-1 are: decreases in silica, magnesia, lime and soda and increases in potash, total iron expressed as Fe_2O_3

and alumina. It is interesting that silica is less in the hornblende from D130-2 than that of D130-1 in spite of the fact that D130-2 is a more siliceous rock (page 23).

Variation Diagram for D152-4-1 to 4-4 Suite

This suite was collected across an individual pillow and is described petrographically in Chapter 4, page 31. Chemical analyses were obtained for the suite (Table 8) and an oxide versus distance diagram was plotted (Figure 7). It should be mentioned here that the mineralogical data obtained by the point count method for D152-4-2 and 4-3 (Table 2, page 31) do not agree with the chemical analyses given for these specimens (Table 8). Approximate computations from the mineral percentages of Table 2 indicate that the silica content is similar for both specimens (approximately 53 percent) whereas a difference of 6.25 percent between them is indicated by the chemical analyses. This discrepancy may be due to inhomogeneity within a specimen, accidental contamination or perhaps errors in the point counting. The relationship of core to selvage compositions is not greatly affected, however, and for the purposes of discussion the chemical analyses are assumed to be correct.

A definite pattern of compositional variations relative to specimen D152-4-2 from the central part of the pillow (see description of sample locations on page 31) is evident from the variation diagram (Figure 7). Also, greater changes in the oxides relative to D152-4-2 have occurred at the top part of the pillow than at the bottom. Variations in the oxides from the bottom of the pillow to the top (left to right in Figure 7) are:

Table 8

Chemical Analyses for the D152-4-1 to 4-4 Suite

Oxides	D152-4-1	D152-4-2	D152-4-3	D152-4-4
SiO_2	57.60	50.50	56.75	61.10
Al_2O_3	15.65	19.02	17.68	17.40
Fe_2O_3	1.58	2.68	1.70	0.98
FeO	7.84	9.24	6.04	4.80
MgO	3.84	4.04	3.47	2.96
CaO	7.82	7.80	8.35	6.14
Na_2O	2.01	3.20	2.68	3.30
K_2O	0.29	0.18	0.27	0.62
H_2O	1.42	2.03	1.26	1.13
CO_2	0.16	0.07	0.24	0.21
TiO_2	0.80	0.96	0.86	0.92
MnO	0.17	0.16	0.14	0.08

