PETROLOGY, GEOCHEMISTRY, AND GEOCHRONOLOGY OF A PLUTON IN THE THELON TECTONIC ZONE, NORTHWEST TERRITORIES

by

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ABSTRACT

The Thelon Tectonic Zone is a major structural, metamorphic and lithological feature of the Precambrian Shield in the Northwest Territories. Situated within this Zone is a 30 square kilometre plutonic body. Rubidium-Strontium whole rock geochronology yields an age range of 1650 - 2200 Ma for the emplacement of this pluton. Field and petrographic evidence indicates that the pluton has suffered post-emplacement deformation, representative of a late Proterozoic metamorphic event. Major and trace element geochemistry suggests that this high Ca, ferrogranodiorite-tonalite intrusive body is associated with a subduction-related, continental margin tectonic environment.

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CHAPTER 1 INTRODUCTION

1.1 Purpose of Study

The purpose this study is to determine the origin of a plutonic body and its relationship to the history of the Thelon Tectonic Zone where it is situated. Major element chemistry and petrographic analyses are used to classify the pluton. Trace element analyses are studied as petrogenetic indicators. A Rb-Sr geochronological study of the pluton determines its approximate age range.

1.2 Location and Accessibility

The field work for this study was done during the summer of 1985 which was the final field season of a three-year Geological Survey of Canada 1:250,000 scale bedrock mapping project. This project was under the direction of Dr. P. H. Thompson and included the Tinney-Hills 1:250,000 scale map sheet and the western half of the adjacent Overby Lake map sheet. The area is bound by 66° to 67° N latitude and 105° to 108° W longitude. The study is to determine the significance of the Thelon Tectonic Zone (TTZ) (Thompson and Ashton, 1984).

The TTZ (Thompson and Henderson, 1983) trends NNE-SSW running from the Arctic coast east of Bathurst Inlet in the Northwest Territories to southeast of Great Slave Lake where it becomes overlain by Phanerozoic rocks. Its width varies from 75 to 100 kilometres and it is approximately 800 kilometres in length (fig. 1-1).

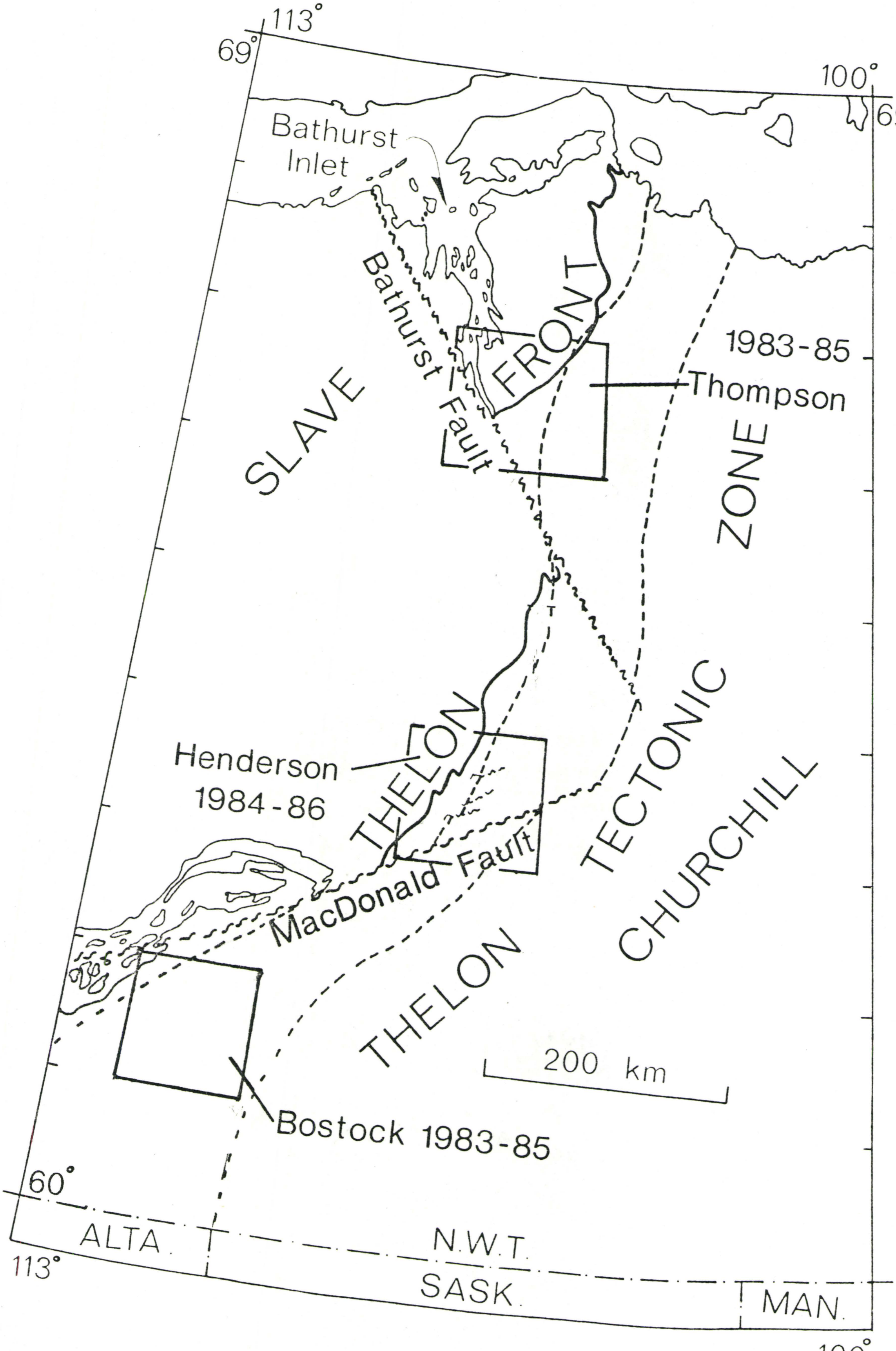
The base camp was located on the northwest shore of Overby Lake, approximately 600 kilometres northeast of Yellowknife. Access to the area and bi-weekly resupply was by Twin Otter aircraft based in Yellowknife.

