PETROLOGY, GEOCHEMISTRY, AND GEOCHRONOLOGY OF SOME PRECAMBRIAN ROCKS OF THE NORTH-WESTERN MELVILLE PENINSULA, NORTHWEST TERRITORIES

PETROLOGY, GEOCHEMISTRY, AND GEOCHRONOLOGY OF SOME PRECAMBRIAN ROCKS OF THE NORTH-WESTERN MELVILLE PENINSULA, NORTHWEST TERRITORIES

BY

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ABSTRACT

The northwestern Melville Peninsula in the area of 69°34'N/84°50'W consists of Precambrian Shield rocks that have suffered multiple metamorphic events, including a high grade metamorphic event in the late Archean, ranging from upper amphibolite to granulite grade locally. The oldest unit present is a tonalite-granodiorite-granite suite showing both foliation and lineation and a somewhat migmatic texture. This biotite-hornblende orthogneiss has produced a Rb-Sr whole rock age date of 2.55 +/- 0.2 Ga. Field relationships indicate that this is a metamorphically induced age rather than an emplacement age. A coarse grained granitic pegmatite associated with the orthogneiss has produced a Rb-Sr isochron indicating an age of 1.83 +/- 0.06 Ga. Petrographic and field evidence indicate that this represents the emplacement age of the pegmatite.

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CHAPTER ONE: INTRODUCTION

1.1 PURPOSE OF STUDY

This study is intended to characterise the chemistry and petrography of some of the rock units present in the northwestern Melville Peninsula. A Rb-Sr geochronological study of two of these units investigates the age relationships as interpreted from field relationships.

1.2 INTRODUCTION TO GEOLOGY

The area is predominantly tonalitic to granitic Archean basement gneiss, generally quartz-plagioclase-hornblende-biotite rocks. These rocks have been affected by upper amphibolite to granulite grade metamorphism which has, in the former case, resulted in the creation of ubiquitous leucosomic sweats roughly paralleling the gneissosity. The gneiss has been intruded by a number of mafic dyke swarms, the oldest of which has been investigated in thin section in this study. This latter unit has undergone the same high grade metamorphic event, creating both a lineation parallel to the gneissosity in the adjacent orthogneisses and leucosomic sweats as well. The third unit studied is a coarse-grained granitic pegmatite.

1.3 LOCATION AND ACCESSIBILITY

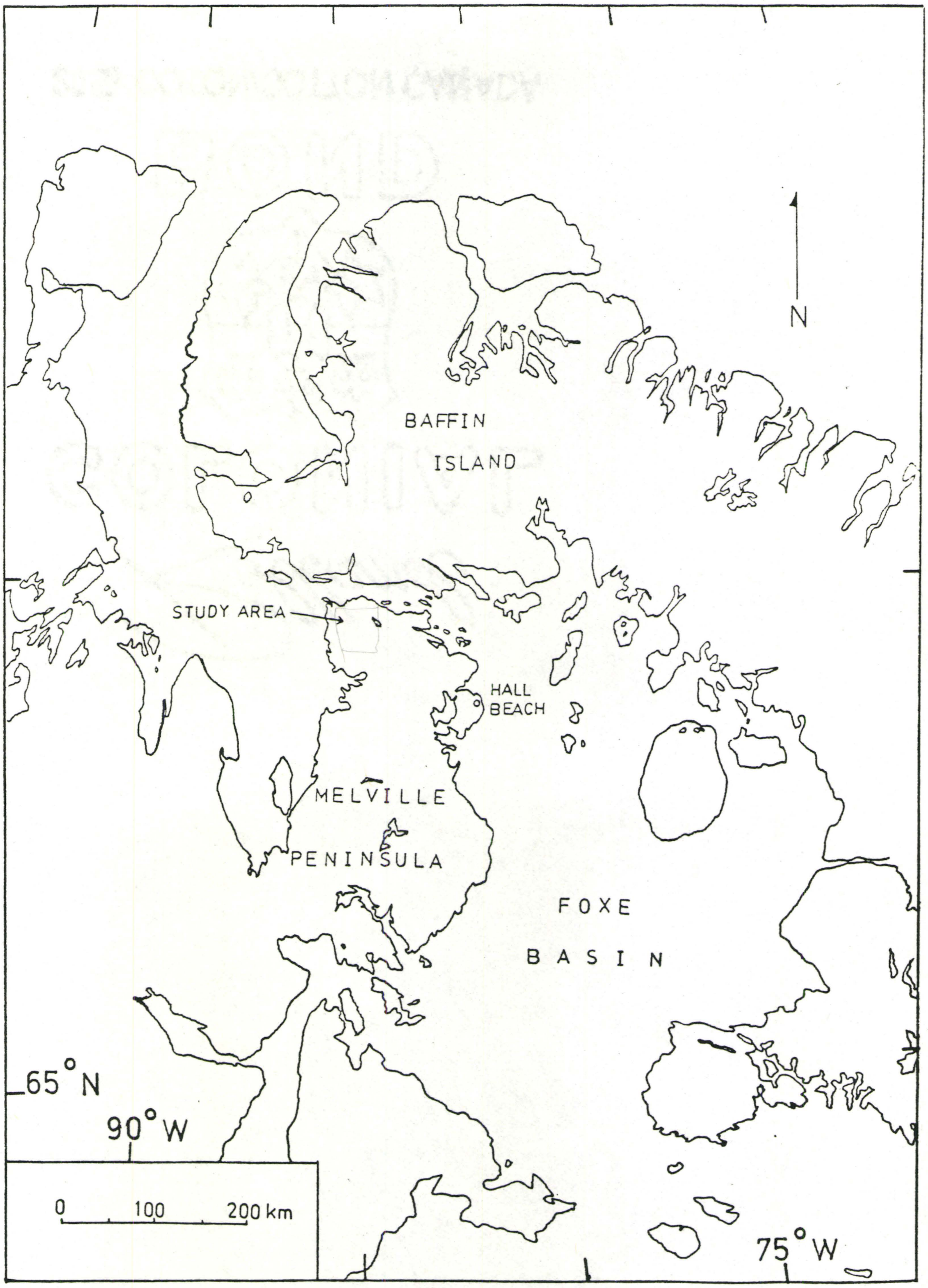
The samples studied were collected in two locations within ten kilometres of Brevoort Lake, in the northwest corner of the Melville Peninsula at approximately 69°34′N/84°50′W. The base camp was located on the northeast side of Brevoort Lake, about one hundred and seventy kilometers northwest of Hall Beach (Figure 1.1).

Access to the mapping area was gained only by air, weather permitting, via Hall Beach. Both of the sample locations are within approximately one hour′s walk of the Brevoort Lake base camp.

The terrain is dominated by glacial phenomena including moraines, eskers, glacially-derived lakes, boulder till, outwash sands and extensive tussock moors. Outcrop exposure is very poor.

The field season lasts for approximately two months, July and August. While July was relatively clear, much of August was unworkable due to extensive fog banks.

FIGURE 1.1


BAFFIN
ISLAND
N
STUDY AREA
HALL BEACH
MELVILLE
PENINSULA
FOXE
BASIN
65° N
90° W
75° W
0
100
200 km

CHAPTER TWO: GEOLOGY

2.1 PREVIOUS WORK

While the Prince Albert Group metasediments to the south and southeast in the districts of Keewatin and Franklin have been studied (Schau, 1978; Schau, 1982; Frisch, 1982; Henderson, 1983) and in the Hall Lake area (Schau 1974, unpublished), but relatively little work has been done on the northern and western Melville Peninsula. The first geological reconnaissance mapping of the area was undertaken by Heywood in 1973 (Heywood, 1974) for the Geological Survey of Canada. The first in-depth study of the northern and western Melville Peninsula began in the 1984 field season by Schau (Schau and Ashton, 1985) as a three year project. No radiometric ages have been published from this area, though some K-Ar and zircon work has been done on the areas to the south.

2.2 REGIONAL GEOLOGY

The regional geology has been summarised from Stockwell et al (1970). Most of the Melville Peninsula is comprised of rocks of the Canadian Shield classified physiographically as the Davis Region. The Melville Plateau in general is a relatively smooth, featureless upland at elevations ranging from 450 to 600 meters above sea level. The terrain in the north and west of the peninsula is relatively rugged.

Most of the Melville Peninsula lies within the Churchill Province, characterised by Hudsonian ages (primarily K-Ar and Rb-Sr) in the range of 1600 to 1800 Ma. In general, Churchill Province rocks consist of Aphebian sediments which have been metamorphosed to varying grades by the Hudsonian Orogeny, even to the extent of being migmatised or converted into granitic gneisses. Northeasterly trending fold axes predominate. Granitic intrusions were emplaced into the Aphebian sediments during the Hudsonian Orogeny. The Aphebian metasediments rest unconformably on Kenoran granitic gneisses and other possibly older, Archean rocks. The Melville Peninsula suffered from the most intense folding and metamorphic effects of the Hudsonian Orogeny.

There is one area of non-Shield rock on the peninsula. The area east and north of Hall Lake, on the east coast, is a constituent of the Artic Lowlands physiographic region of Paleozoic age.

2.3 BREVOORT LAKE AREA

The local geology which includes the units involved in this study is outlined below in order of decreasing age, based on field relationships:

Unit 1 - Tonalitic to granitic orthogneiss that has been metamorphosed to upper amphibolite grade regionally and to granulite grade locally. The granulite grade rocks are characterised by olive coloured weathering surfaces and the presence of orthopyroxene. The amphibolite grade rocks weather to lighter shades, generally grey to white, and contain hornblende rather than orthopyroxene. The amphibolite grade unit is in general a biotite-hornblende granodiorite, and underlies or is cut by all other units in this area. Schau (Schau and Ashton, 1985) suggested that it may correlate with a tonalite unit further south described by Frisch (1982).

Unit 2 - Lineated, pinkish weathering granite, distinguished by the presence of a foliation or lineation defined by biotite and hornblende respectively (Schau and Ashton, 1985), and the presence of flattened quartz and feldspar grains. This unit cuts unit 1 and is cut by unit 3.

Unit 3 - Lineated black-weathering meta-amphibolite dykes, characterised by the presence of both orthopyroxene and clinopyroxene in the granulite grade terrains and by the absence of orthopyroxene from the amphibolite grade rocks (Schau and Ashton, 1985).

Unit 4 - A metasedimentary rock suite which includes gneiss, amphibolite, quartzites, sillimanite schist and meta-pyroxenite (Schau and Ashton, 1985). Schau (Schau and Ashton, 1985) suggests that this unit may be correlated with the Prince Albert Group metasediments elsewhere, thus indicating a middle-Archean age of 2900 Ma (Frisch, 1982).

Unit 5 - Massive, pink weathering, hornblende-biotite granite, aplite and coarse grained pegmatite (Schau and Ashton, 1985). Outcrops of amphibolite grade rock contain about 15% leucosomic pods or stringers, of composition comparable to that of the larger granitic bodies. Schau (Schau and Ashton, 1985) has postulated that partial melting of the tonalite-granodiorite-granite unit (Unit 1) has produced this granite. The relationship between this melting event and the high grade metamorphic event evidenced elsewhere is as yet not fully known, based on field relationships alone. Subsequent to the formation of the Unit 5 granites, at least two generations of mafic dyke swarms have been intruded around a major faulting episode, all of which are probably of Proterozoic age (Schau and Ashton, 1985).

2.4 STRUCTURAL RELATIONSHIPS

The field relationships between Schau's Unit 1 (granite-granodiorite-tonalite), Unit 3 (meta-amphibolite dykes) and Unit 5 (granite) have been studied in detail on an outcrop composed solely of these three units. Refer to Figure 2.1 for an outcrop map. Units 1 and 5 were studied geochronologically.

The Unit 1 granite-granodiorite-tonalite gneiss, hereafter referred to as orthogneiss, is cut by both Units 3 and 5. The orthogneiss displays a foliation and a lineation conformable to the lineation of the amphibolite, indicating that the event which produced the mineral orientation postdates the emplacement of both of these units. Both the orthogneiss and the amphibolite display narrow leucosomic sweats or stringers running roughly parallel to strike (Plate 1 A, B) within fifteen degrees. Blocks of orthogneiss alone, and of orthogneiss cut by amphibolite are present, surrounded by coarse grained pegmatite of Unit 5 (Plate 2). There has been movement of these blocks, as the sweats and amphibolites are not conformable even where separated by just a few centimeters of pegmatite.

The Unit 5 pegmatite shows no mineral orientation except locally where coarse biotite leaves may display a poorly defined foliation over a few centimeters

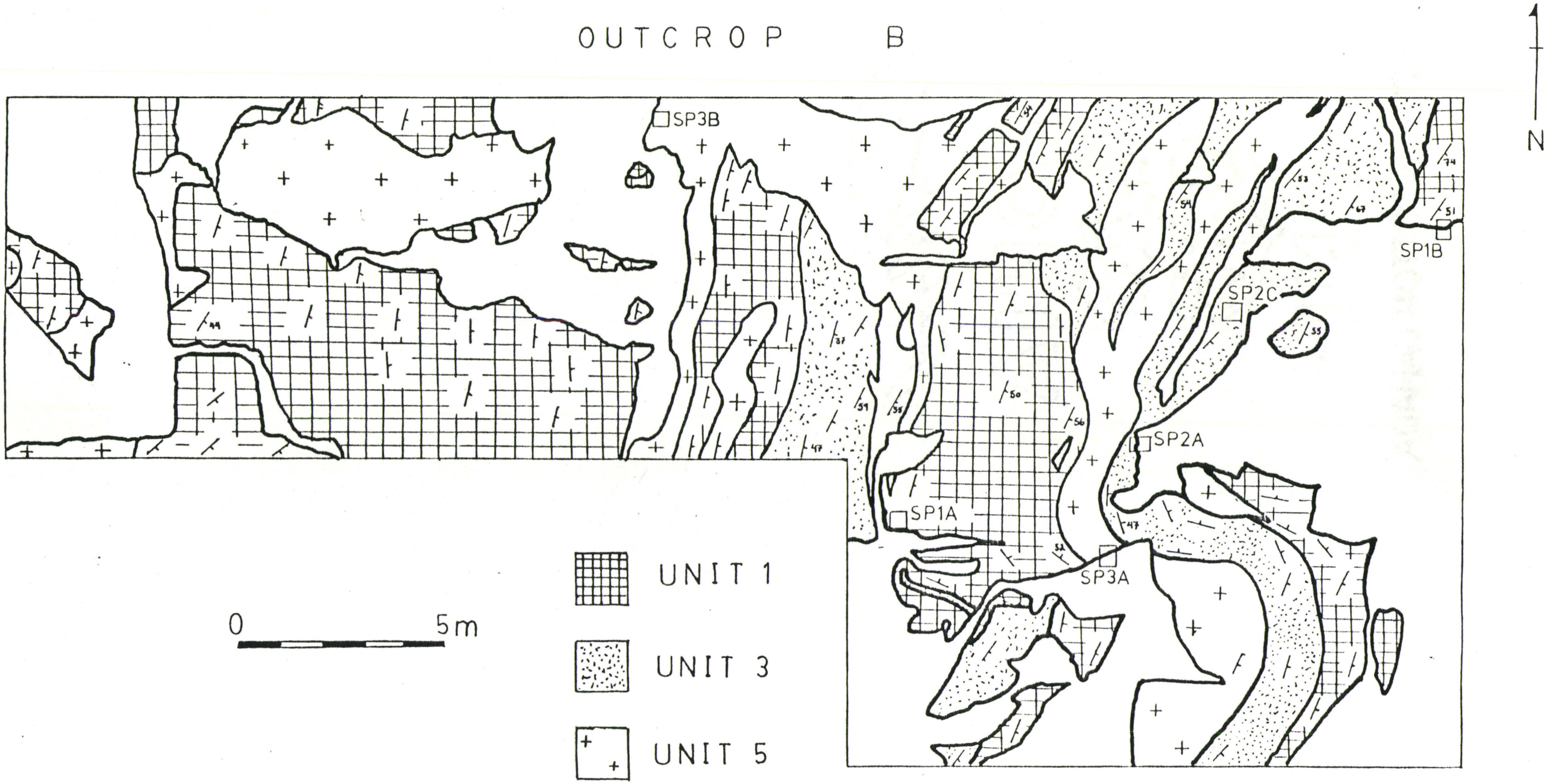

OUTCROP B
N
SP3B
SP1B
SP2C
SP2A
SP1A
SP3A
0
5m
UNIT 1
UNIT 3
UNIT 5

FIGURE 2.1

PLATE 1

A : S - Folded leucosomic sweats in Unit 1 gneiss

B : Thin leucosomic sweats or stringers in Unit 3 meta-amphibolite.