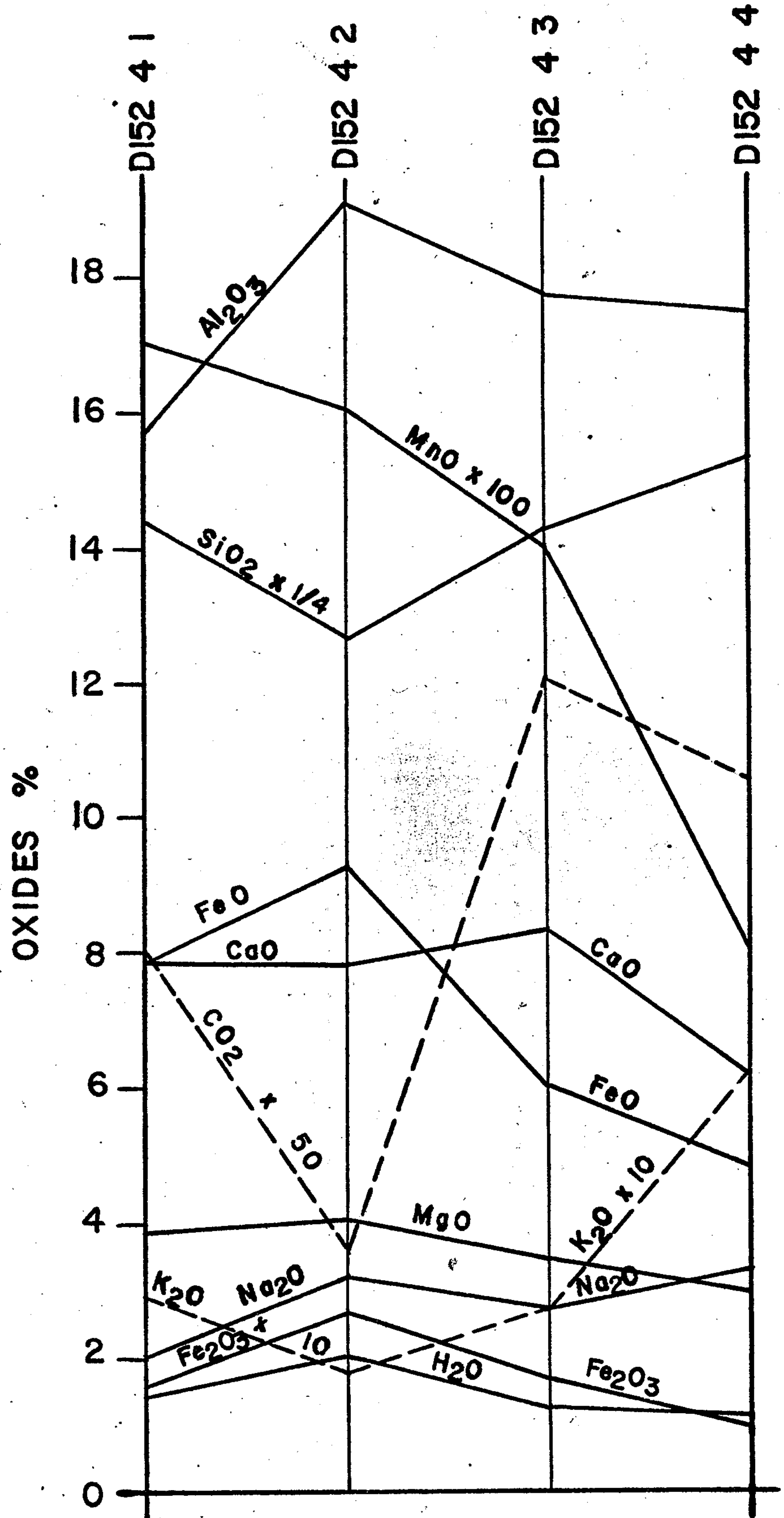

Figure 6: Oxide versus distance plot showing chemical variations across an individual pillow in the greenstone at the south contact of the quartzo-feldspathic band at Site D152 (see plate 4)

Silica. Silica decreases from 57.60 percent in D152-4-1 to 50.50 percent in D152-4-2 and increases to 61.10 percent in D152-4-4.

Alumina. Alumina increases from 15.65 percent in D152-4-1 to 19.02 percent in D152-4-2 and then decreases to 17.40 in D152-4-4. The large increment in alumina from 15.65 percent to 19.02 percent reflects the increase in plagioclase noted during petrographic examination of these specimens.

Iron. Ferric iron rises from 1.58 percent in D152-4-1 to 2.68 in D152-4-2 and then decreases to 0.98 percent in D152-4-4. Ferrous iron varies in a subparallel relationship to ferric iron from 7.84 percent to 9.24 percent and then down to 4.80 percent. Ferrous to ferric iron ratios increase from the center of the pillow outwards from a minimum of 3.45 in D152-4-2 to maxima of 4.95 in D152-4-1 and 4.90 in D152-4-4.

Magnesia. Magnesia varies in a similar manner to iron, rising from 3.84 percent to 4.04 percent and then decreasing to 2.96 percent.

Lime. Lime is constant in the first two specimens of the suite (7.82 and 7.80 percent), rises to 8.35 percent in D152-4-3 and then decreases to 6.14 percent in D152-4-4.

Soda. Soda variations are somewhat irregular.

Potash. Potash values decrease from 0.29 percent in

D152-4-1 to 0.18 percent in D152-4-2 and then increases to 0.62 percent in D152-4-4.

Water (H_2O). Water increases from 1.42 percent in D152-4-1 to 2.03 percent in D152-4-2 and then decreases to a minimum of 1.13 in D152-4-4.

Carbon Dioxide. This constituent decreases from 0.16 percent in D152-4-1 to 0.07 percent in D152-4-2 and then increases to 0.24 in D152-4-3. There is a slight decrease to 0.21 in D152-4-4.

Titania. Variations in titania are irregular.

Manganese. Manganese in contrast to the other oxides decreases consistently throughout the suite from a maximum of 0.17 percent in D152-4-1 to a minimum of 0.08 in D152-4-4.