The pluton is located 26 kilometres south-southeast of the base camp and was reached by Hughes 300C helicopter. Because of severe time restrictions , field work consisted of a single looping traverse across the pluton, during which 6 geochemical and 10 additional petrographic samples were taken. This lack of adequate field work limits the study considerably.

1.3 Previous Work

During the field season of 1955, Wright (1957), carried out Operation Thelon. This reconnaissance scale (1 inch to 8 miles) helicopter supported mapping of the Eastern District of MacKenzie, Northwest Territories contained the area from 102° to 108° W longitude and from the tree line, approximately 61° to 62° N, to 66° N latitude. This operation was part of a larger Geological Survey of Canada project to map the Canadian Shield in the barrenlands of the Northwest Territories, to more accurately assess the economic potential of the region and to determine problematic areas for more detailed work. Operation Thelon did not include the Tinney Hills-Overby Lake (T.H.O.L.) map area but did include the adjacent map area to the south.

Figure 1-1: Regional Map showing the location of the Thelon Tectonic Zone with respect to the Slave and Churchill Provinces and 1:250,000 bedrock mapping projects.


113°
69°
100°
69°
Bathurst
Inlet
Bathurst
Fault
FRONT
1983-85
Thompson
SLAVE
ZONE
THELON
Henderson
1984-86
TECTONIC
CHURCHILL
MacDonald Fault
THELON
200 km
Bostock 1983-85
60°
ALTA.
N.W.T.
113°
SASK.
MAN.
100°

Continuation of this project was carried out during the field season of 1962 by Fraser (1964). Operation Bathurst involved reconnaissance scale helicopter supported mapping of the area between 100° and 112° W longitude and extending from latitude 65° N to the Arctic coast.

Both Wright and Fraser recognized a major structural feature, interpreted by Wright (1967) as delineating the eastern limit of the Slave Structural Province. This structure was termed the Thelon Front and it was the proposed boundary between the Slave and Churchill structural provinces. Contrasts in structure, lithology, age and metamorphic grade characterized this boundary.

To determine the age, origin and significance of this feature, a number of 1:250,000 scale bedrock mapping projects were and/or are being carried out by the Geological Survey of Canada under the direction of P. H. Thompson, J. B. Henderson, R. A. Frith and H. H. Bostock (fig. 1-1).