A

B

PLATE 2

A large (~1 m) block of Unit 1 gneiss, cut by both leucosomic sweats and Unit 3 amphibolite bands, enclosed within Unit 5 pegmatite. The amphibolite bands in this block are disconformable with those in the gneiss below, indicating movement of the block relative to the adjacent gneiss, if only of a few centimetres.

distance. This unit cross cuts both the orthogneiss and the amphibolite (Plate 3), transgressing mineral orientations and unit contacts. It is the lack of foliation in the pegmatite and its cross cutting nature that define it as the youngest unit.

The outcrop has a north-north easterly foliation corresponding to the northeasterly regional strike. All three units show evidence of a late deformational event that all of the defined by S-folding (Plate 4), with fold axes generally trending northeast to easterly, plunging at forty to fifty degrees. This conforms to the regional tectonic orientation characteristic of the Hudsonian deformation. The limbs of the S-folds trend north north-easterly, roughly conformable with unit strikes. The leucosomic sweats in the orthogneiss also display a similar S-folding.

The amphibolite unit displays boudinage, both on a small scale (Plate 5) and on a large scale, in the form of outcrops aligned in an en-echelon array (Grant, pers. comm., 1984).

PLATE 3

Unit 5 pegmatite cutting across a contact between Unit 1 gneiss, on the lower left, and Unit 3 amphibolite, in the lower centre. North is towards the top, and the latter two units are both striking ~10°.

PLATE 4

A and B both show a large S folded amphibolite, facing roughly southwest. The red notebook and the hammer are located on the pegmatite (Unit 5) at bends in the fold.

A

B

PLATE 5

A : Boudinaged amphibolite in pegmatite, trending NNE.

B : The centre boudin from A above, showing the kinking and folding of the amphibolite, indicating its relatively brittle nature.

A

B

2.5 PETROGRAPHY

Granite-granodiorite-tonalite gneiss

These gneisses have been sampled in two locations. The series 240 to 242 consists of six samples collected in three pairs from within an area of approximately 200 m^2. These are very similar to one another, based on thin section analyses. This suite will henceforward be referred to as Outcrop A. Another set of samples was collected, albeit somewhat less rigorously, from a single outcrop of approximately 25 m^2 which consisted of two orthogneiss samples (SP1A and SP1B), two amphibolite samples (SP2A and SP2C) and two pegmatite samples (SP3A and SP3B). This suite will be referred to as Outcrop B. These latter gneiss samples have many more stringers and sweats of leucosome. These two outcrops are separated by approximately 8 km. Refer to area sketch map of Figure 2.2.

The results of point counting give the modal compositions classified according to the IUGS classification of Streckeisen (1976). Figure 2.3 shows that all of the gneisses plot within the granodiorite field, with the exceptions of sample 242B (granite) and SP1B (tonalite). Refer to Table 2.1 for modal analyses.

These rocks are dominated by quartz, plagioclase,

FIGURE 2.2

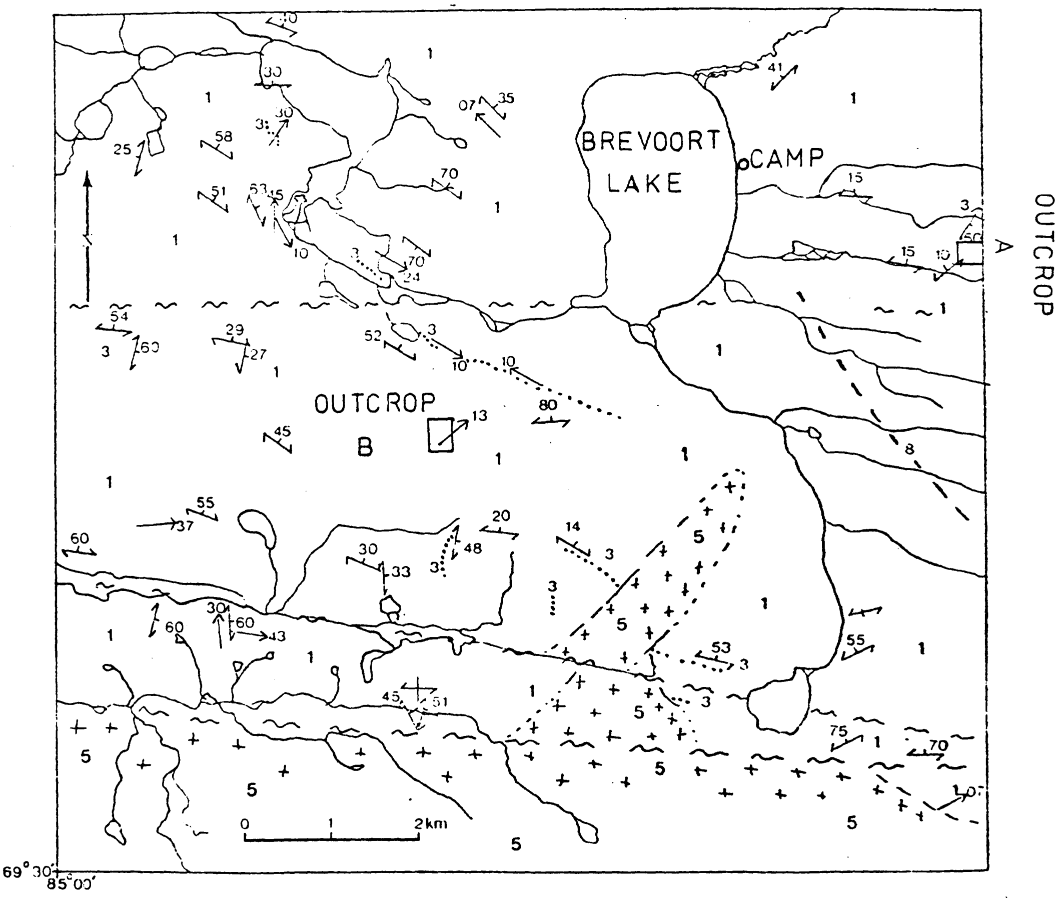


FIGURE 2.3

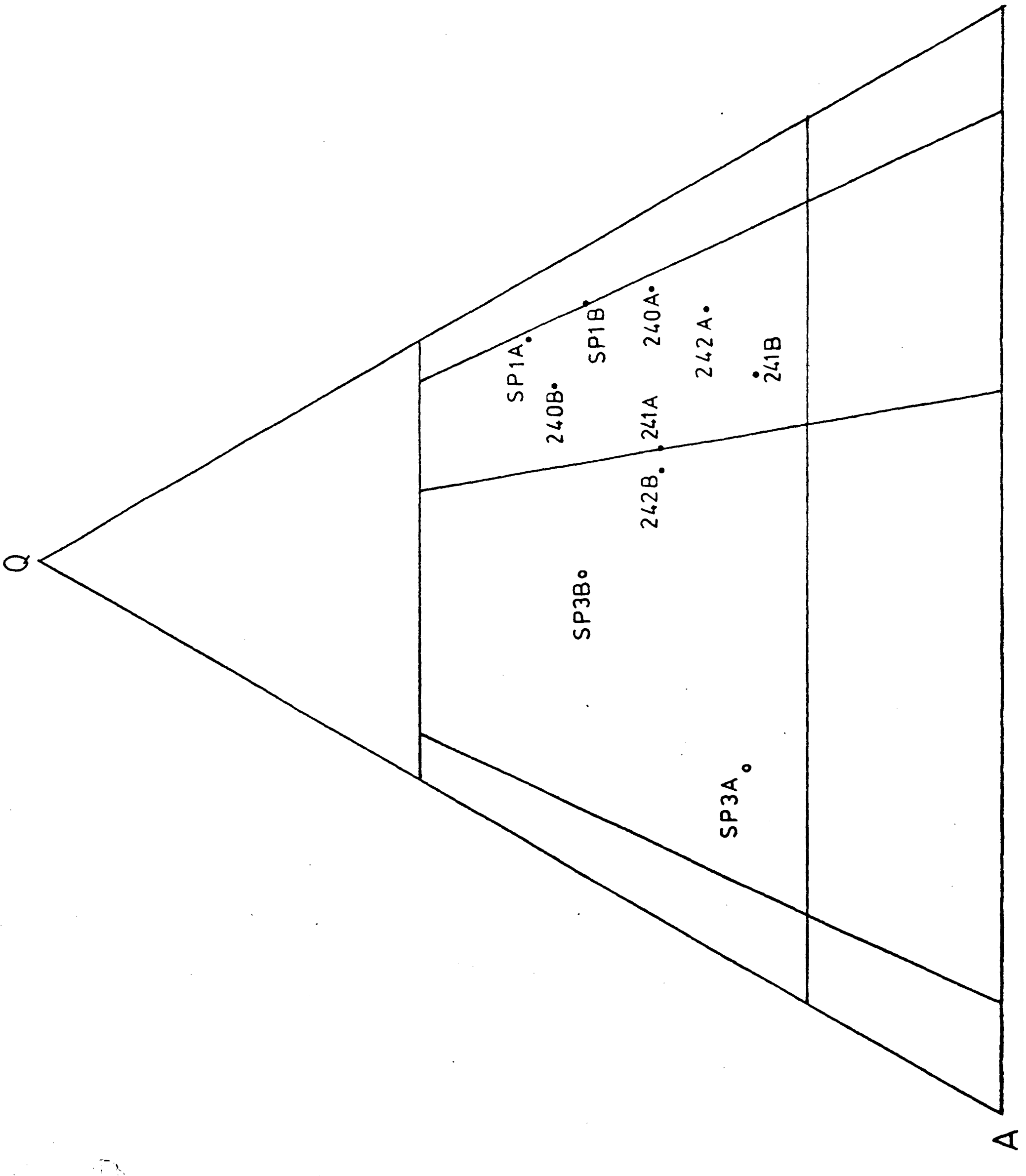


TABLE 2.1

MODAL ANALYSES (%)

Min.	SP1A	SP1B	240A	240B	241A	241B	242A	242B
qz	37.1	31.8	23.1	34.0	28.3	19.2	17.9	27.3
plag	34.4	37.9	36.0	30.8	33.8	40.8	33.9	30.7
or	3.4	2.8	4.1	3.9	15.2	14.3	6.7	16.8
mc	1.1	1.3	0.7	4.3	2.5	1.3	0.4	1.7
hb	11.1	9.5	24.9	15.9	10.8	16.5	24.8	14.2
bi	11.0	16.3	9.1	9.5	7.5	6.2	13.4	7.8
cpx	–	–	–	–	–	–	–	–
opaq	0.7	0.5	1.6	0.9	1.5	1.3	1.6	1.0
other	1.0	0.1	0.6	0.9	0.2	0.3	0.6	0.5
plag	Ab_{68}	Ab_{66}	Ab_{53}	Ab_{70}	Ab_{68}	Ab_{72}	Ab_{58}	Ab_{65}

Min.	SP2A	SP2C	SP3A	SP3B
qz	3.7	13.8	25.8	43.6
plag	24.8	26.0	17.3	26.9
or	3.2	4.0	12.3	6.0
mc	–	–	41.5	23.4
hb	57.5	51.0	–	–
bi	1.8	2.8	1.3	0.2
cpx	4.3	–	–	–
opaq	1.0	0.8	0.7	–
other	3.7	1.6	1.2	–

Counts based on minimum 800 counts per slide.

"other" = holes in slide, occasionally apatite hornblende and biotite. The alkali feldspar content varies from ~10% to 37% of the total feldspar and from about 3% to 17% of the rock. The Michel-Levy test gives plagioclase compositions ranging from Ab_{72} to Ab_{53} with optically negative biaxial figures. This corresponds to calcic oligoclase to andesine plagioclase. The plagioclase feldspars exhibit albite twinning in all cases, generally with quite fine, distinct twinning lamellae, although in some cases the twinning appears clouded and indistinct. Carlsbad and pericline twins are also present, though not abundant. Most of the plagioclase grains are fractured to varying degrees and possess inclusions of subhedral to euhedral apatite and quartz. Most of the plagioclase has suffered minor sericitisation (ie. <5%). In some cases the extinction is shadowed or undulatory in nature, indicative of post-crystallisation strain.

Potassic feldspar is present in form of both orthoclase, and less commonly, microcline, the latter displaying rather poorly defined polysynthetic twinning and occasionally perthite (Plate 6 A, B). The abundance of orthoclase in the sections studied appears to be inversely related to the proportions of biotite and hornblende, especially the former. A weak inverse relationship is apparent with microcline also.