It is noteworthy that analyses for D152-4-1 and 4-3 are similar and that misleading results would have been obtained if only these two specimens had been collected as representative of the core and selvage respectively.

Specimens D152-4-C and E

D152-4-C and E were taken from the center and edge respectively of a pillow a few tens of feet north of the pillow described in the previous section. Chemical analyses were obtained for these specimens (Table 9).

The analyses for D152-4-C and E are similar and may be misleading, possibly analogous to D152-4-1 and 4-3 in the previous section. Silica, alumina, and magnesia differ by less than the accuracy of the analyses and the remainder, except perhaps for lime, are probably within errors incurred in sampling.

Table 9

Chemical Analyses for Specimens D152-4-C and E

Oxides	D152-4-C	D152-4-E
SiO_2	59.70	59.40
Al_2O_3	16.84	16.95
Fe_2O_3	1.15	1.36
FeO	5.66	6.00
MgO	2.84	3.05
CaO	6.61	8.20
Na_2O	3.18	2.08
K_2O	0.38	0.28
H_2O	1.20	1.02
CO_2	0.17	0.15
TiO_2	0.85	0.88
MnO	0.11	0.14

Barth's Standard Cell Calculations

Barth's standard cell calculations were made for the D152-4-1 to 4-4 suite using the analyses of Table 8 (Table 10). Variations in the cations were measured relative to D152-4-2, which is considered to be the least altered specimen in the suite.

Table 10

Barth's Standard Cell Calculations

for the D152-4-1 to 4-4 Suite

D152-4-2	Oxygen Prop.	Cation Prop.	Cations to 160 ox.
SiO_2	1.6832	0.8416	47.130
Al_2O_3	0.5595	0.3730	20.888
Fe_2O_3	0.0504	0.0336	1.882
FeO	0.1283	0.1283	7.185
MgO	0.1010	0.1010	5.656
CaO	0.1393	0.1393	7.801
Na_2O	0.0516	0.1032	5.779
K_2O	0.0019	0.0038	0.213
H_2O	0.1127	0.2254	12.622
CO_2	0.0032	0.0016	0.090
TiO_2	0.0240	0.0120	0.672
MnO	0.0023	0.0023	0.128
Total	2.8574		110.046

D152-4-1	Oxygen Prop.	Cation Prop.	Cations to 160 ox.	Diff.
SiO_2	1.9200	0.9600	52.992	-5.862
Al_2O_3	0.4602	0.3068	16.935	-3.953
Fe_2O_3	0.297	0.0198	1.093	-0.789
FeO	0.1089	0.1089	6.011	-1.174
MgO	0.0960	0.0960	5.299	-0.357
CaO	0.1396	0.1396	7.706	-0.095
Na_2O	0.0324	0.0648	3.577	-2.202
K_2O	0.0031	0.0062	0.342	-0.129
H_2O	0.0788	0.1576	8.700	-3.922
CO_2	0.0072	0.0036	0.199	-0.109
TiO_2	0.0200	0.0100	0.552	-0.120
MnO	0.0024	0.0024	0.132	-0.004
Total	2.8983		103.538	

Note: Variations are measured relative to D152-4-2

Table 10 (continued)

D152-4-3	Oxygen Prop.	Cation Prop.	Cations to 160 ox.	Diff.
SiO_2	1.8916	0.9458	51.938	-4.808
Al_2O_3	0.5199	0.3466	19.003	-1.855
Fe_2O_3	0.0318	0.0212	1.164	-0.718
FeO	0.0838	0.0838	4.602	-2.583
MgO	0.0867	0.0867	4.761	-0.895
CaO	0.1491	0.1491	8.188	-0.387
Na_2O	0.0432	0.0864	4.745	-1.034
K_2O	0.0029	0.0058	0.319	-0.106
H_2O	0.0700	0.1400	7.688	-4.934
CO_2	0.0112	0.0056	0.308	-0.218
TiO_2	0.0214	0.0107	0.588	-0.084
MnO	0.0020	0.0020	0.096	-0.032
Total:	2.9136		103.400	