CHAPTER 2 GENERAL GEOLOGY

2.1 Regional Geology

The T.H.O.L. map area is comprised of typical Slave Structural Province rocks to the west and Churchill Structural Province rocks of the Queen Maud block to the east.

The Slave Province consists of low to intermediate grade metavolcanic and metasedimentary rocks of the Archean Yellowknife Supergroup (Y.K.S.), with a complex curvilinear structural style intruded by massive granitoid rocks (Henderson et al, 1982). The Y.K.S. was folded, metamorphosed and intruded by granitic rocks during the Kenoran Orogeny. Lying unconformably on the Y.K.S. is the Goulburn Group consisting of shallow marine interbedded clastic and carbonate sediments of Aphebian age. During the Hudsonian Orogeny, these Aphebian rocks were folded, metamorphosed and intruded by alkaline rocks as were the underlying Archean rocks (Stockwell et al, 1976). Within the T.H.O.L. map area the Goulburn group is restricted to the Bathurst Inlet area and a number of small outliers within the Archean basement. Three distinct swarms of dykes were intruded at 2150,2100 and 1200 Ma respectively. The former two swarms are restricted to the Slave Province while the latter, the MacKenzie dykes, occur in the Bear and Churchill provinces as well.

The Queen Maud Block of the Churchill Province consists of high grade gneisses and foliated granitoids with a linear, northerly structural pattern (Henderson et al, 1982). The oldest rocks in the Churchill are probably Archean volcanics and sediments metamorphosed during the Kenoran Orogeny to varying degrees, in some cases, to migmatites and granitic gneisses. Unconformably overlying the gneisses are Aphebian sediments that were intruded by granitic rocks during the Hudsonian orogeny, causing metamorphism, in some cases, to migmatites and granitic gneisses. This makes subsequent differentiation between high grade Archean and Aphebian rocks difficult. K-Ar dating yields some Kenoran ages with abundant Hudsonian ages (Stockwell et al, 1976).

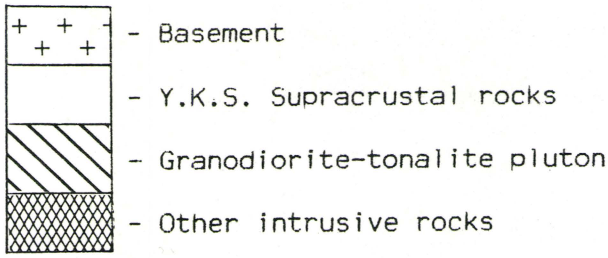
Thompson divided the map sheet into the Bathurst and Ellice River terrains, separated to the west and east respectively by the main boundary zone (fig. 2-1). This zone is defined by a marked change in lithology, a low grade transcurrent shear zone, a characteristic low aeromagnetic expression and a swarm of metamorphosed and variably deformed basic dykes. This boundary was interpreted to be the Thelon Front, which is the western edge of T.T.Z. (Thompson et al, 1985).