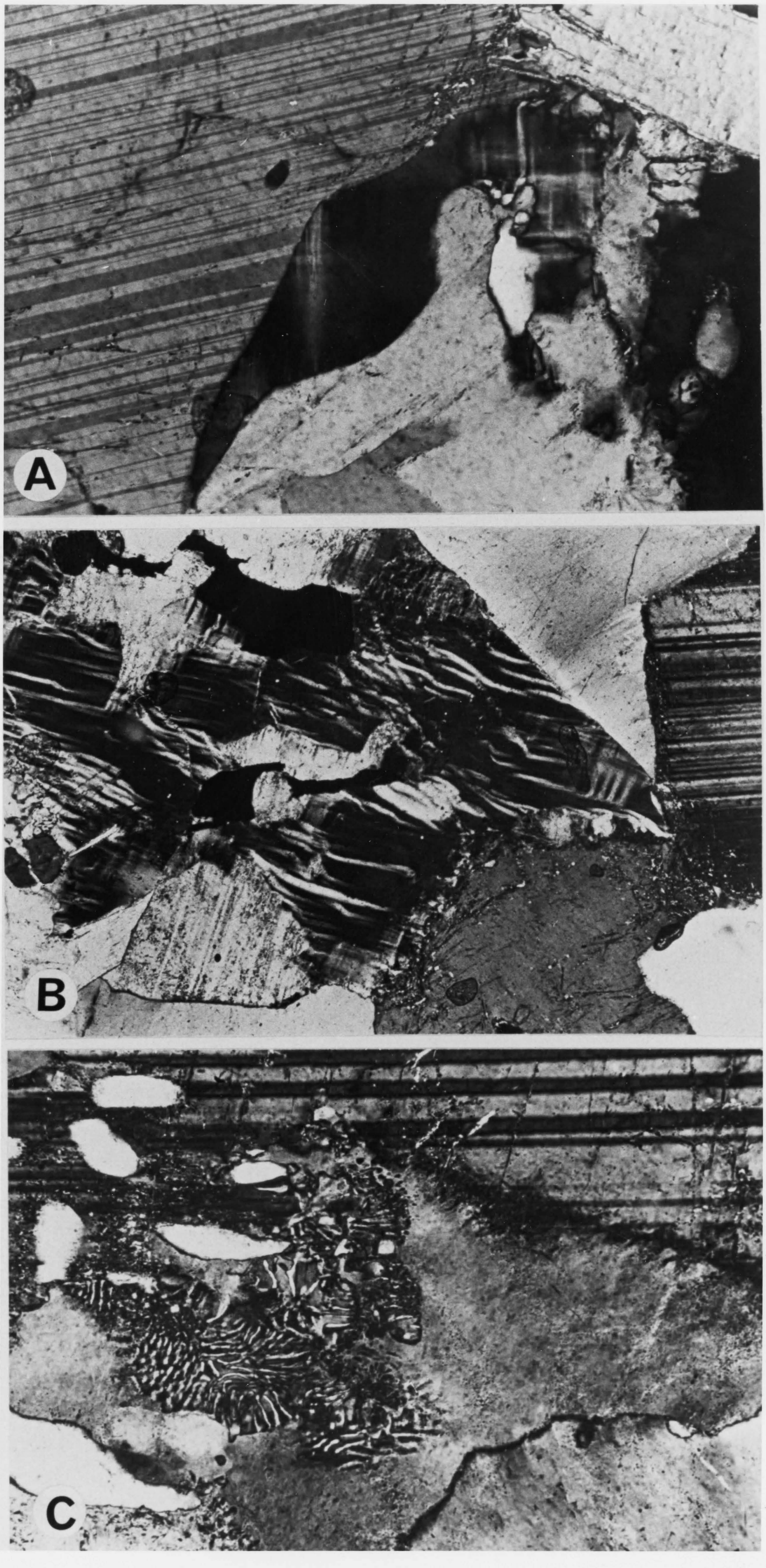
The quartz grains are comparable in size to the feldspars, justifying description of the rock in general

PLATE 6

A : Microcline in Unit 1 gneiss from 242B exhibiting polysynthetic twinning. (x 160)

B : Perthitic microcline in Unit 1 gneiss from 241B. (x 63)

C : Myrmekitic quartz - plagioclase intergrowth at the boundary between plagioclase, on the upper right, and alkali feldspar, in right centre, in Unit 1 gneiss from 241B. (x 160)


A
B
C

as granular. They show varying degrees of undulatory extinction, generally positively proportional to grain size. Quartz is also present in small myrmekitic intergrowths with plagioclase feldspar along the interfaces between plagioclase grains and alkali feldspar grains (Plate 6 C).

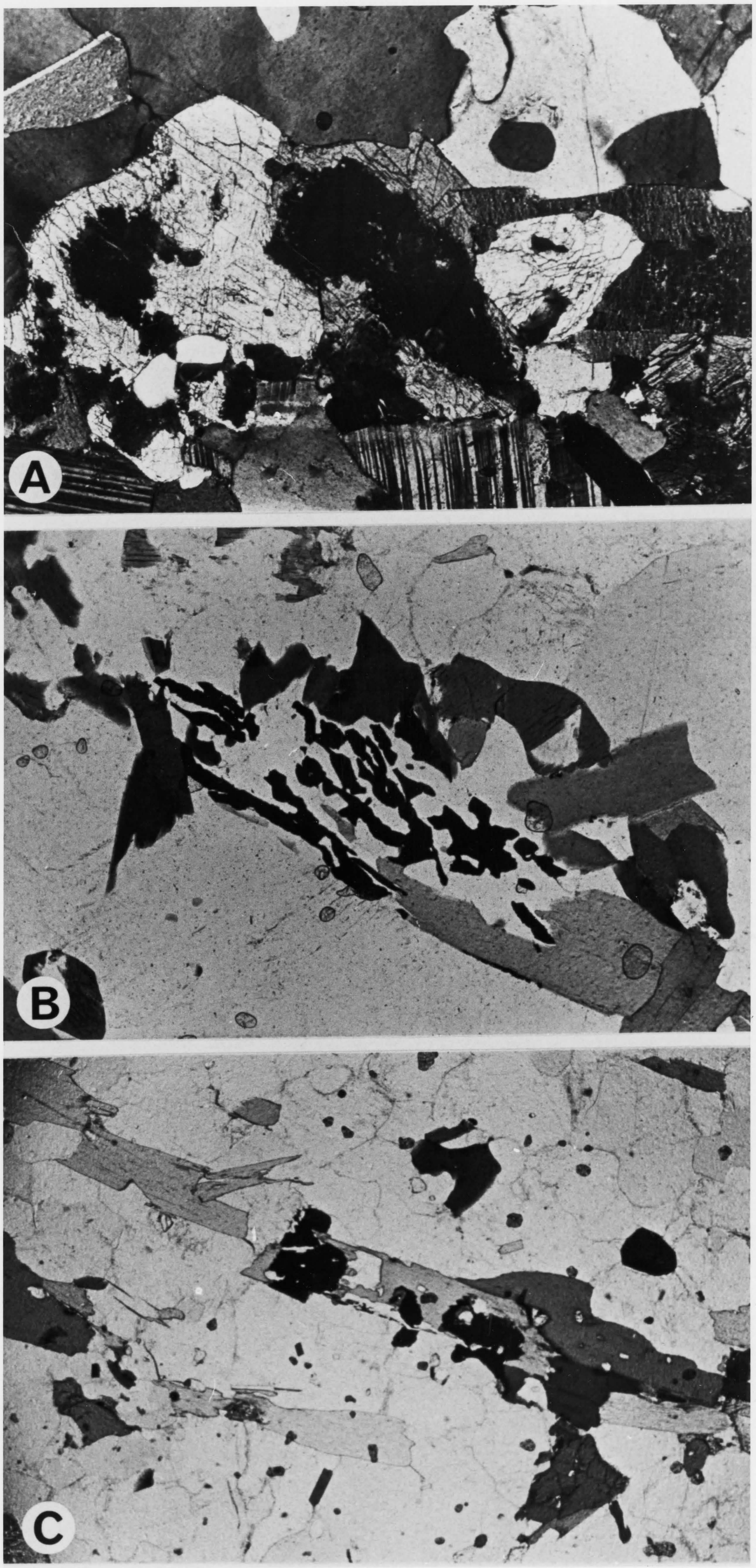
Biotite is present as relatively large (0.5 to 1.5 mm) euhedral flakes or laths, exhibiting the characteristic single basal cleavage and strong pleochroism ($X < Z$) in subhedral to euhedral grains. Amphibole is present displaying pale green colour in subhedral to euhedral grains. Two cleavages are present and distinct at 56° and 124° and the extinction is inclined to the C crystallographic axis of the grains indicating a monoclinic symmetry (Plate 7 A). It has the typical mid second-order birefringence and moderate to strong pleochroism ($X < Y < Z$) and may be classified as hornblende. The amount of hornblende varies from less than ten percent in biotite rich samples to nearly twenty-five percent in others. The biotite tends either to crosscut hornblende grains or to abut them, the former indicating that the biotite postdates the hornblende and the latter indicating the two to be coeval.

Opaques are present in varying amounts, generally associated with hornblende and biotite, commonly as rims along cleavages or grain boundaries (Plate 7 B, C).

PLATE 7

A : Weathered hornblendes showing two distinct cleavages at 56° and 124°, in Unit 1 gneiss from SP1A. (x 63)

B and C show opaques forming at the interfaces between biotite grains and hornblendes, in Unit 1 from SP1B. (x 63:B, x 25:C)


A
B
C

Larger grains of opaques are present, generally anhedral or subhedral, but euhedral grains are found. Rutile is present in minor amounts.

Inclusions of other accessory minerals are most evident in biotite grains and hornblende. These include euhedral apatites as well as zircon and monazite, the latter two distinguished by the pleochroic haloes surrounding them in biotite and hornblende grains.

Granitic Pegmatite

The pegmatite has been sampled in one location (Outcrop B) and consists of two samples, SP3A and SP3B. The pegmatite is a relatively massive (i.e. no preferred mineral orientations), inhomogeneous, coarse grained body. This unit displays a pinkish red colour with a slight orange tint. While the two samples studied contained approximately one percent or less modal biotite and no hornblende, the biotite content from hand samples can run as high as 40% or 50% in biotite rich zones or bands. The modal biotite percentages obtained are probably representative of the majority of the unit, which tends to be biotite poor.

The rock in general, and notably the feldspars, is very coarse grained, generally of 4.5 to 5.0 mm diameter and as large as 2 cm. The rock is a quartz-feldspar rock, with minor biotite. The two samples plot in the granite field of the IUGS classification diagram (Streckeisen, 1976). Refer to Figure 2.3.

Feldspar dominates the rock, and is primarily microcline, distinguished by its polysynthetic twinning and biaxially negative optic sign. Almost all of the microcline is perthitic, such that sodic plagioclase has been exsolved out of the feldspar as it cools (Plate 8 A, B, C). Large perthitic grains are common, and in SP3A perthitic microcline makes up more than 40% of the rock. Orthoclase is present in lesser quantities in both samples. Plagioclase is generally heavily altered to sericite which may be relatively coarse grained. This alteration tends to obscure the twinning almost entirely, making optic sign and extinction position determinations difficult. Where possible, the Michel-Levy test on the albite twinning indicates a plagioclase of oligoclase composition. Zoning is evident in some of the plagioclase.

Large quartz grains are present, showing strong undulatory extinction. The contacts between adjacent grains tend to be heavily sutured, while the contacts between quartz and its neighbours are relatively linear. Vermicular quartz is present in myrmekitic intergrowths at the boundaries between microcline and plagioclase and quartz grains (Plate 9).

Biotite is present in small amounts as cleavage

PLATE 8

A : Coarse grained microcline displaying polysynthetic twinning in Unit 5 pegmatite, from SP3A. (x 25)

B : Microcline displaying both polysynthetic twinning and perthitic exsolution, in the Unit 5 pegmatite from SP3A. (x 25)

C : Strongly perthitic microcline in SP3B, such that the polysynthetic twinning is almost completely obscured by the exsolution. (x 25)

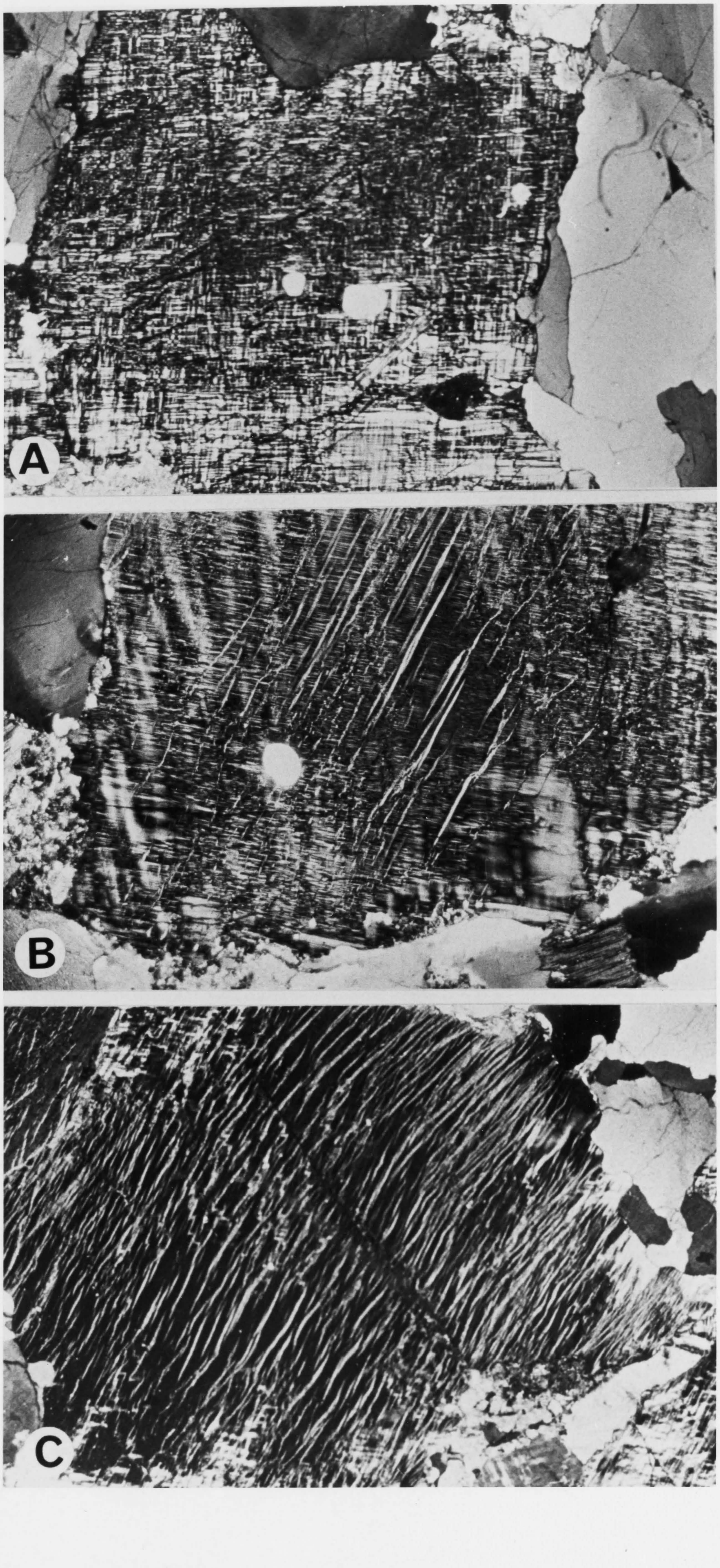
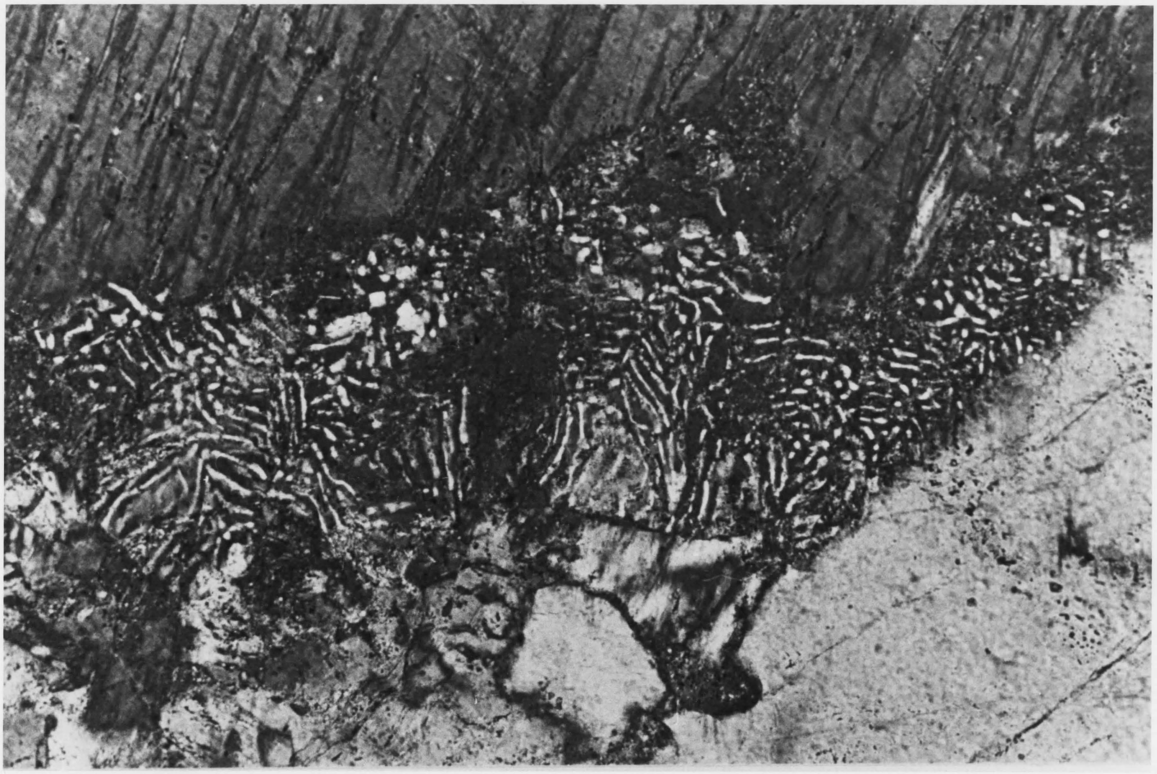