D152-4-4	Oxygen Prop.	Cation Prop.	Cations to 160 ox.	Diff.
SiO_2	2.0366	1.0183	54.799	-7.669
Al_2O_3	0.5118	0.3412	18.361	-2.527
Fe_2O_3	0.0183	0.0122	0.657	-1.225
FeO	0.0667	0.0667	3.589	-3.596
MgO	0.0740	0.0740	3.982	-1.674
CaO	0.1096	0.1096	5.898	-1.903
Na_2O	0.0532	0.1064	5.726	-0.053
K_2O	0.0066	0.0132	0.710	-0.497
H_2O	0.0627	0.1254	6.748	-5.874
CO_2	0.0096	0.0048	0.258	-0.168
TiO_2	0.0230	0.0115	0.619	-0.053
MnO	0.0011	0.0011	0.059	-0.069
Total:	2.9732		101.406	

CHAPTER 6

DISCUSSION

General Statement

Several possible origins for the band of quartzo-feldspathic rocks under study are discussed and evaluated. The main theories are:

a) a primary origin in which the siliceous rocks are considered to be a layer of acid and intermediate flows and tuffs enclosed in basic volcanic rocks

b) a secondary origin in which originally basic flows and tuffs have been metasomatized along a zone of shearing by late magmatic emanations from one of three nearby acid intrusions.

Other possibilities are discussed as modifications of these two.

Primary Origin

Work done by J. C. Davies (1965) for the Ontario Department of Mines in the Kenora District to the east has confirmed the presence of abundant rhyolitic and dacitic flows and fragmental equivalents interlayered with basalt and andesite. Intercalations of arkose, greywackes and argillites have also been recorded.

Examining the quartzo-feldspathic band as a primary or stratigraphic feature would imply the following sequence of events as seen at locality D152:

1) The accummulation of a series of pillowed and massive andesites and basalts, perhaps with some tuffaceous horizons.
2) Outpourings of intermediate and acid pillow lavas.
3) Extrusion of a massive rhyolite flow incorporating blocks of pillowed andesitic or basaltic lava.
4) A phase of explosive activity during which a rhyolite tuff bed was deposited.
5) Deposition of basic volcanic rock, possibly largely tuffaceous, directly above the north contact and then a thick sequence of basic flows.
6) Folding, faulting and shearing of the rocks. Evidence of shearing is present in the form of stretched pillows above the south contact of the quartzo-feldspathic zone and the stretched and shredded borders of basic inclusions in the rhyolite. Shredded plagioclase and hornblende crystals and the development of a finely laminated albite-quartz-sericite schist are cataclastic textures which have been noted during petrographic examination of several specimens.
7) Regional metamorphism to plagioclase amphibolite

grade (garnet zone) attended the folding and shearing.

8) Granites, quartz-feldspar porphyry and the Falcon Lake Stock were emplaced. Shearing and gold and sulphide mineralization are associated with the latter.

Site D130 is similar except no pillow structure or amphibolite inclusions in the rhyolite were observed.

Secondary Origin

J. F. Davies (1954) while mapping in the Falcon Lake area was led to the conclusion that the quartzo-feldspathic band is the result of pervasive metasomatism of massive andesites and thinly bedded tuffs giving rise to rhyolite-like rock and delicately banded chert-like rock.

The presence of cataclastic textures in some of the sections studied by Davies and the occurrence of a cryptocrystalline cherty rock at the south margin of the porphyry body near the east end of Falcon Lake suggested the possibility that silica bearing solutions originating in the porphyry were conducted along a shear zone in the andesites.

Considering the quartzo-feldspathic band as a secondary feature due entirely to alkali-silica metasomatism of basic volcanic rocks implies the following sequence of events:

1) The accummulation of a thick series of andesites, basalts and basic tuffs.
2) Folding and shearing of the series, the shears being localized in tuff beds.
3) Regional metamorphism attending the deformation.
4) The emplacement of the granite, the quartz-feldspar porphyry and the Falcon Lake Stock, these events possibly closely related to folding and metamorphism.
5) Volatiles from one of the three igneous bodies were conducted along the shear zone in the volcanic series and caused pervasive metasomatic replacement.

Critique

A principal objection to either hypothesis per se arises due to the presence of gradational features noted in the field, and in petrographic and chemical studies. Modifications to the hypotheses are therefore necessary to accord with the data.