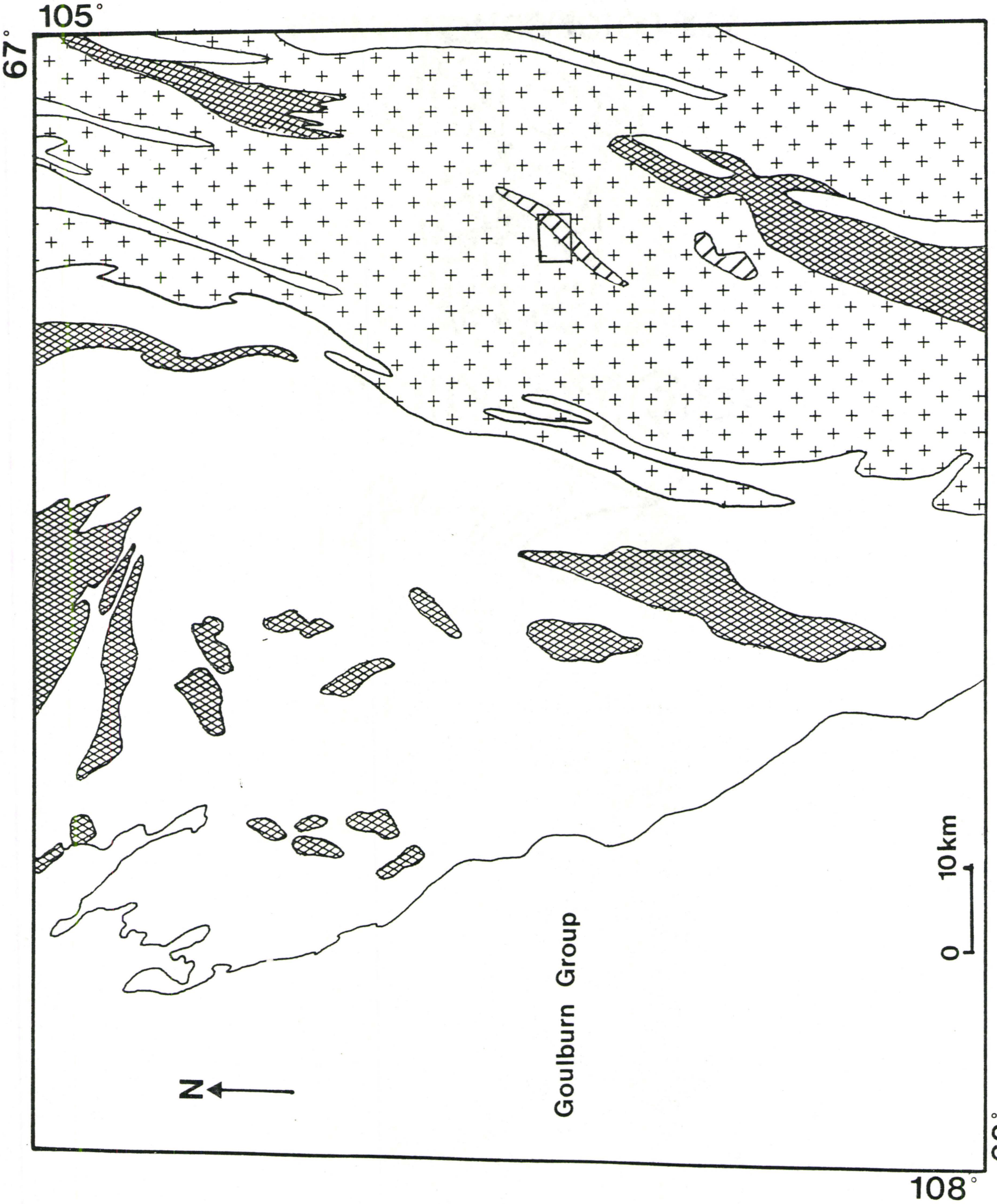
2.2 Geology of the Thesis Area

Three units are of interest in the area- the pluton of this study and the country rocks adjacent to the west and east respectively.

The pluton is lense shaped, 1.5 km. wide and 20 km. long with

Figure 2-1: Simplified Regional Geological Compilation Map after Thompson (et al, 1986), showing study area.




105°
67°
Goulburn Group
N
0
10km
66°
108°

its long axis trending northeast-southwest (fig. 2-1). It is a dark-weathering, medium grained, equigranular to porphoritic rock varying structurally, from massive to weakly foliated. Compositionally, it varies from granodiorite to tonalite. Minor shear zones, several metres wide, tend to be concordant with the foliation and are manifested by linear topographic features and grain size reduction. Clinopyroxene cores rimmed by hornblende and biotite are common. Mafic inclusions, suggesting an intrusive origin, are also abundant.

The western contact is sharp and is represented topographically by a long narrow swamp. The pink weathering rocks across this contact are massive to gneissic, medium grained, equigranular biotite bearing granites. They belong to the unit defined by Thompson et al (1985) as the "pink gneiss/ migmatite/ granitoid" unit and are believed to be amphibolite in grade.

The eastern contact appears to be gradational and is marked by an increase in the intensity of the foliation and the presence of migmatites. This assessment of the eastern contact is somewhat questionable given the lack of field time to study it. Thompson has defined the rocks to the east of the pluton as part of the "orthopyroxene gneiss/ migmatite/ charnokite" unit and are granulite in grade. No orthopyroxene was observed within the contact zone, however the presence of migmatites suggests that the pluton is immediately adjacent to the granulite grade unit of Thompson (Thompson et al, 1985).