A
B
C

PLATE 9

Myrmekitic quartz bordering a perthitic feldspar grain in the Unit 5 pegmatite from SP3A. (x 160)



fragments, which may show a weak colinearity. The biotite is altering to muscovite around the edges of some biotite grains. Muscovite is also present in fractures in the plagioclase and the microcline. Zircon inclusions are present in the biotite, distinguished by pleochroic haloes, and minor chlorite is altering from the biotite.

Oxides are present in minor amounts consisting of opaque minerals, hematite and rutile.

Meta-amphibolite Dyke

This unit has been sampled in two locations from Outcrop B. Weathered hornblendes stand out as lighter brown lineates on weathered surfaces. Leucosomic sweats are present throughout, displaying coarse grained hornblendes as well as felsics (Plate 10 A, B). These rocks are dominantly hornblende (>50%) and contain lesser amounts of plagioclase and quartz. Clinopyroxene is present in SP2A as relatively small grains associated with the hornblende (Plate 11 A, B).

Plagioclase is the dominant feldspar and shows only minor alteration to sericite. Michel-Levy tests on the albite twinning indicate a sodic andesine composition. Alkali feldspar is present at low levels in the form of orthoclase. Microcline is absent.

PLATE 10

A : Leucosomic sweats in the Unit 3 meta-amphibolite, cut in the top right corner by Unit 5 pegmatite.

B : A coarse hornblende grain associated with a leucosomic sweat in Unit 3 amphibolite. (x 1)

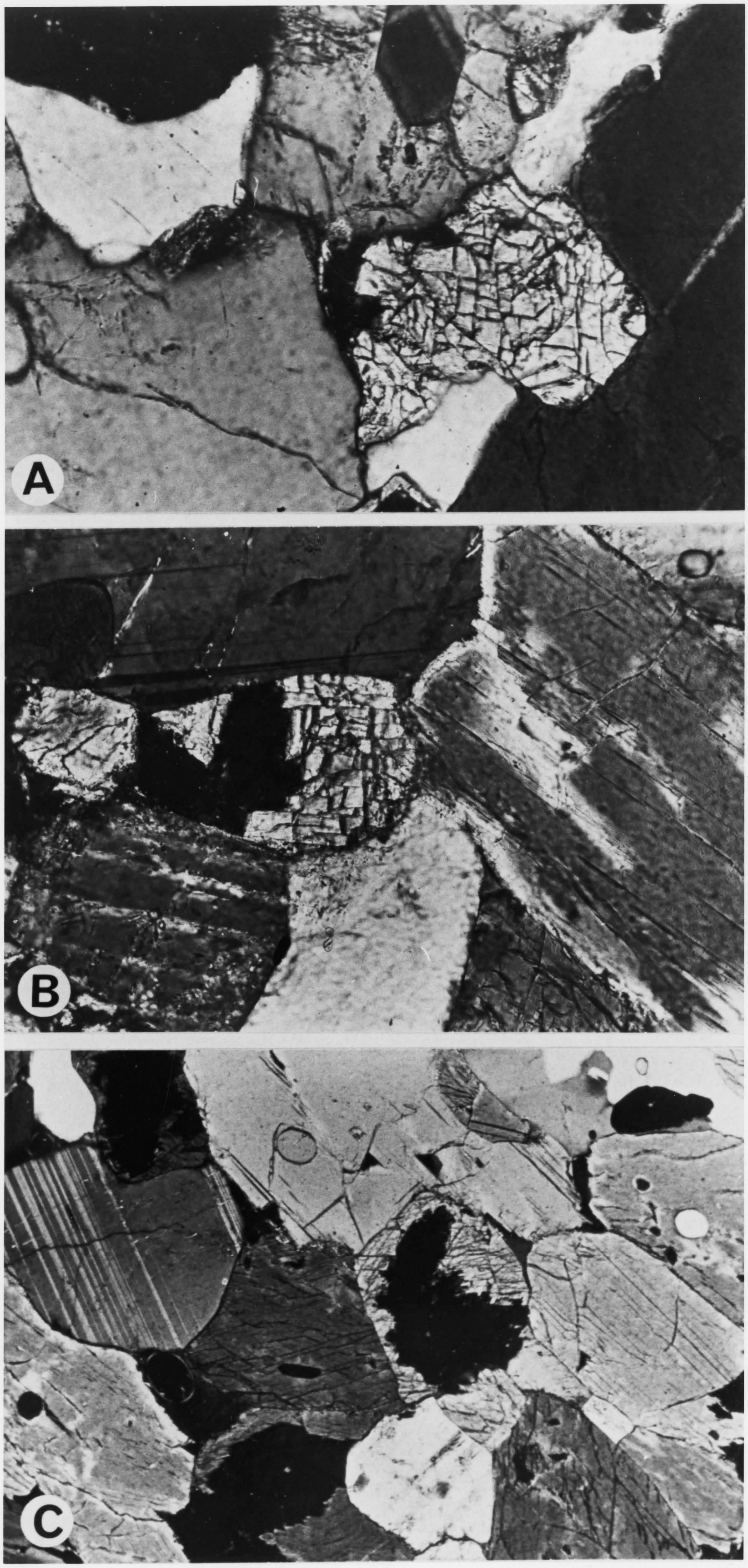
A

B

PLATE 11

A and B show small clinopyroxene grains forming in the interstices from hornblendes in the amphibolite from SP2A. (x 160)

C : Two distinct cleavages in weathered hornblende in the Unit 3 amphibolite from SP2C. (X 63)


A
B
C

Quartz is present in minor amounts, ranging from less than 4% in the clinopyroxene bearing sample to ~14% in the other.

Hornblende is present as anhedral to subhedral grains, displaying the two diagnostic cleavages at 56° and 124° (Plate 11 C). The hornblende appears to be being replaced by biotite laths as the latter cut through grains of amphibole leaving optically continuous hornblende on either side. Simple twinning is common in the amphiboles (Plate 12 A), as are inclusions showing pleochroic haloes.

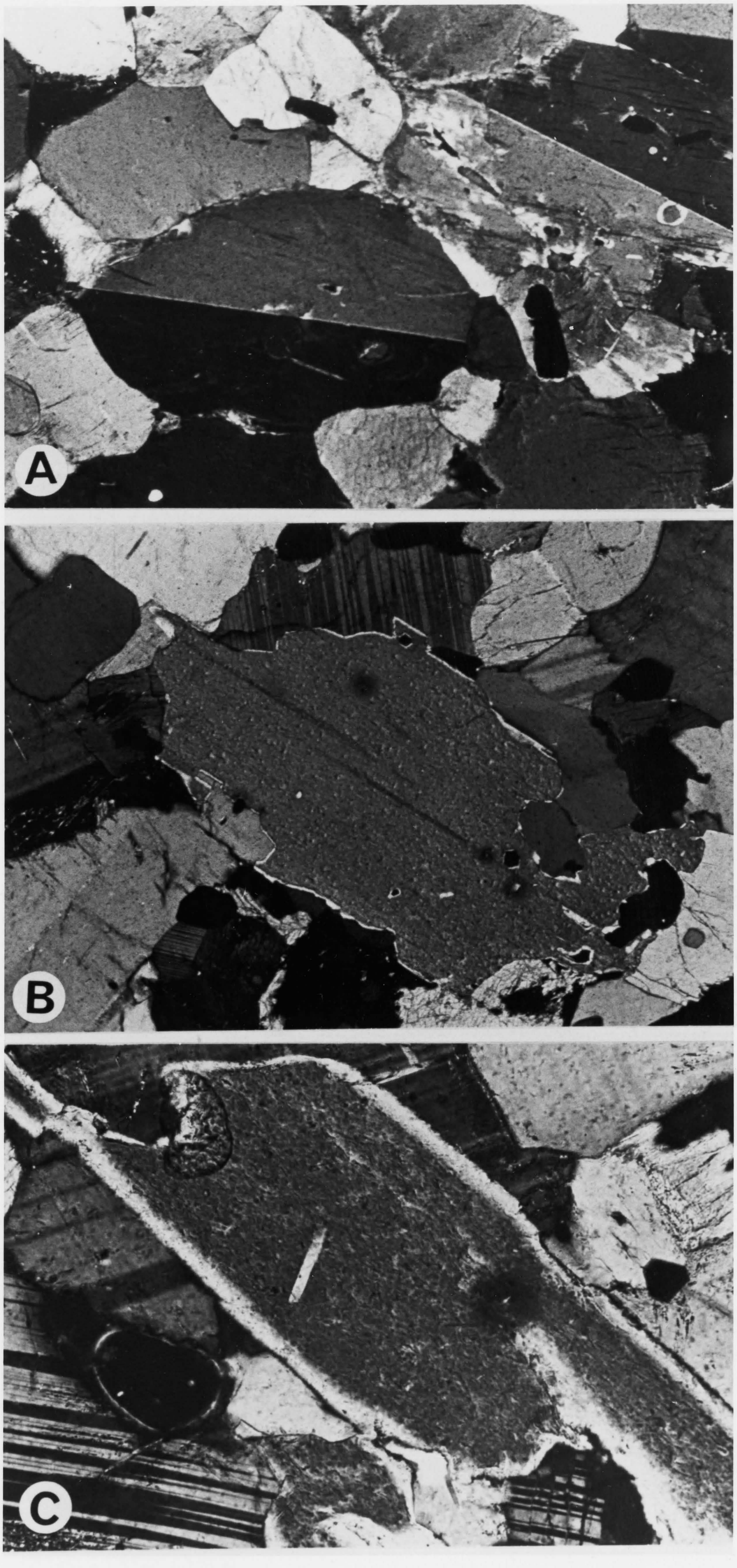
Biotite is present as elongate euhedral to subhedral laths, often displaying pleochroic haloes around inclusion of zircon (Plate 12 B, C).

Opaques are present associated with the hornblende as fine anhedral to euhedral grains along fractures or grain boundaries. Minor rutile and inclusions of apatite are also present.

PLATE 12

A : Simple twinning in two adjacent hornblende grains in SP2A, from Unit 3. (x 63)

B and C show pleochroic haloes surrounding small inclusions in biotites in the amphibolite from SP2C. Note the presence of euhedral apatites in black. (x 63:B, x 160:C)


A
B
C

CHAPTER THREE: ANALYTICAL PROCEDURES

3.1 SAMPLING TECHNIQUE

In sampling for the purpose of Rb/Sr geochronology, one must ensure that the following two basic premises are adhered to in order to produce a geochronologically meaningful age:

i) that the samples are representative of a comagmatic, hence coeval rock suite.

ii) that the integrity of the system has been maintained. i.e. the system has remained isotopically closed.

With this in mind, special care was taken when obtaining samples to avoid fractures and to remove weathered surfaces from the samples. Unit 1 granite-granodiorite-tonalite gneiss samples were taken as far from younger intrusive amphibolite units as possible, in order to minimise the effect of isotopic contamination due to the intrusive event. The main difficulty in maintaining sample "purity" when sampling the granite-granodiorite-tonalite unit involved the presence of narrow (ie. a few centimeters wide) leucosomic sweats throughout the rock, roughly paralleling the foliation and lineation. On the assumption that the sweats were the product of some post-emplacement metamorphic event, to obtain isotopic evidence of the emplacement event age, an attempt was made to exclude the leucosomic sweats from the samples as well as the gneissic rock adjacent to the sweats for at least two or three centimetres. In this way the isotopic effects of the metamorphism could be negated while still maintaining a closed system. The Unit 1 granite-granodiorite-tonalites from which samples SP1A and SP1B were collected (Outcrop B) displayed a much higher density of these sweats, and consequently exclusion of the latter proved to be much more difficult than in the other cases.

Samples 240A, 240B, 241A, 241B, 242A and 242B, were collected in three pairs. Each member of a given pair (i.e. A or B) was one to two metres distant from the other member. Each pair was separated from the other pairs by distances on the order of at least twenty metres. In the sampling from Outcrop B the samples were taken as far from the unit contacts as possible. At the same time, sampling was severely restricted by the difficulty in obtaining samples from the outcrop. As it had suffered severe glacial erosion, most of the outcrop consisted of smooth, relatively flat surfaces, so that samples had to be taken where possible. Use of a portable coring drill was advocated but was not made available. This would have facilitated more effective sampling, both in terms of obtaining fresher samples and in minimising the restrictions applied by the smooth outcrop surface.

A portable gamma-radiation spectrometer was used to measure the ^{40}K radioactive decay energies of the Outcrop A samples, in order to estimate whether or not a spread in K, hence in Rb values was present. This particular technique proved to be ineffective in this instance, as later chemical analyses showed very constant K_2O values, which belies the variation in ^{40}K values observed in the field.

Rock samples were obtained via sledge hammer, and consisted of approximately five to ten kilograms of small fresh chips and at least one large hand specimen suitable for thin sections and other geochemical purposes.

3.2 SAMPLE CRUSHING

Samples were first crushed by hand using a hammer to remove any remaining weathered surfaces and to remove the leucosomic sweats and the adjacent gneiss from the granodiorite-tonalite samples. Following this, the sample chips were crushed in a jaw crusher and then in a Bico ceramic disk pulveriser. Finally, small aliquots of the sample were crushed to approximately 300 mesh using a tungsten carbide ring and puck assembly in a

Spex tungsten carbide shatterbox. Each item of crushing equipment was carefully cleaned using both wire and soft bristled brushes, acetone, and compressed air. The shatterbox was rinsed with hot water and scrubbed thoroughly between samples, and dried with compressed air. In order to further minimise contamination, the shatterbox was precontaminated using a small aliquot of sample which was crushed for about two minutes and then discarded, whereupon the shatterbox was again cleaned with water and dried with compressed air. The finely crushed sample, having gone through the shatterbox, was then stored in airtight plastic containers. Pulverised sample and 100 to 200 mesh sample crushes have also been retained in plastic containers or in plastic sample bags.