Gradational Features

Gradational features appear to occur on all scales in the rocks of the quartzo-feldspathic band from the main contacts of the zone inwards, to that observed in inclusions and individual pillows.

Sharp contacts between the various rock units were seldom observed but, although outcrops are fairly abundant, they are discontinuous, very fine grained and often obscured by lichens.

Petrographic and chemical evidence at site D130 appear to lend support to the existence of gradational contacts from basaltic or andesitic composition at the periphery of the siliceous body to rhyolitic composition in the central part.

Figures 2 and 3 reveal a pattern of mineral variation in successive specimens from the regionally metamorphosed basic volcanic rocks into the quartzo-feldspathic body. Quartz increases regularly from less than 8 percent to nearly 50 percent. Hornblende diminished and is absent within 100 feet of the contacts. Biotite appears to replace hornblende and increases to a maximum at the point where the latter has disappeared. With increasing distance from the contacts, biotite decreases with the appearance and accession concurrently of muscovite (sericite) and potash feldspar. Where muscovite and potash feldspar are a maximum biotite is a minimum and magnetite is absent. Plagioclase is roughly constant except for peaks in D130-2 and D130-5 which may be significant and is discussed later in this chapter (page 74). Traces of blue tourmaline (schorlite) were noted in D130-4 and D130-5 replacing biotite.

A more detailed picture is provided by suite D130-A to E, five specimens collected across the south contact and into the quartzo-feldspathic body across a total width of 40 feet. Figure 5 summarizes the chemical variations in the suite. In general, the cafemic constituents decrease, silica and the alkalies increase and the alumina curve drops off only a few percent from D130-A to E.

Chemical analyses of hornblende from D130-1 and D130-2 (Table 7, page 41) showed significant variations in this mineral. D130-1 is higher in silica, magnesia, line and soda and lower in alumina, total iron, and potash.

Chemical analyses of plagioclase from D130-A, C, and E showed compositions of andesine-labradorite, andesine and sodic albite respectively.

Mineral variations across an individual pillow are described on page 31 and are summarized in Table 2. Only quartz shows a consistent variation from high values in the peripheral parts of the pillow to low in the core. Chemical variations (Figure 7) however, are systematic. Variations relative to D152-4-2 which is the lowest in silica (notwithstanding the discrepancy noted on page 51) are: decreases in alumina, ferrous and ferric iron, magnesia, water and titania and increases in silica and potash. Soda is irregular but shows a general increase from the bottom of the pillow to the top. Lime is fairly constant except at the top of the pillow where it drops off. Manganese decreases consistently from the bottom to the top. Greater variations in the oxides were noted in the top part of the pillow than in the bottom part perhaps indicating an overall gradient superimposed over the local variations.

Two specimens from the center and edge of another pillow were studied (page 34). Mineral percentages are much more variable than in the first pillow (Tables 2 and 3). Notably, the chemical variations are not great (see page 53) and examination of Tables 8 and 9 show that similar results would have been obtained from the apparently more variable D152-4-1 to 4-4 suite if only D152-4-3 and D152-4-1 had been collected as representative of the center and edge respectively of the first pillow studied.

Mineral variations across an amphibolite inclusion at site D152 (FL-1 to 7 suite plus WHL-9, an auxiliary specimen of the host rock) are symetrical about the least altered central part (see Figure 4). Variations from the center outwards are somewhat similar to those of the D130-1 to 6 suite. The appearance and accession of biotite attends a decrease in hornblende. Quartz increases and then decreases to minima corresponding to peaks in the plagioclase curves. A trace of tourmaline was noted in FL-7.

From the evidence of gradational contacts, it is difficult to avoid the conclusion that at least some metasomatism in one form or another has been operative and that the primary origin as outlined earlier is untenable. It is not unequivocal from this evidence however, that a pervasive type of metasomatism generated by an external magma source has occurred.