CHAPTER 3 PETROGRAPHY

Petrography samples were collected from 14 locations along a 3 km linear traverse across the pluton (fig. 3-1). From petrographic and field evidence three units have been defined. They are from west to east - Massive to Gneissic Granite, Weakly Foliated Granodiorite-Tonalite Pluton, and Migmatitic Granite Gneiss. All samples are classified using the IUGS scheme (Streckeisen, 1976) and plotted as figure 3-2.

3.1 Massive to Gneissic Granite.

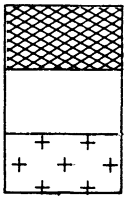
Two samples were collected at station 1 - a massive granite and a gneissic granite. Modal analyses based on a minimum of 600 points (table 3-1) show that both samples lie within the granite field. (fig 3-2).

These rocks consist of potassic feldspar, quartz, plagioclase feldspar, chloritized biotite and muscovite. The overall texture is massive to foliated, anhedral equigranular.

Potassic feldspar occurs as coarse anhedral grains of perthitic microcline (plate 1a), varying from 25% in the gneiss to 44% in the massive granite. Inclusions of quartz, biotite and plagioclase occur within the potassic feldspar. Minor alteration to sericite is present on some grains.

Plagioclase feldspar occurs as subhedral to anhedral grains

Figure 3-1: Reconnaissance Geology of the thesis area and Station Map.



- Massive to gneissic granite
- Granodiorite-tonalite pluton
- Migmatitic granite gneiss