3.3 XRF SAMPLE PREPARATION

For X-ray fluorescence spectrographic analyses, the 300 mesh materials were taken in approximately 5 g allotments and mixed thoroughly with approximately 1 ml of Mowiol, an organic binding agent, in a clean four or five dram glass vial. The sample was then pressed into a 30 mm diameter Chemplex or Spex aluminum pellet cup and subsequently compressed to about 25 tons pressure using a Spex 30 ton press. Each sample analysed for Rb and Sr was represented by four or five replicate powder pellets, in order to obtain the most representative results for each sample. Sample homogeneity was also effected by spinning the sample during the XRF analyses.

Both major element and trace element analyses were performed on a Philips, Model PW1450 AHP, automatic, sequential X-ray fluorescence spectrometer. For analytical data refer to Table 4.1 and 4.2.

For XRF major element analyses, 0.5000 g of 300 mesh material was mixed in a clean 4 dram glass vial with 3.0000 g of a flux composed of a one to one mixture of anhydrous lithium metaborate and lithium tetraborate. This mixture was then thoroughly mixed to facilitate rapid and homogeneous melting of the mixture. This powder was heated to about 1200°C in a Pt/Au crucible until it melted into a homogeneous liquid, whereupon it was poured into a Pt/Au mold of 30 mm diameter. This was allowed to cool, producing a fused glass bead which was subsequently analysed on the XRF spectrometer. For a detailed account of the fusion preparation procedure, refer to McMaster XRF Fusion Technique.

3.4 MASS SPECTROMETRY SAMPLE PREPARATION

For mass spectrometric analysis, approximately 250 mg of 300 mesh material was weighed into a clean teflon bomb (Parr Industries), along with 5 ml of 42% hydrofluoric acid and 0.5 ml of 16 N nitric acid, both of which were purified from reagent grade via the sub-boiling distillation technique in teflon bottles. The bombs were then encased in steel jackets and heated to 135°C for approximately four days. Following dissolution, the samples were evaporated to dryness and converted to chloride form using 6 N hydrochloric acid. After approximately two days in the oven at 135°C the samples were removed and cooled. The sample chloride solution was evaporated to dryness and redissolved in 2 ml of 2.40 N hydrochloric acid and then centrifuged. The sample solution was then eluted with 2.40 N hydrochloric acid through cation exchange columns containg Dowex Bio-Rad AG50W-X8, 200 to 400 mesh (hydrogen form) resin. The Sr aliquot was eluted out and evaporated to dryness in either a 1.5 ml conical polypropylene Eppendorf micro test tube or a 5 ml Vycor beaker. The Sr salt was then loaded onto a single 0.030 mm wide tantalum filament which had been etched with 1 N phosphoric acid. The filaments had been preconditioned such that they were heated under vacuum to approximately 8 amps for thirty minutes. For a detailed discussion of the Sr separation techniques, refer to Beakhouse and Heaman (1980).

Elevated Rb values in the orthogneisses (Unit 1) were noted in the Sr aliquots after wet chemical separation of the Sr. In samples SP3A, SP3B, SP1A, 240A and 240B the Rb was removed by passing the samples through the cation exchange columns a second time. For samples 241B, 242A, 242B, and SP3B-7 a ^{85}Rb peak was detected on the mass spectrometer but was burned off during the analyses with no detectable influence on the ^{87}Sr/^{86}Sr ratios.

3.5 MASS SPECTROMETRY

Strontium isotopic analyses were performed on two mass spectrometers in the McMaster Geology Department. The majority of the analyses were performed by a VG 354, 27 cm radius, 90° magnetic sector single focussing mass spectrometer. A multiple collector system enables maximum precision to be obtained as firstly, more of the total ion beam available can be collected over a given time interval, and secondly, the error introduced by peak-jumping methods is minimised as the effect of beam fluctuations with time is reduced. Magnetic field switching and data analysis are controlled by a Hewlett-Packard computer.

Samples SP3A and 240A were also analysed on a McMaster built, 25.4cm radius, 90° magnetic sector, Nier-type mass spectrometer (SS-2). Magnetic field switching and on-line data reduction were controlled by an IBM PC with a Techmarr baseboard controlling the electronic input/output interface. The basic program used is reproduced in part in Appendix 2.

$^{87}Rb/^{86}Sr$ calculations were undertaken assuming a $^{85}Rb/^{87}Rb$ ratio of 2.5995 and a $^{86}Sr/Sr_{TOT}$ ratio of 0.0986 (Faure, 1979). A λ_{Rb} value of 1.42 E-11 $yr.^{-1}$ was used for age determinations.

3.6 PRECISION AND ACCURACY

To obtain the maximum homogeneity for each sample, replicate analyses were made of all powder pellets for Rb-Sr analysis. Two samples were run for major element analyses as triplicates. The means of these replicates were used. For this data refer to Tables 3.1 and 3.2. In order to monitor the machine error standards other than those used to calibrate the analyses were analysed. Comparisons of the standard values produced with literature values are in Table 3.3. Built in error on individual XRF analyses is assumed to be +/- 1% (Heaman, 1980).

For mass spectrometer analyses, analytical data with

TABLE 3.1

Rb - Sr REPLICATE DATA

Sample #	Rb (ppm)	Sr (ppm)	Rb/Sr
SP1A	124	254	0.48575
	121	251	0.48079
	122	251	0.48461
	126	257	0.48980
	124	254	0.48643
MEAN	123 +/- 2	253 +/- 3	0.48548 +/- 984
240A	108	340	0.31767
	109	337	0.32491
	108	336	0.32240
	114	341	0.33446
	109	341	0.31808
MEAN	110 +/- 3	339 +/- 2	0.32350 +/- 611
240B	112	331	0.33818
	109	339	0.32096
	117	344	0.34025
	115	348	0.33089
MEAN	113 +/- 4	341 +/- 7	0.33257 +/- 755
241A	116	352	0.33042
	118	346	0.34170
	116	350	0.33214
	118	348	0.33929
	116	343	0.33818
MEAN	117 +/- 1	348 +/- 3	0.33635 +/- 432
241B	100	336	0.29785
	102	337	0.30273
	108	336	0.32268
	108	335	0.32195
MEAN	105 +/- 4	336 +/- 1	0.31130 +/- 1115

Sample #	Rb (ppm)	Sr (ppm)	Rb/Sr
242A	116	356	0.32581
	112	359	0.31157
	107	350	0.30441
	112	355	0.31455
	119	358	0.33326
MEAN	113 +/- 5	356 +/- 4	0.31792 +/- 1031
242B	116	345	0.33626
	118	349	0.33894
	116	346	0.33491
	118	347	0.33880
MEAN	117 +/- 1	347 +/- 2	0.33723 +/- 171
SP3A	186	211	0.88357
	190	209	0.90948
	188	209	0.90003
	186	210	0.88468
	189	210	0.89844
MEAN	188 +/- 2	210 +/- 1	0.89524 +/- 984
SP3B	251	215	1.16845
	248	210	1.17781
	249	213	1.17003
	247	214	1.15487
MEAN	249 +/- 2	213 +/- 2	1.16779 +/- 826
SP3B-1	239	178	1.34627
	239	178	1.34525
	240	177	1.35372
	244	179	1.36419
MEAN	241 +/- 2	178 +/- 1	1.35236 +/- 76
SP3B-2	218	221	0.98714
	220	224	0.98183
	225	225	1.00019
	208	230	0.90489
MEAN	225 +/- 7	229 +/- 4	0.98563 +/- 97

Sample #	**Rb (ppm)**	**Sr (ppm)**	**Rb/Sr**
SP3B-3	213	237	0.89828
	211	235	0.90041
	215	236	0.90844
	208	230	0.90489
MEAN	212 +/- 3	235 +/- 3	0.90301 +/- 39
SP3B-4	271	188	1.43914
	273	185	1.47273
	273	189	1.43927
	273	191	1.42879
MEAN	273 +/- 1	188 +/- 3	1.44502 +/- 166
SP3B-5	287	163	1.76536
	288	162	1.78025
	290	161	1.79770
	287	160	1.79922
MEAN	288 +/- 1	162 +/- 1	1.78563 +/- 139
SP3B-6	305	168	1.81368
	303	170	1.78740
	303	167	1.81112
	304	170	1.78756
MEAN	304 +/- 1	169 +/- 2	1.79994 +/- 125
SP3B-7	312	209	1.49632
	313	208	1.50341
	306	206	1.48445
	310	209	1.48313
MEAN	310 +/- 3	208 +/- 1	1.49183 +/- 84

TABLE 3.2

MAJOR ELEMENT REPLICATE DATA

Element		SP3B		
	A	B	C	MEAN (+/- Std. Dev.)
SiO_2	72.08	72.54	72.49	72.37 +/- 0.25
Al_2O_3	14.78	14.83	14.80	14.80 +/- 0.03
Fe_2O_3	0.78	0.80	0.76	0.78 +/- 0.02
MgO	0.64	0.07	0.40	0.37 +/- 0.29
CaO	0.56	0.58	0.51	0.55 +/- 0.04
Na_2O	2.59	2.59	2.82	2.67 +/- 0.13
K_2O	8.45	8.47	8.08	8.33 +/- 0.22
TiO_2	0.09	0.09	0.09	0.09 +/- 0.00
MnO	0.0	0.0	0.0	0.0 +/- 0.0
P_2O_5	0.03	0.03	0.03	0.03 +/- 0.00

Element		240B		
	A	B	C	MEAN (+/- Std. Dev.)
SiO_2	63.23	62.95	63.83	63.34 +/- 0.45
Al_2O_3	16.12	15.92	15.99	16.01 +/- 0.10
Fe_2O_3	6.81	7.06	6.56	6.81 +/- 0.25
MgO	1.68	1.73	1.44	1.62 +/- 0.16
CaO	4.57	4.63	4.41	4.54 +/- 0.11
Na_2O	3.26	3.28	3.42	3.32 +/- 0.09
K_2O	3.23	3.33	3.25	3.27 +/- 0.05
TiO_2	0.75	0.76	0.75	0.75 +/- 0.01
MnO	0.09	0.08	0.09	0.09 +/- 0.01
P_2O_5	0.26	0.26	0.26	0.26 +/- 0.00

All data normalised to 100 %.
Oxides reported as Weight %.

TABLE 3.3

XRF STANDARD ANALYSES

A: MAJORS

Element	Lit. Value	JG-1 25/02/85	
SiO_2	72.75	73.03	73.00
Al_2O_3	14.27	14.21	14.26
Fe_2O_3	2.18	2.09	2.05
MgO	0.76	0.72	0.69
CaO	2.18	2.10	2.15
Na_2O	3.41	3.36	3.36
K_2O	3.98	4.06	4.06
TiO_2	0.27	0.26	0.26
MnO	0.07	0.07	0.06
P_2O_5	0.09	0.09	0.11

All data normalised to 100 %.
Oxides reported as Weight %.

B: TRACE ELEMENTS

Sample #	Rb (ppm)	Sr (ppm)	Rb/Sr
JG-1			
Lit. Values	185	184	1.00543
26/02/85	179	190	0.94352
	184	188	0.98014
	189	192	0.98034
12/03/85	179	183	0.97789
	189	190	0.99056
	190	195	0.97605
	189	196	0.96372
T-1			
Lit. Values	32	390	0.08205
26/02/85	27	368	0.07410
	27	374	0.07179
	28	386	0.07366
	29	385	0.07472

All literature values reported from Abbey (1978).

standard deviations is given in Table 3.4. One sample (240 A) was analysed on both the VG 354 and the McMaster SS-2. Both analyses are listed in Table 3.5. The data obtained from the VG 354 was used to plot the isochrons, due to the higher precision of this data. This was because the program used to manipulate the data from the SS-2 used all the data from each run and did not exclude those means outside a 99% confidence interval. Eimer and Amend and NBS 987 standards were analysed and standard data from both mass spectrometers is listed in Table 3.6.

3.7 THIN SLABBING ANALYSIS

In order to more fully define the pegmatite isochron, otherwise composed of only two points, SP3A and SP3B, sample SP3B was sliced into seven slabs of 1.0 cm width (Figure 3.1). The slabs were cut parallel to a biotite rich band included in the sample. Given the inhomogeneity of the pegmatite, a substantial spread in Rb-Sr values was obtained.

The weathered surfaces were sawn off all sides of the sample slabs. The samples were first broken by hand into quarters or fifths and then crushed in a Bico ceramic disk pulveriser. Finally the samples were crushed to 300 mesh in a Spex tungsten carbide

TABLE 3.4

SR ISOTOPIC DATA

Sample #	$^{87}Sr/^{86}Sr$	$^{86}Sr/^{88}Sr$
SP1A	0.756518 +/- 8	0.119831 +/- 250
240A	0.738996 +/- 7	0.12000 +/- 65
240B	0.740432 +/- 6	0.119325 +/- 141
241B	0.740117 +/- 6	0.120447 +/- 54
242A	0.738310 +/- 6	0.120011 +/- 52
242B	0.739568 +/- 6	0.119801 +/- 112
SP3A	0.788060 +/- 7	0.119117 +/- 197
SP3B	0.806228 +/- 7	0.119669 +/- 75
SP3B-1	0.815832 +/- 6	0.119680 +/- 86
SP3B-2	0.791157 +/- 6	0.119193 +/- 54
SP3B-4	0.822396 +/- 6	0.119861 +/- 229
SP3B-5	0.853213 +/- 7	0.120562 +/- 29
SP3B-6	0.853951 +/- 7	0.119681 +/- 77
SP3B-7	0.829476 +/- 6	0.120273 +/- 73

Errors are "Standard Error" as reported by the Hewlett - Packard from the VG-354. The method of error determination differs from the conventional standard deviation and is peculiar to the VG software.