Several discontinuities in the mineral variation diagrams of Figures 2 and 3 are possible with the sample spacing used (D130-1 to 6) and, in fact, at least one is demonstrated by the oxide variation diagrams of Figures 5 and 6. Here, within 40 feet of the south contact at site D130, the most siliceous rock sampled occurs (D130-E) containing 78.9 percent silica and highly sodic albite. From the mineral variation diagrams (Figures 2 and 3) the most acidic rocks seem to occur some 200 feet further north of the south contact and these are not as siliceous as that of D130-E. Further, differentiation in the magma chamber is necessary to account for the wide range in composition of the volcanic products commonly ejected during a volcanic cycle and successive deposits of basalt, andesite, dacite and rhyolite flows and pyroclastics would also show similar trends to those in the variation diagrams. Whether so complete a differentiation series could be represented in a formation as thin as 500 feet is open to question however.

It is difficult to explain some of the chemical variations noted in the hornblende analyses of D130-1 and D130-2 (Table 6), especially an apparent desilication in the presence of excess silica under the conditions of alkali-metasomatism. In a normal differentiation series, however, lime and magnesia should decrease and iron increase, alumina should increase in substituting for silica in the tetrahedra and potash should increase with respect to soda. A process of differentiation, therefore, offers a possible explanation for the variations.

Alteration

It remains to investigate the various processes which may have operated to produce the apparent alteration features observed. These can be conveniently discussed under the following headings:

a) Hydrothermal origin

b) Autometamorphism

c) Dynamic and Regional Metamorphism

a) Hydrothermal Origin

A pervasive type of metasomatism causing almost total reconstitution of the rocks in the area of the quartzo-feldspathic band requires a considerable volume of mineralizing fluids which presumably would indicate a hydrothermal process. The prerequisites for such a process are a permeable horizon and abundant evidence for shearing in the band is present (page 58).

Hydrothermal fluids may have originated in a nearby acid intrusion or in the volcanic source magma giving rise to a solphateric alteration. Three different acid igneous intrusions are present in the vicinity of the quartzo-feldspathic band:

1. The Falcon Lake Stock
2. The Bordering Granites
3. The Quartz-feldspar Porphyry

1. The Falcon Lake Stock.

This body lies within 3/4 mile north of the western tip of the quartzo-feldspathic band. Numerous minor shears within the volcanic rocks bordering the stock are mineralized with gold and sulphides. These shears are associated with the stock. According to J. F. Davies (1954, page 21):

> "....the deposits consist of zones of silicified and mineralized rock with subordinate vein quartz....sulphides are generally disseminated throughout the gangue of silicified country rock and quartz."

Evidently, sulphides were an essential constituent of the hydrothermal fluids which originated in the stock.

Sulphides were not found in any of the thin sections studied. Further, the trend of the zone indicates a lack of structural association with the stock. For these reasons it seems improbable that the Falcon Lake Stock could have supplied the material for hydrothermal alteration.

2. The Bordering Granites.

The granite batholith to the south is in contact with the volcanic rocks under Falcon Lake probably within 1/2 mile of the north shore. Very little information is available concerning this granite but it would seem that if the granite was the source of the fluids several similar zones of alteration would be distributed along the contact rather than a single isolated zone.

3. Quartz-feldspar Porphyry.

An irregular sill of quartz-feldspar porphyry outcrops along the north shore of Falcon Lake at the east end. This body is controlled by a curving shear set probably associated with the folding and lies on strike with the quartzo-feldspathic band which also shows evidence of having been sheared. Davies (1954, page 14) states:

> "...Besides the main zone of these rocks near the center of the north shoreline of Falcon Lake, thin bands of identical rock occur at the north and south margins of the porphyry intrusive...."

The writer visited only one site in the area of the porphyry. The samples collected by the writer that appeared to be altered volcanic rock were not conclusive. In any case, the quartz-feldspar porphyry remains as an attractive possibility on the basis of strong structural association with the quartzo-feldspathic band if the zone is in fact a result of pervasive metasomatism.

It is not necessary to seek an external source for hydrothermal fluids, however. Hot acid gases associated with volcanism escape along fractures to the surface causing extreme metasomatism of the wall rock. The gases are predominantly steam, perhaps largely meteoric in origin, with such acids as sulphuric, sulphurous, boric, hydrochloric, hydrofluoric, etc., volatile chloride salts, carbon dioxide and other constituents.