■ ▲ ● - Station location- petrographic sample

△ - Station location- geochemistry sample

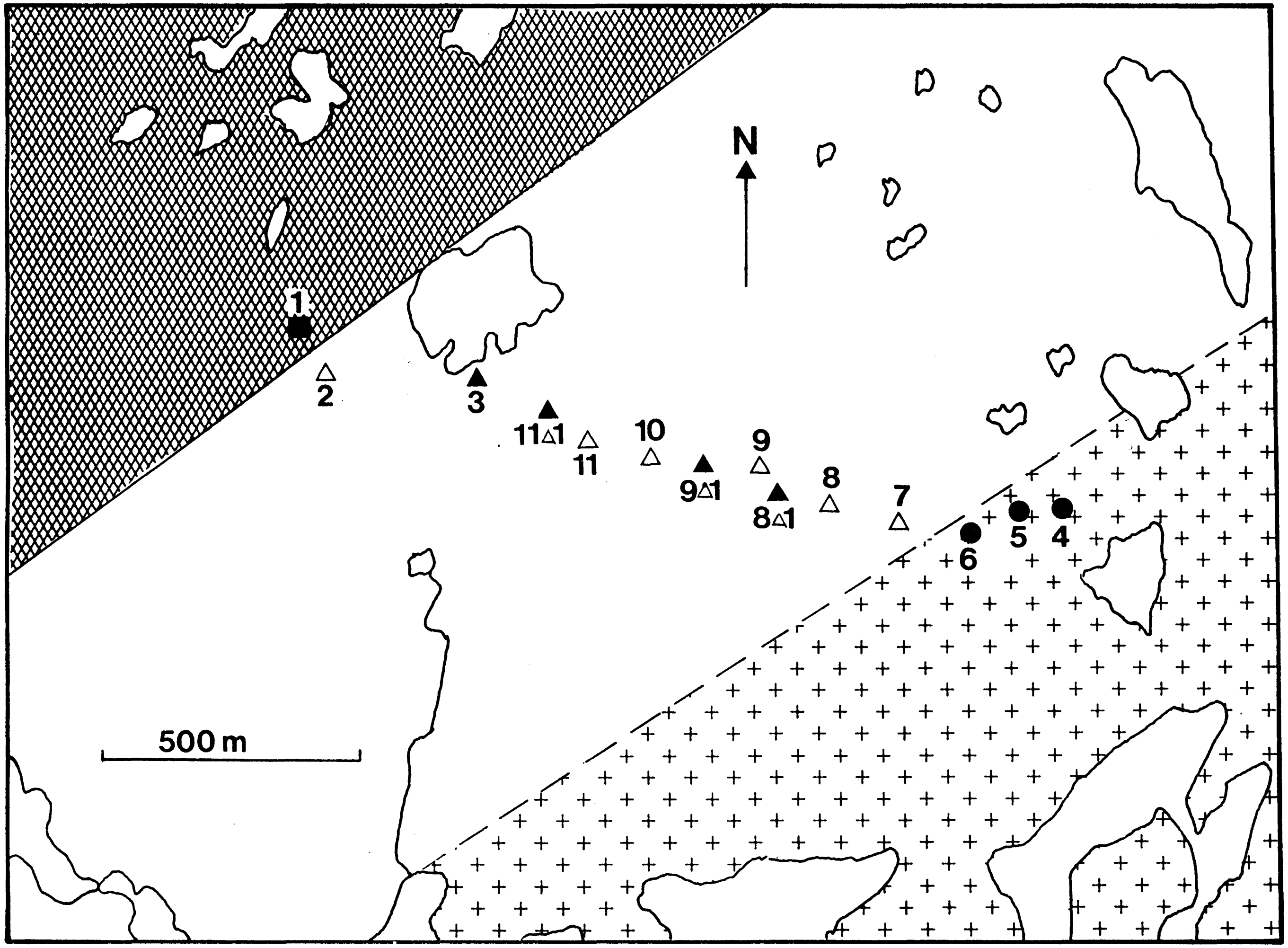

N
500 m
1
2
3
11△1
11
10
9△1
9
8△1
8
7
6
5
4

Figure 3-2: Modal classification of pluton samples using the scheme of Streckeisen (1976).

■ - Massive to gneissic granite

● - Migmatitic granite gneiss

▲ △ - Granodiorite-tonalite pluton, petrography and geochemistry samples respectively.