TABLE 3.5

MASS SPECTROMETER DUPLICATE SAMPLE

Sample 240A

Mass Spectrometer	**^{87}Sr/^{86}Sr**	**^{86}Sr/^{88}Sr**
McMaster SS-2	0.7393 +/- 5[1]	0.119359 +/- 519[1]
VG-354	0.738996 +/- 6[2]	0.12000 +/- 65[2]

1. Conventional Standard Deviation [with n(n-1) denominator].

2. VG-354 Standard Error

TABLE 3.6

MASS SPECTROMETRY STANDARD VALUES

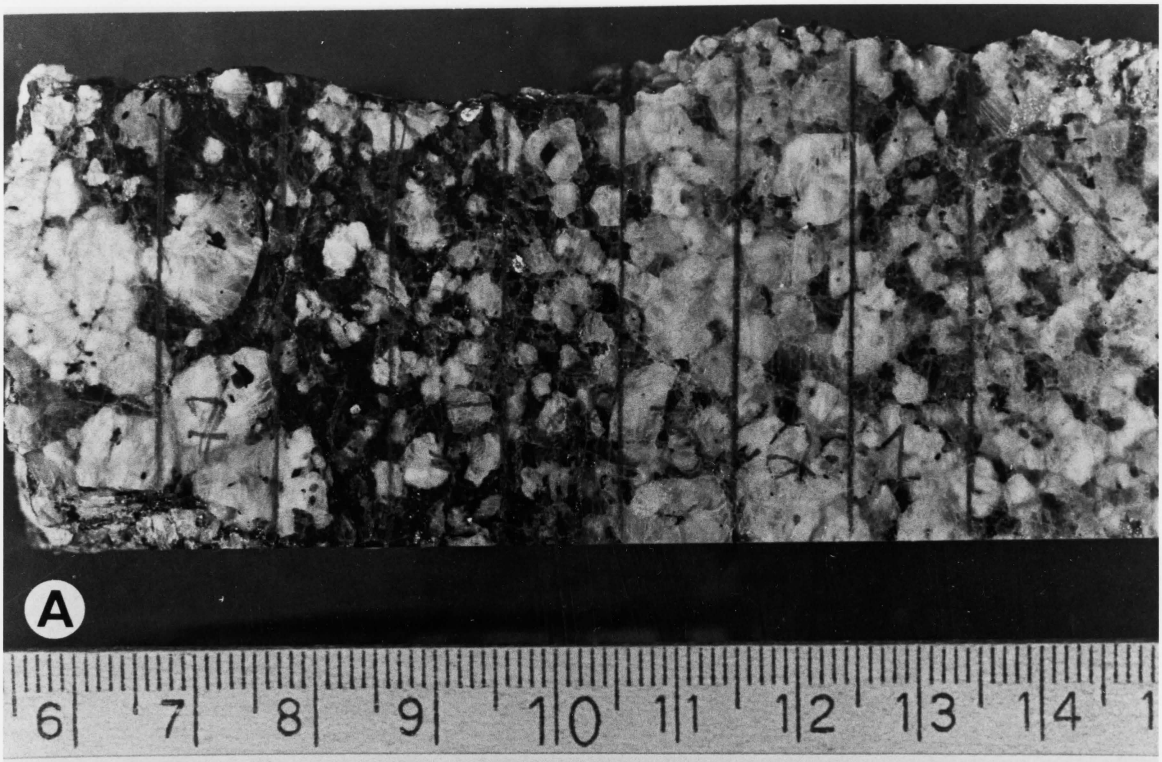
Sample	Date	$^{87}Sr/^{86}Sr$ Value	Mass Spec.
E & A Std.	06/03/85	0.708041 +/- 9	VG 354
		0.708046 +/- 7	VG 354
	12/03/85	0.708049 +/- 6	VG 354
	26/03/85	0.708012 +/- 6	VG 354
	02/04/85	0.708009 +/- 6	VG 354
NBS 987	18/03/85	0.710281 +/- 12	VG 354
	26/03/85	0.710246 +/- 11	VG 354
	02/04/85	0.710235 +/- 6	VG 354

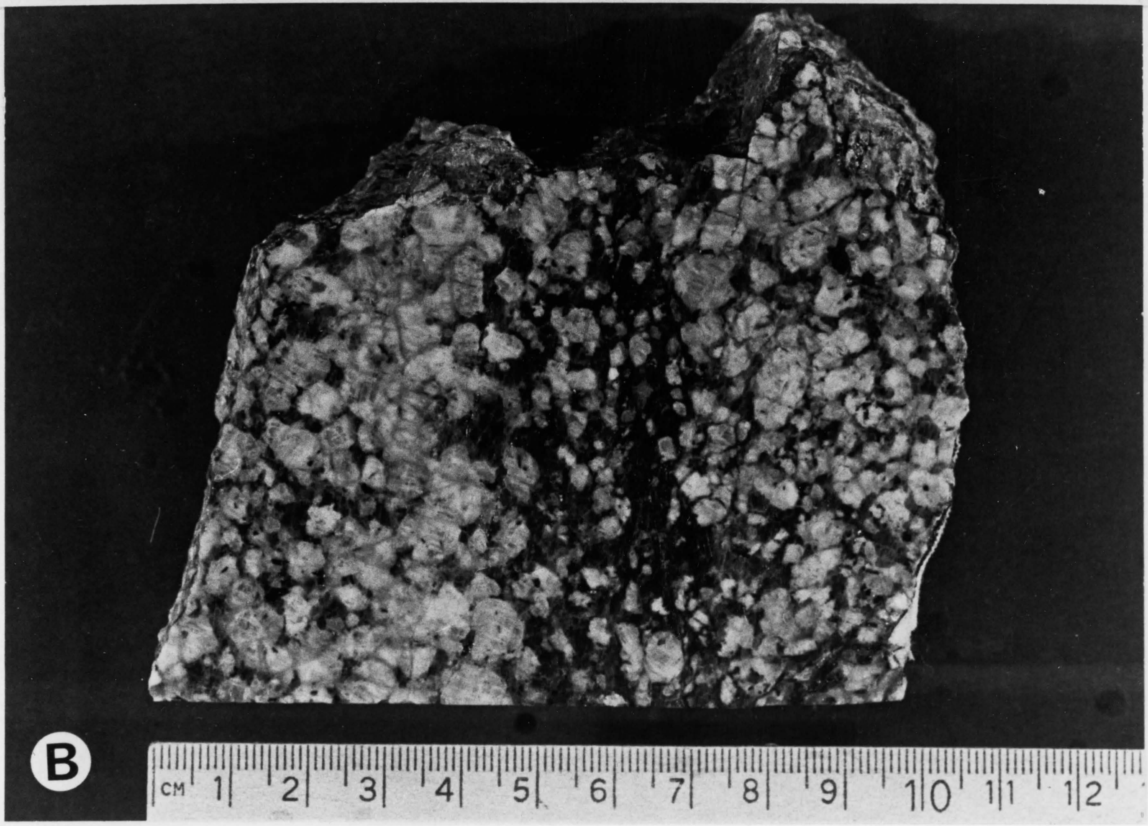
FIGURE 3.1

Unit 5 Pegmatite Thin Slabs

Sample SP3B sliced into 7 slabs of ~1 cm width.

Biotite rich band is part of SP3B-5 and 6, primarily.


A
6
7
8
9
10
11
12
13
14


B
CM
1
2
3
4
5
6
7
8
9
10
11
12

shatterbox as outlined in section 3.2.

Four powder pellets were made from each slab for XRF determinations of the Rb/Sr ratios.

CHAPTER FOUR: GEOCHEMISTRY

4.1 ELEMENTAL GEOCHEMISTRY

Major element analysis of seven of the Unit 1 samples and two pegmatite samples allows a general chemical classification to be made for these two units. Due to the highly weathered nature of the meta-amphibolite dykes in the study outcrop, no chemical analyses of this unit were made.

The Unit 1 granite-granodiorite-tonalite gneisses from Outcrop A are extremely homogeneous with respect to major element chemistry, which corresponds to the homogeneity observed from the modal analyses. The SiO_2 content ranges from approximately 62% to 64%, while the Al_2O_3 content is approximately 16% for all members of this sample suite (Refer to Table 4.1). These values are fairly typical of granodioritic rocks, albeit that the SiO_2 is slightly depleted and the Al_2O_3 slightly enriched relative to average values for rocks of the granitic clan sensu largo (Nockolds et al, 1978). The high Fe_2O_3 content is somewhat anomalous (around 7%) and more characteristic of a ferrogranodiorite as described by Nockolds et al. The lone sample of Unit 1 from Outcrop B that underwent chemical analysis (SP1A) lies

TABLE 4.1

MAJOR ELEMENT DATA

Element	SP1A	240A	240B	241A	241B	242A	242B
SiO_2	66.36	62.49	63.34	64.07	63.51	63.01	63.07
Al_2O_3	14.89	16.02	16.01	15.97	15.63	15.99	15.88
Fe_2O_3	6.33	7.69	6.81	6.69	7.53	7.41	7.44
MgO	1.09	1.54	1.62	1.34	1.40	1.70	1.56
CaO	3.97	4.68	4.54	4.28	4.52	4.66	4.60
Na_2O	3.24	3.10	3.32	3.38	3.08	2.77	2.92
K_2O	2.98	3.16	3.27	3.13	3.09	3.27	3.33
TiO_2	0.79	0.89	0.75	0.81	0.86	0.86	0.85
MnO	0.07	0.11	0.09	0.08	0.10	0.08	0.09
P_2O_5	0.26	0.31	0.26	0.25	0.26	0.25	0.27

Element	SP3A	SP3B	A.G.*	Gran.*	Ferr.*
SiO_2	74.40	72.37	73.86	66.88	64.90
Al_2O_3	14.49	14.80	13.75	15.66	13.33
Fe_2O_3	0.50	0.78	2.04	4.21	9.16
MgO	0.08	0.37	0.26	1.57	0.52
CaO	1.10	0.55	0.72	3.56	3.52
Na_2O	2.77	2.67	3.51	3.84	3.74
K_2O	6.64	8.33	5.13	3.07	3.38
TiO_2	0.0	0.09	0.20	0.57	0.89
MnO	0.0	0.0	0.05	0.07	0.14
P_2O_5	0.02	0.03	0.14	0.21	0.23

* :A.G. = Alkali Granite
Gran. = Granodiorite
Ferr. = Ferrogranodiorite
Average chemical compositions,
from Nockolds et al. (1978)

All data normalised to 100 %.
Oxides reported as Weight %.

further towards the tonalite field than do the six samples from Outcrop A on the IUGS classification diagram (Figure 2.3). Correspondingly SP1A exhibits higher SiO_2 and lower Al_2O_3 values more typical of a tonalite as characterised by Nockolds et al. This sample is depleted in all other major element cations except Ti, relative to the Outcrop A suite, especially the alkaline earth metals.

Trace element geochemistry on Rb and Sr indicates trace elemental homogeneity in the Outcrop A sample suite (Table 4.2). Sample SP1A is significantly depleted in Sr and slightly enriched in Rb (Figure 4.3).

The pegmatite samples show elemental abundances characteristic of a highly differentiated rock. Silica is approximately 5% higher than the orthogneissic values. The alkaline earths and the other metals are all depleted in the pegmatite relative to the granodiorite. Similarly, the Rb content of the pegmatite is elevated (by a factor of two) and the Sr content depleted, relative to the granodioritic suite samples (Figure 4.3). The elevated K/Na ratios characterise highly fractionated rocks (Heier and Adams, 1964), and the Na abundance has decreased relative to the gneisses (Figure 4.1). The K/Rb ratios for the pegmatites are essentially the same as those of the Unit 1 orthogneiss (Figure 4.2).

TABLE 4.2

Rb - Sr DATA

Sample #	Rb (ppm)	Sr (ppm)	Rb/Sr
SP1A	123	253	0.48548
240A	110	339	0.32350
240B	113	341	0.33257
241A	117	348	0.33635
241B	105	336	0.31130
242A	113	356	0.31792
242B	117	347	0.33723
SP3A	188	210	0.89524
SP3B	249	213	1.16779
SP3B-1	241	178	1.35236
SP3B-2	225	229	0.98563
SP3B-3	212	235	0.90301
SP3B-4	273	188	1.44502
SP3B-5	288	162	1.78563
SP3B-6	304	169	1.79994
SP3B-7	310	208	1.49183

FIGURE 4.1

CaO - Na_2O - K_2O Ternary Diagram

Closed circles = Unit 1 gneisses (this study)

Open circles = Unit 5 pegmatite (this study)

Enclosed field and crosses = Tonalite of Frisch (1982)

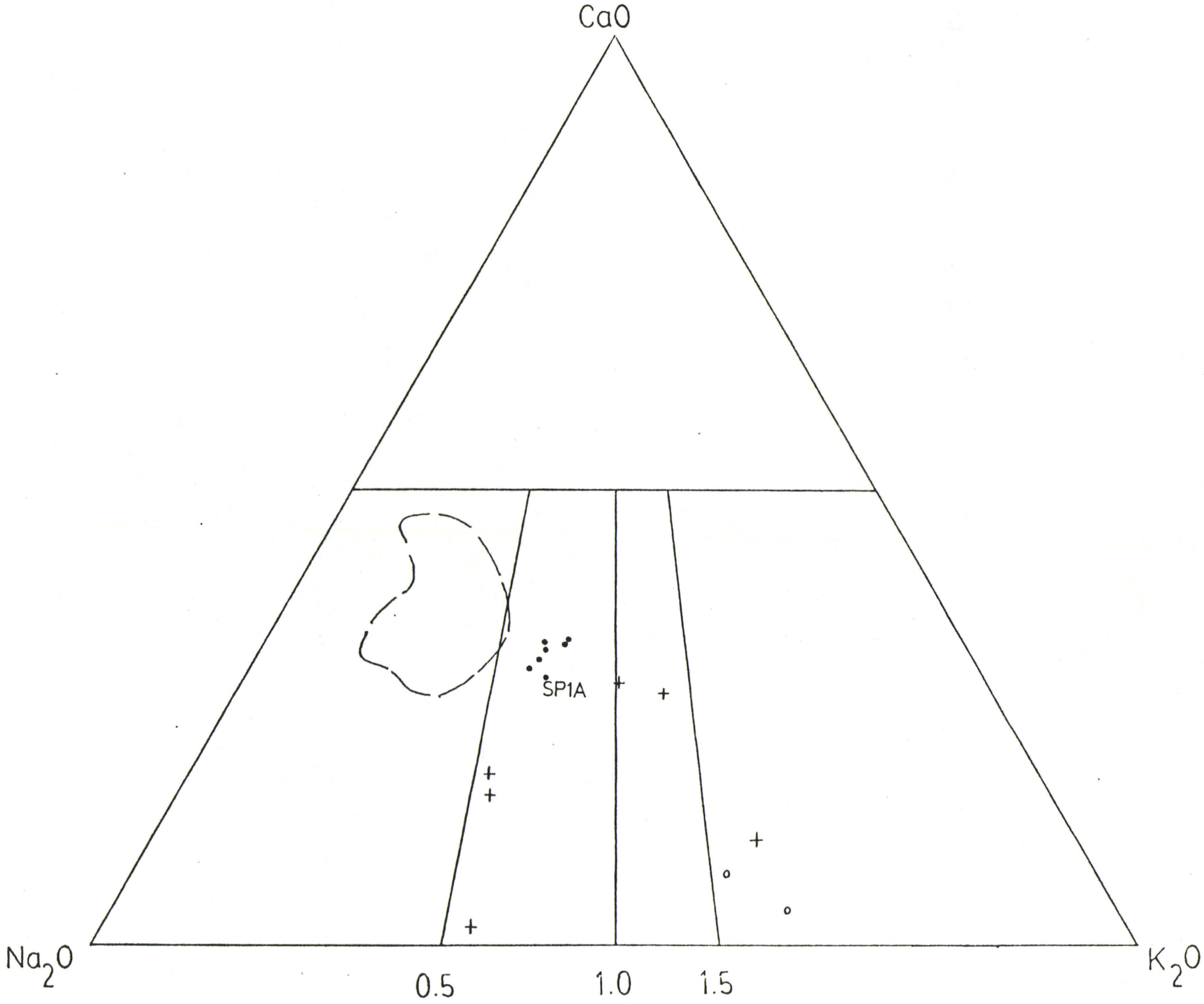

CaO
Na$_2$O
K$_2$O
0.5
1.0
1.5
SP1A

FIGURE 4.2

K - Rb Diagram

Closed circles = Unit 1 gneisses (this study)