Barth (1948), after Stearns and Macdonald, describes an interesting example of solphateric alteration at Kilauea Caldera. Here, gases escaping along faults have altered the adjoining lavas and tuffs. Steam containing low concentrations of sulphuric, sulphurous and carbonic acid has altered the basic volcanic rocks to a rock composed largely of opal with subordinate clay minerals and relict magnetite and ilmenite. The original textures are remarkably well preserved.

The cherty rock with contorted agate-like banding (Plate 5) observed in the central zone at site D9 may have been formed by solphateric alteration and subsequent recrystallization during regional metamorphism.

The occurrence of tourmaline replacing biotite may be due to boric acid having been present in the steam. The amount of tourmaline is small however, and could have been derived from the original rocks.

Alkalies could have been introduced as volatile chlorides in the steam.

Terzaghi (1935) interprets highly potassic rocks as having been formed by hydrothermal alteration. In a later paper (1948) he describes the hydrothermal alteration of rhyolites and obsidians of Esteral, France. The solutions and possibly gases are believed to be part of the volcanic cycle but some alkalies may in part have been derived by local leaching and redistribution in the rocks. Terzaghi found evidence in some samples of alkali feldspars having been replaced by quartz, in others sericite and clay minerals having crystallized in place of feldspars, and in still others alkali feldspars, quartz and sericite or clay minerals having been deposited in veinlets.

There is little to choose between an external source and a volcanic source for the hydrothermal solutions which may have given rise to the metasomatism in the quartzo-feldspathic band. Both sources would produce similar results. Evidence of shearing favours both possibilities equally and a gradational zone could be expected in either case.

b) Autometamorphic Origin

Autometamorphism here includes autolysis and spilitic and keratophyric reactions which some attribute to diagenesis. The degree of alteration implied is moderate and therefore an original acidic composition for the quartzo-feldspathic band is presupposed. In view of the abundance of acidic volcanic rocks in the Kenora area to the east, an hypothesis based on an original acidic composition of the quartzo-feldspathic band must be considered as a possibility.

It is clear that metasomatism at least on a limited scale has been operative from the significant compositional variations within individual pillows. Variations from the core to the selvages of the pillow of the D152-4-1 to 4-4 suite were calculated using Barth's Standard Cell method and were found to be: increases in SiO_2, K_2O and CO_2 and decreases in Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, H_2O and TiO_2.

T. G. Vallance (1965) found that pillows of Pliocene and younger ages, which have glassy selvages, usually have similar compositions of selvages and cores whereas older pillows with devitrified selvages showed considerable variations. Soda everywhere diminished and silica also (as much as 20 percent) as a rule decreases from core to selvage. Water generally increases, and a variety in distribution was found for magnesia, iron, lime, carbon dioxide, alumina, potash and titania, although alumina tends to be uniform, carbon dioxide is usually higher in the core, and potash most often increases from core to selvage.

Silica and water in the D152-4-1 to 4-4 suite differed from Vallance's patterns but open space deposition and regional metamorphism may account for the differences. Several examples of reversals of these trends were noted by Vallance and it should be born in mind that the pillows probably were systems open to their environment.

The lavas studied by Vallance have not undergone strong metamorphism (between prehnite-pumpellyite and low grade greenschist) and he therefore concludes that the alterations were diagenetic and due to the mobilization, particularly of silica and the alkalies during devitrification.

M. H. Battey (1955) studied some New Zealand keratophyres which are interbedded with spillites. He came to the conclusion that silica, soda and potash are mobile under the influence of moderate temperatures over a prolonged period resulting in the redistribution of these elements during or after consolidation and not requiring additions from outside sources. Battey suggests that a possible relationship may exist between potash enrichment and glassy lavas.

Tomkeieff (1941) studied the basalts of Haddenrig quarry near Kelso. He divided the rocks into four units which he interpreted as members of a gradational series resulting from autolysis of the basalt. The rocks grade from fresh olivine basalt with phenocrysts of olivine, labradorite, and pyroxene, through albitized olivine basalt, metabasalt and finally to a highly altered trachytic rock which he terms potash spilite. Quartz-carbonate veins occasionally with chalcedony, chlorite and gouge clay cut the rocks of the quarry. The most significant variations are in soda, potash, water and carbon dioxide. Soda reaches a maximum in the zone of albite basalt, water in the zone of metabasalt and potash and carbon dioxide in the zone of potash spilite. It is interesting that the maximum variation in soda is not great (2.54 to 4.36 percent) and it seems in general that one of the alkalies strongly predominates over the other in reactions of this kind.