Open circles = Unit 5 pegmatite (this study)

Enclosed field = Tonalite of Frisch (1982)

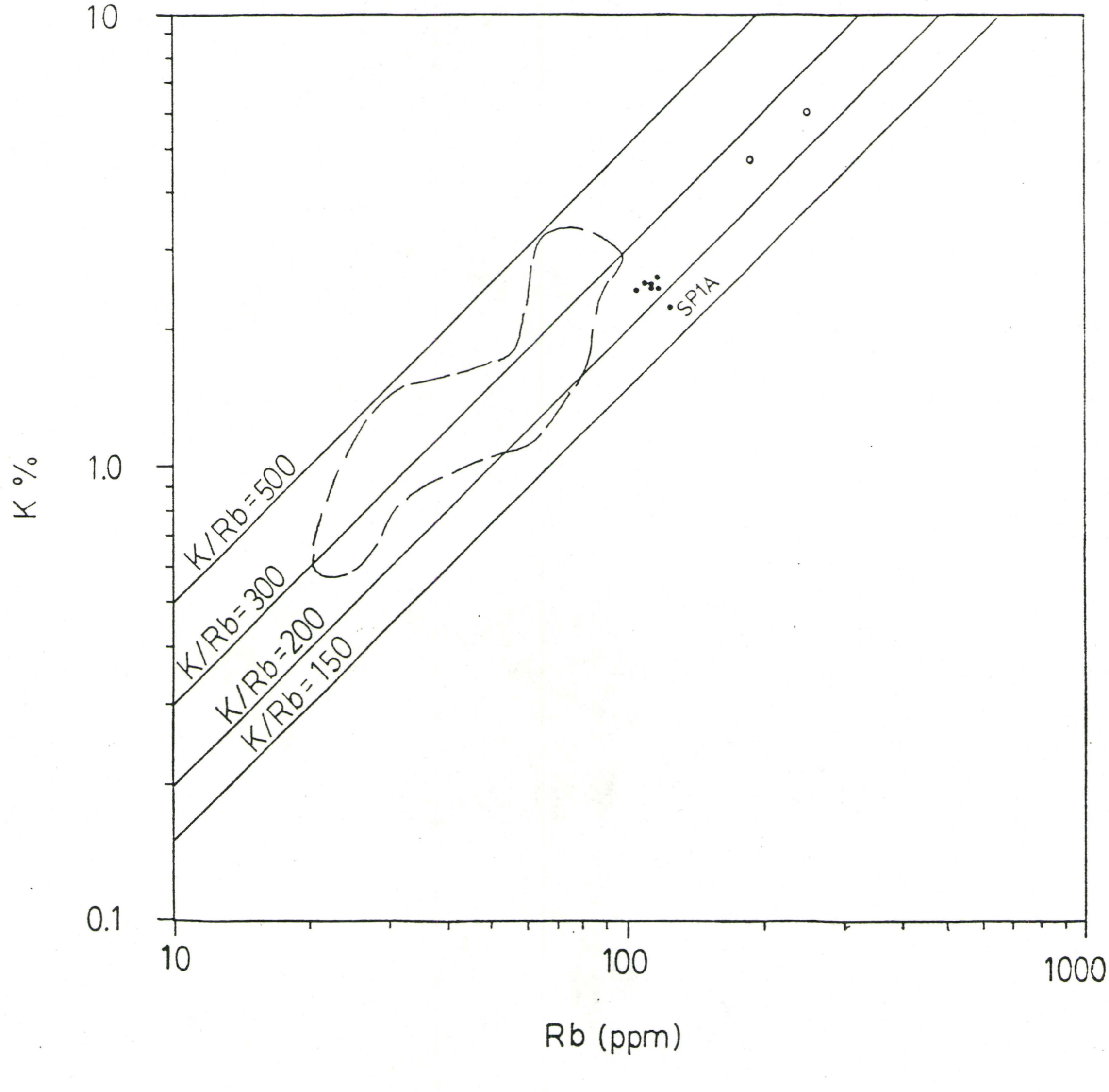

10
1.0
0.1
K %
10
100
1000
Rb (ppm)
K/Rb=500
K/Rb=300
K/Rb=200
K/Rb=150
SP1A

FIGURE 4.3

Rb - Sr Diagram

Closed circles = Unit 1 gneisses (this study)

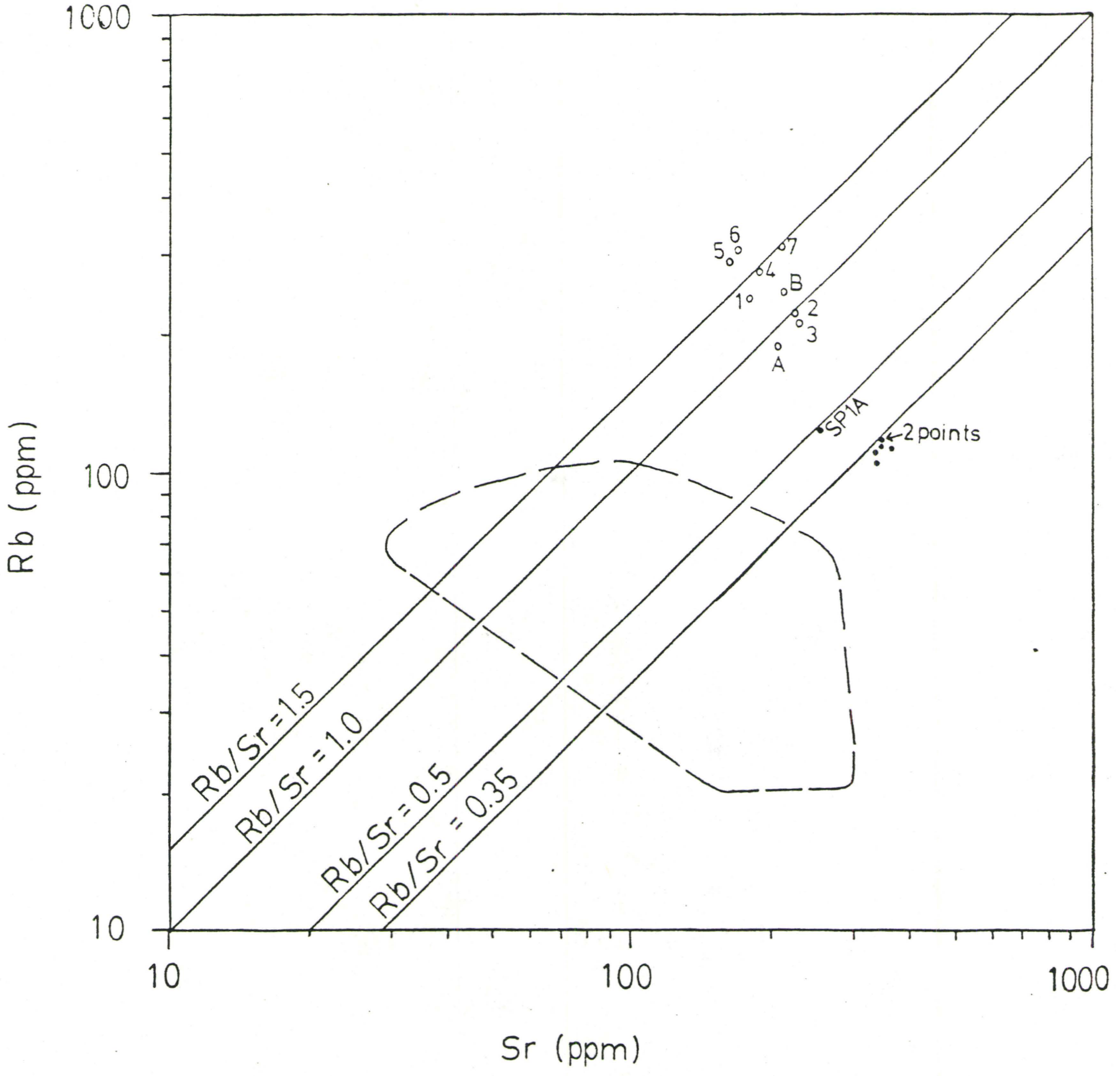
Open circles = Unit 5 pegmatite (this study)

A = SP3A

B = SP3B

1 to 7 represent the 7 SP3B thin slabs

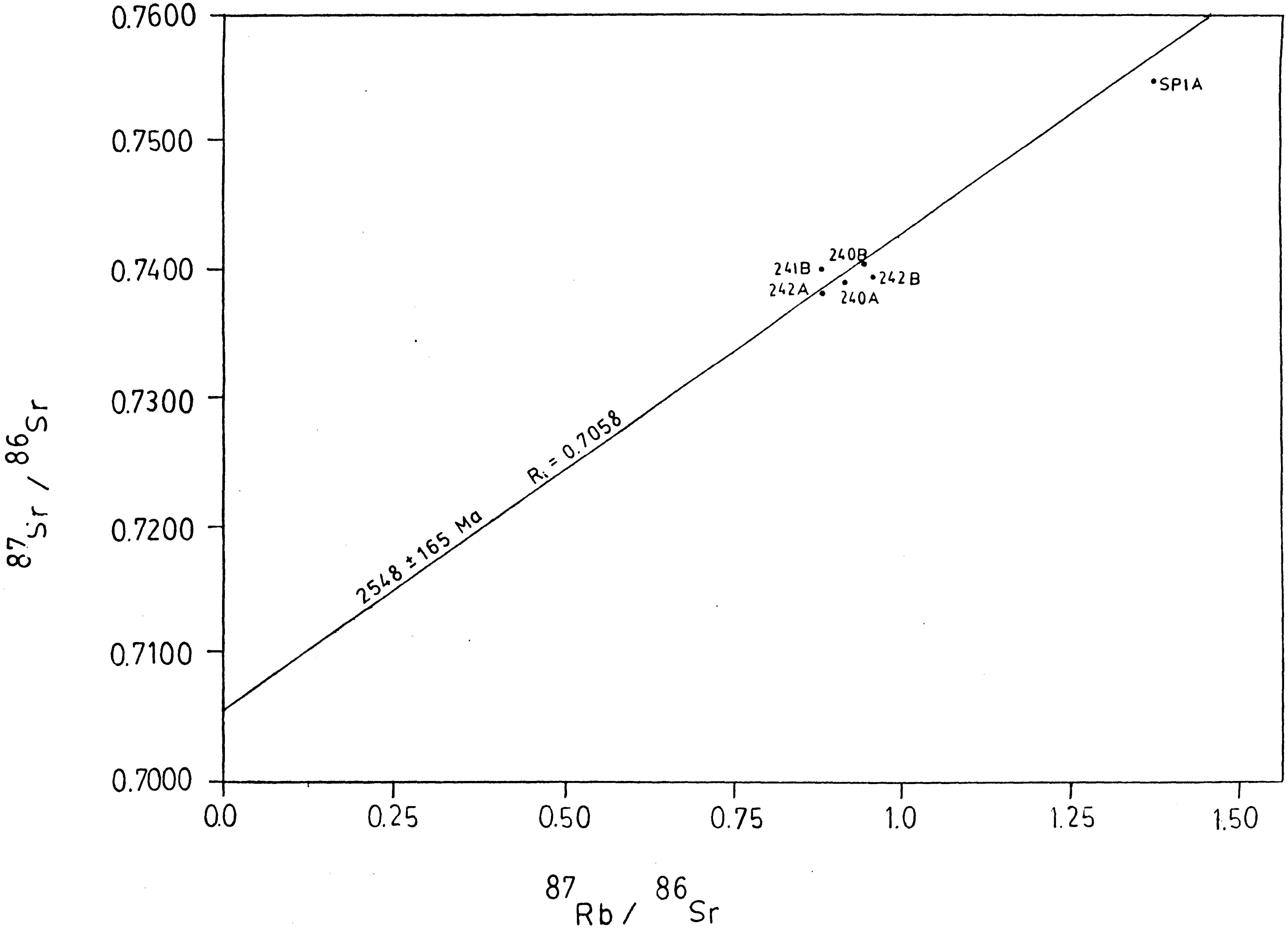
Enclosed field = Tonalite of Frisch (1982)


1000
100
10
Rb (ppm)
10
100
1000
Sr (ppm)
Rb/Sr=1.5
Rb/Sr=1.0
Rb/Sr=0.5
Rb/Sr=0.35
5
6
7
4
B
1
2
3
A
SP1A
2 points

4.2 GEOCHRONOLOGY

Rb-Sr geochronological investigations were made on six samples of orthogneiss, Unit 1, which are SP1A, 240A, 240B, 241B, 242A and 242B. Eight samples of the pegmatite from Unit 5 were analysed: SP3A, SP3B, and six of the thin slabs from SP3B: SP3B-1, SP3B-2, SP3B-4, SP3B-5, SP3B-6 and SP3B-7.

Based on all of the available data points, two Rb-Sr whole rock isochrons were produced. For the Unit 1 orthogneiss, an age of 2548 +/- 165 Ma with an R_i = 0.7058 was produced using the regression method of York (1966)(Figure 4.4). Given that this is essentially a two point isochron, defined by SP1A and the cluster of points from samples 240 to 242, the accuracy of this value may be questionable. The pegmatite produced an age of 1828 +/- 61 Ma with an R_i = 0.7186, using the regression of York (1966)(Figure 4.5). The points for SP3B-5 and SP3B-6 lie along a line slightly higher than that of the other samples. These two slabs are taken from a biotite enriched band in the pegmatite (Figure 3.1). This may imply a somewhat more open system behavior allowing exchange of Rb and Sr, although there is no positive evidence to this effect. An isochron excluding SP3B-5 and SPB3-6 produces an age of 1665 +/- 75 Ma.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0.7500
0.7400
0.7300
0.7200
0.7100
0.7000
0.0
0.25
0.50
0.75
1.0
1.25
1.50
$^{87}Sr / ^{86}Sr$
$^{87}Rb / ^{86}Sr$
SP1A
240B
241B
242B
242A
240A
$R_i = 0.7058$
2548 ± 165 Ma

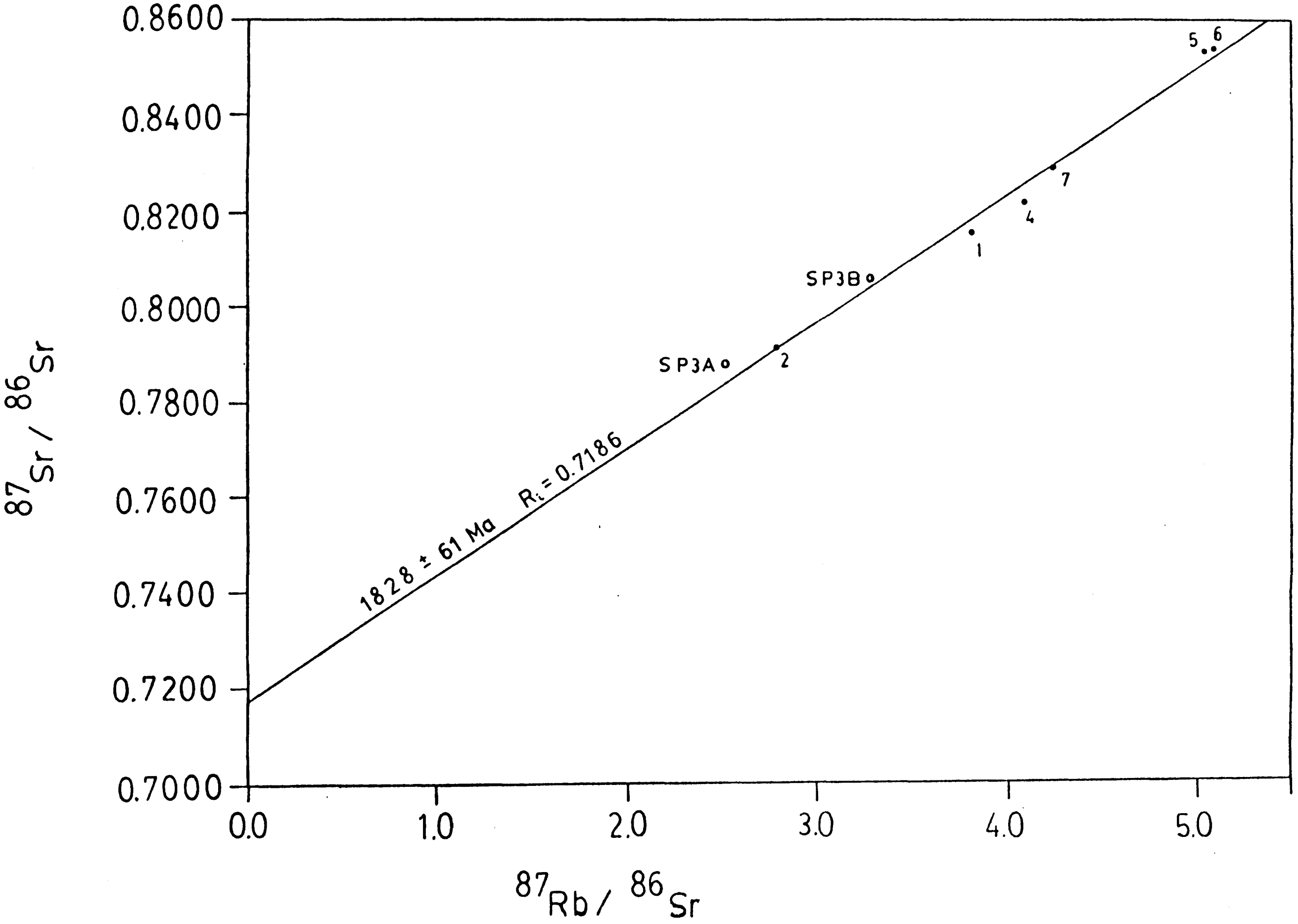
FIGURE 4.4

FIGURE 4.5

Unit 3 Whole Rock Isochron

Open circles = large volume crushes

Closed circles = SP3B thin slabs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0.8400
0.8200
0.8000
0.7800
0.7600
0.7400
0.7200
0.7000
0.0
1.0
2.0
3.0
4.0
5.0
$^{87}Sr / ^{86}Sr$
$^{87}Rb / ^{86}Sr$
1828 ± 61 Ma
$R_i = 0.7186$
SP3A
SP3B
1
2
4
5
6
7

CHAPTER FIVE: DISCUSSION AND CONCLUSIONS

The relationships between Units 1, 3 and 5 and the melting and metamorphic events responsible for the sweats, the foliations, and the Unit 5 pegmatite are the subject of this discussion. The identification of a foliation and a lineation common to both the orthogneiss and the amphibolite, but absent in the pegmatite, implies that the metamorphic event responsible for the mineral orientation post dates the gneiss and the metabasic dyke emplacement but predates the pegmatite emplacement. The presence of leucosomic sweats in the gneiss and the amphibolite slightly disconcordant with the foliation or lineation implies that:

a) sweating or partial melting conditions were attained after the emplacement of the amphibolite dykes but before the emplacement of the pegmatite.

b) the event which generated the measured foliation and lineation in the older two units was not responsible at the same time for producing the leucosomic sweats.

If the pegmatite was generated by partial melting of the gneissic unit by a later metamorphic event, then at least two metamorphic events of relatively high grade are indicated.

The presence of blocks of orthogneiss and amphibolite up to 1 m in size within the pegmatite, combined with the observation that the S-folded pegmatite unit cuts across similarly folded, sweat bearing members of the gneissic and amphibolitic units indicates that:

a) the granitic pegmatite is an intrusive unit into the gneissic and amphibolitic units, and if derived from partial melting of the gneiss, it has been so derived at a different (lower) stratigraphic level.

b) the event responsible for the S-folding postdates emplacement of the pegmatite.

The presence of boudinaged amphibolite implies that the amphibolite was more brittle or mechanically competent than was the pegmatite surrounding it at the time of deformation. The boudinage appears to be a reaction to the same stresses that formed the S-folding. The pegmatite would tend to be less competent than the amphibolite at high temperatures, since the melting curves of granitic material and of amphibolite differ by 100° to 200° C for moderate or shallow crustal depths (Yoder and Tilley, 1962; Luth et al, 1964). Hence, temperatures characteristic of upper amphibolite grade metamorphism would tend to mobilise granitic rocks well before more basic rocks, for pressures less than about 8 kb (Yoder and Tilley, 1962).

The formation of the granitic pegmatite implies substantial water content in the host rock (Luth et al,

1964) and infers the highly differentiated composition observed (Heier and Adams, 1964). Corresponding to expected trends had the pegmatite been derived by partial melting of a rock of composition equivalent to Unit 1, as hypothesised by Schau (Schau and Ashton, 1985), the potassium is heavily enriched in the pegmatite, and sodium depleted, relative to the orthogneiss country rock for the pegmatite. Given that Na is predominantly carried in plagioclase feldspars, and the majority of the K in the alkali feldspars in the pegmatite, the relative proportions of the feldspars should reflect the elemental trends. The alkali feldspar content of the pegmatite is at least double that of the gneisses, and the K_2O content is enriched accordingly. The plagioclase content of the gneisses is greater than that of the pegmatites, and the latter show a slight depletion in Na content relative to the gneisses. The pegmatite composition corresponds to the first liquid of a granitic system, such that the granodioritic pre-melt protolith is rich in albite relative to orthoclase, and hence is more sodic than the ternary Or-Ab eutectic composition (Figure 5.1). Melting produces a eutectic first liquid which is more potassic and less sodic than the original, as observed.

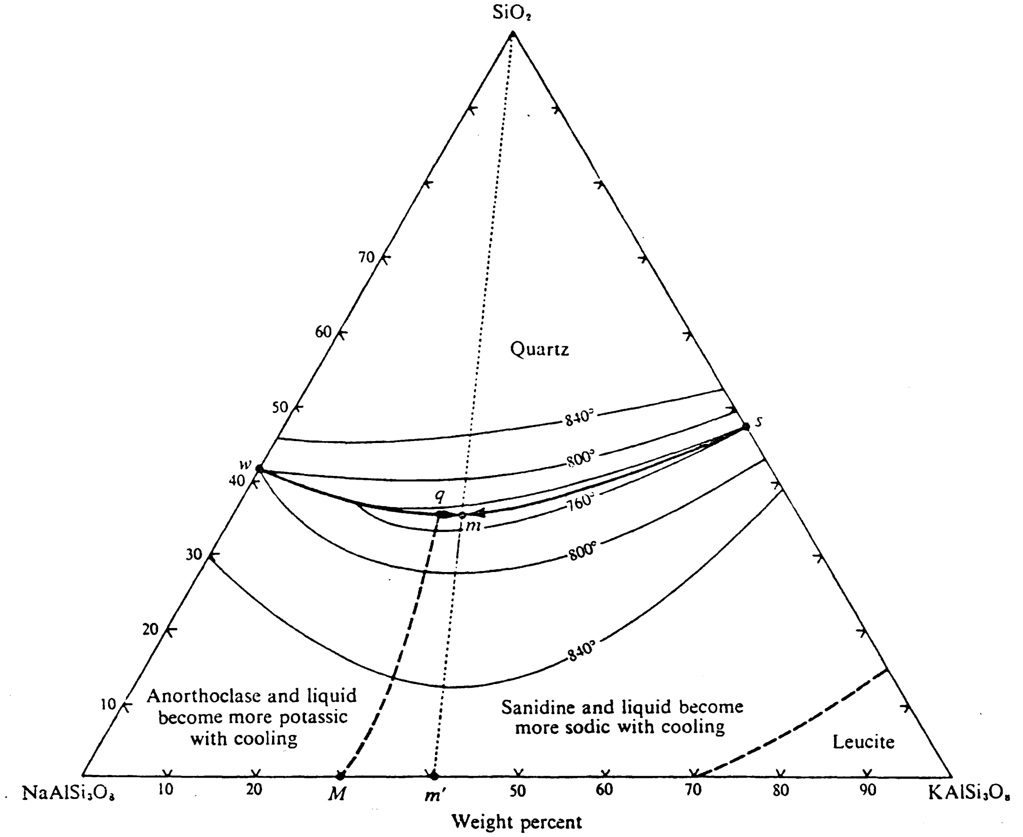
Rb is positively correlated with K in the pegmatite, but does not significantly alter the K/Rb ratio (Figure 4.2). This lack of dependence of K/Rb on K values

FIGURE 5.1

Qz - Or - Ab TERNARY DIAGRAM

Sub-liquidus rock compositions lying in the field to the left of the SiO_2 - m - m′ join, as do the Unit 1 gneisses, will produce a eutectic first melt (at composition "m") which is both more potassic and less sodic than the protolithic composition.

From Carmichael et al, (1974).



The liquidus surface for water-saturated liquids at 1000 bars confining pressure in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2; the boundary curve *wqms* separates the quartz from the feldspar field, and *m* is the isobaric minimum. Isotherms show the configurations of the liquidus surface, which is divided into two areas by the unique fractionation curve *qM* separating liquids which become more sodic from those which become more potassic as cooling proceeds. (After Tuttle and Bowen, 1958.)

corresponds to the findings of Abramovich (1960). Extreme fractionation is not implied, as this would be indicated by a lower K/Rb ratio, as weight dependent fractionation would occur between the two cations (Heier and Adams, 1964). (Ba/Rb and Rb/Tl ratios are more fractionation sensitive than K/Rb rations (Heier and Adams, 1964), but Ba and Tl were not analysed.) Sr depletion in the pegmatite corresponds to strontium's relatively high distribution coefficient ($D^{Sr}_{solid-liquid}$) for both plagioclase and alkali feldspars. Typical values are $D^{Sr}_{plag-liquid} = 4.4$ in "acidic" rocks and $D^{Sr}_{K-feldspar-liquid} = 4$ (Cox et al., 1979).

A possible mechanism for the formation of the Unit 5 pegmatite and the leucosomic sweats requires that melt can be produced by not only increased temperature but by increased P_{H_2O}. Increasing P_{H_2O} produces a linear decrease in the granitic melting temperature, for pressures in excess of ~1 kb (Yoder and Tilley, 1962). Similarly, an increase of less than 1 wt.% water can convert a gneissic rock into a migmatite (Johannes, 1984). The presence of late biotites in both the Unit 1 gneisses and the amphibolite supports the presence of a late aqueous phase. Given that P-T conditions increase with depth, the addition of a relatively small amount of water, possibly provided by localised breakdown of amphibole, could have produced both the sweating at the present erosional level, representing incipient migmatisation, and larger scale melting at greater depth. Density contrast between the pegmatitic differentiate and the surrounding Unit 1 granodioritic crust would allow the pegmatite to rise and intrude the present erosional level Unit 1 rocks.

In order to confirm this mechanism by geochronological means, it would be necessary to date the leucosomic sweats and find an age corresponding to the age of formation of the Unit 5 pegmatite.

The Unit 1 Rb-Sr isochron is defined by sample SP1A and a relatively homogeneous cluster of points from samples 240 to 242. SP1A was from an outcrop with significantly more leucosomic sweats than the other six Unit 1 samples, implying a greater likelihood of isotopic contamination by such sweats in SP1A, where the Unit 1 gneiss samples may have experienced Rb and Sr isotope migration as a result of the sweating event. Correspondingly, plots of CaO-Na_2O-K_2O and Rb-Sr show that SP1A lies between the Outcrop A samples and the pegmatite samples (Figures 4.1, 4.3). Hence, SP1A may lie on a "mixing line" between a granodioritic end member and a granitic (pegmatite) end member. If this is the case, then the 2548 Ma age is geologically meaningless, although further Rb-Sr isotopic data from Outcrop B gneiss is required to determine this. If this isochron can be so negated, then the age represented by the current isotopic composition of the gneisses is unknown, and Unit 1 could conceivably have been reset to the 1.8 Ga event. SP1A does not plot between the Outcrop A samples and the pegmatite samples on a K vs. Rb plot (Figure 4.2). As the pegmatite is strongly enriched in K, contamination by the pegmatite should be reflected by an enrichment in the K content of SP1A. If the leucosomic sweats are K-spar rich, then the relative abundance of these sweats in Outcrop B may reflect preferential depletion of the K from the Unit 1 gneiss, and hence not preclude the mixing hypothesis proposed.

If the 1.8 Ga event was less severe than the 2.6 Ga event, assuming that the latter is a viable age, then the Rb-Sr systematics of the gneiss may have been reset to the younger event on a smaller scale (i.e. on the order of a cm) (Krogh and Davis, 1973; Hofmann, 1979; Heaman, pers. comm., 1984). However, although Unit 1 gneiss samples are available for thin-slab study, the homogeneity of these rocks on every level precludes the production of a meaningful Rb-Sr isochron. The geochronology of the Unit 1 gneisses cannot be determined without further sampling.

A correlation between Unit 1 and a tonalite unit to the south studied by Frisch (1982) was suggested by Schau (Schau and Ashton, 1985). While Frisch observed that this unit cut the 2900 Ma old Prince Albert Group, this relationship implies remobilisation of an older unit as well as implying generation of a younger one (Frisch, 1982). Plots of Frisch's Unit on $CaO-Na_2O-K_2O$, K-Rb and Rb-Sr diagrams show no overlap between this tonalite and Schau's Unit 1 (Figures 4.1, 4.2, 4.3). This merely fails to confirm a correlation, rather than precluding one, as assuming unit homogeneity over hundreds of kilometers is not necessarily justified.

Further field work is required in order to determine the relationship between the Unit 1 gneisses and the metasediments (Unit 4) of the Prince Albert Group (Schau, 1985). Rb-Sr isotopic work on a wider scale is required to date Unit 1, or investigation of other isotopic systems is required, if Unit 1 is as uniformly homogeneous as in this study.

A model for the evolution of the area is given in Table 5.2.

TABLE 5.2

EVOLUTIONARY MODEL OF UNITS 1, 3, AND 5

Age	Event
?	Emplacement of Unit 1
?	Intrusion of amphibolite Unit 3
2.6 Ga	Amphibolite grade metamorphism
	-generation of foliation
1.8 Ga	Partial melting
	-sweating
	-pegmatite emplacement
?	S-folding

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