Giluly (1933) interprets an albite granite near Sparta, Oregon as the result of soda-silica metasomatism of portions of gabbroic rocks, diorite and quartz diorite masses. The solutions are believed to have originated during the late magmatic stage of crystallization of a diorite body. The degree of crushing and brecciation of the rocks appears to be related to the amount of replacement.

H. Dewey and J. Flett (1911) studied some British pillow lavas and concluded that spilite is a late magmatic alteration associated with sodic igneous rocks. They also note a common association of radiolarian cherts with pillow lavas.

The high mobility and chemical activity of soda, potash and silica at low temperatures and pressures has been well established. The appreciable solubility of silica and soda in water with carbon dioxide at low temperatures and pressures has been demonstrated experimentally (Iiyama, 1961, referred to in Vallance's paper).

Devitrification of volcanic glass seems to result in the mobilization of silica and the alkalies and to a lesser extent nearly all the other oxides. Metasomatic effects due to the devitrification of large amounts of glassy tuff in a sequence could be appreciable if this is the case.

The concentration of silica, the alkalies, water, boron, etc. in the late magmatic stages is well known and need not be enlarged upon.

c) Dynamic and Regional Metamorphism

Some workers attribute large-scale metasomatism to the mobilization and diffusion of ions along temperature and pressure gradients set up by regional metamorphism. The ions are subsequently deposited in areas far removed from the source.

Boyle (1961) interprets the gold deposits of the Yellowknife District as having been formed by a similar process with deposition occurring in dilatant zones along shears which are low pressure and chemical potential zones. Potash diffused away from zones of intense shearing to zones of lower pressure where it formed sericite by reaction with chlorite and plagioclase or combination with alumina and silica.

It is interesting that shears parallel to the strike and dip of the greenstone usually in tuff beds in the Yellowknife District bear introduced quartz but are barren of gold. Transecting shears however are gold bearing. It is perhaps noteworthy that in the Falcon Lake area, transecting fractures associated with the Falcon Lake Stock are mineralized with gold and sulphides, whereas the quartzo-feldspathic band presently under study which lies less than one mile south of the stock and shows evidence of concordant shearing is unmineralized.

According to Ramberg (1952, page 214), in discussing the interaction between incompatible rock units undergoing recrystallization:

> ".... some elements reach a concentration peak in the reaction zone, and other elements become less concentrated than in either of the original rocks."

The phenomenon of culmination and depression which appears to have occurred in the FL-1 to 7 suite resulting in peaks in the plagioclase curves and corresponding depressions in the quartz curves may be relevant to Ramberg's observation.

The conditions for the deposition of ions diffusing along regional metamorphic gradients are present elsewhere in the area where shearing and thick accummulations of tuff occur. The formation of the single, well defined quartzo-feldspathic zone at Falcon Lake by this process therefore, seems unlikely.

Minor modifications may have occurred however, due to the interaction between units of different composition.

CHAPTER 7

SUMMARY AND CONCLUSIONS

The original composition of the rocks in the quartzo-feldspathic band is not known. Some of the gradational features observed are certainly due to metasomatic transfer of material but as to the degree or origin nothing can be said on the basis of the present evidence. These features are satisfactorily explained by all the various possible origins investigated. The original composition, therefore could range from basic volcanic flows and tuffs to rhyolite.

Pervasive metasomatism by solphateric activity or hydrothermal emanations from a nearby intrusion could have replaced basic volcanic rocks or autolysis, diagenesis or regional metamorphism could have modified originally intermediate to acid rocks. Several combinations of original composition and secondary effects are also possible.

The high solubility, mobility and chemical activity of silica and the alkalies at low temperatures and pressures is well documented and could well be of great significance in regional metamorphism and local metasomatism. The concentrations of these elements and others in the pegmatitic stages of magmatic crystallization is well known and due to the same properties. The uncertainty in determining the genesis of the quartzo-feldspathic band is, therefore, due to the consistent behaviour and mutual association of these elements under a wide variety of conditions.

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