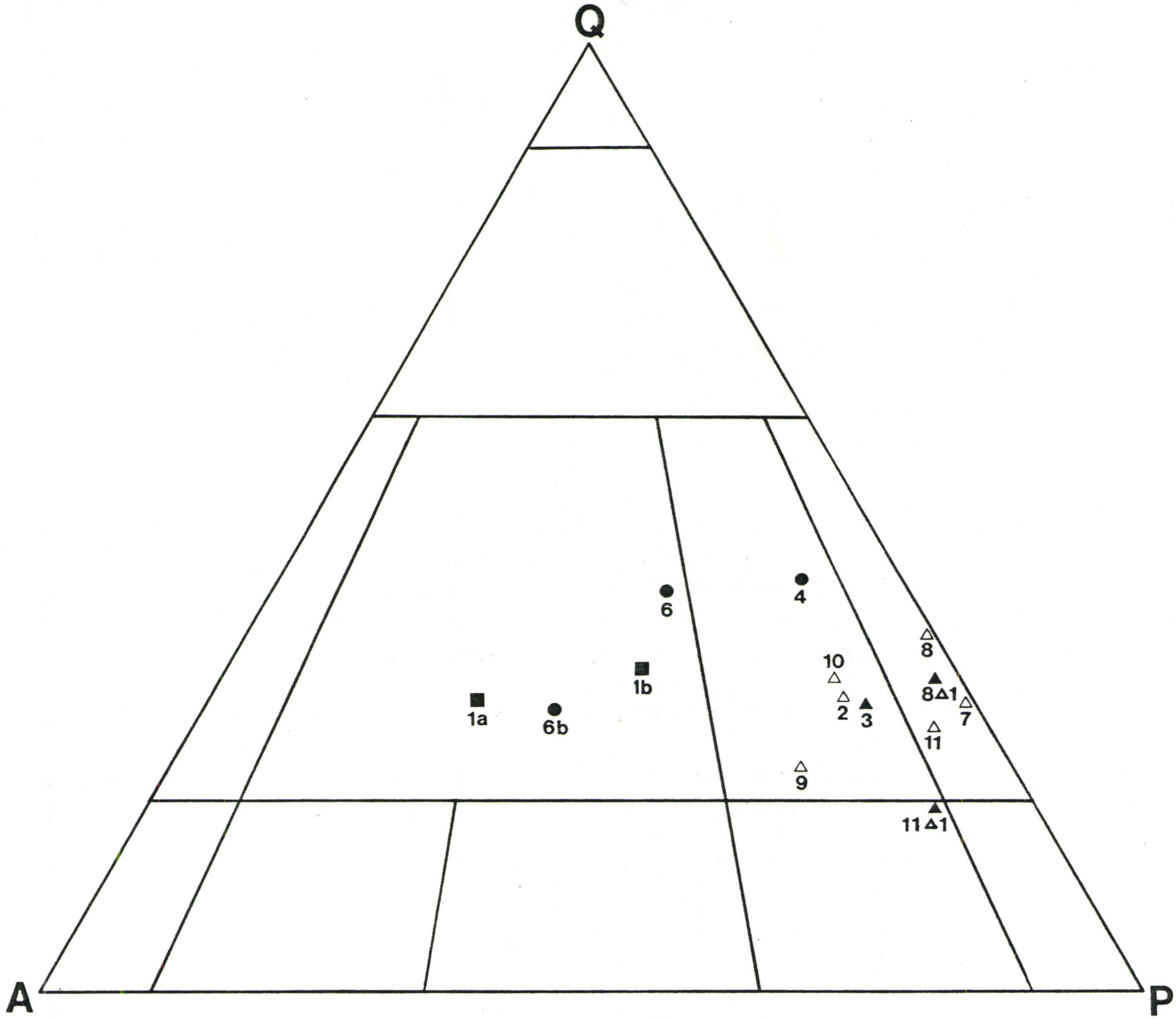

Q
A
P
1a
1b
6
6b
4
10
2
3
8
8
1
7
11
9
11
1

TABLE 3-1 MODAL VALUES (%)

Mineral	MN1a	MN1b	MN2	MN3	MN11 1	MN11	MN10	MN9	MN8 1	MN8	MN7	MN6b	MN6	MN4
Quartz	29.2	30.8	23.0	29.3	13.7	21.3	24.5	18.0	25.0	23.9	19.0	26.7	38.2	36.2
Plag.	23.3	34.7	42.4	46.2	50.8	52.4	41.7	48.3	51.3	47.7	44.2	28.3	32.5	39.2
K-spar.	43.7	25.2	8.8	8.5	6.7	3.8	8.5	11.0	1.2	0.5	0.5	34.7	20.1	7.5
Biot.	2.7	7.3	18.2	14.2	11.7	13.3	11.7	12.8	14.5	25.2	30.3	6.2	8.3	12.5
Hb.	-	-	2.6	-	9.7	2.1	6.3	6.0	4.3	-	-	2.2	-	2.3
Cpx.	-	-	2.9	-	3.2	2.9	4.8	0.7	0.6	-	-	-	-	0.3
Opaques	0.7	1.0	0.3	1.3	3.2	1.5	1.2	1.3	2.1	1.0	3.5	1.3	0.4	1.7
Others	0.5	1.0	1.9	0.5	1.2	2.8	1.3	1.8	0.8	1.7	2.5	0.7	0.5	0.3

Others = apatite, zircon, calcite, epidote, holes in slide

Modal analyses based on minimum 600 points per slide

Plate 1a: Two orientations of perthitic microcline in the massive to gneissic granite (Crossed polars, field of view - 2.5 mm x 4.0 mm).

Plate 1b: Chloritized biotite, centre, in the massive to gneissic granite and severely sericitized plagioclase (Crossed polars, field of view - 1.0 mm x 1.5 mm).

that are, in general, finer in grain size than the potassic feldspar. Twinning is predominantly albite or pericline, with carlsbad twinning occurring rarely. Sericitization of the plagioclase is mild in the gneiss, however, severe sericitization in the massive granite has altered the plagioclase to the point of obscuring twinning making compositional and optical sign determination impossible. Quartz, chloritized biotite and potassic feldspar inclusions occur within the plagioclase.

Quartz occurs as fine grained inclusions in the feldspars, as graphic intergrowths with the feldspars--myrmekite, and as coarse interstitial grains. The latter grains are anhedral and show varied undulatory extinction.

Biotite occurs as small subhedral grains (0.25 - 0.5 mm). These grains exhibit anomalous blue birefringence indicating alteration to chlorite. Opaques have been exsolved along cleavage planes and as rims to the biotite (plate 1b).

Muscovite occurs as tiny (up to 0.2 mm) subhedral block like blades and is usually associated with plagioclase and to a lesser extent potassic feldspar. This muscovite is much coarser than the sericite altering the feldspars.

Oxides occur as exsolution products of biotite and as individual anhedral grains associated with biotite. Red rims on some opaques indicate the presence of hematite.

3.2 Weakly Foliated Granodiorite - Tonalite Pluton.

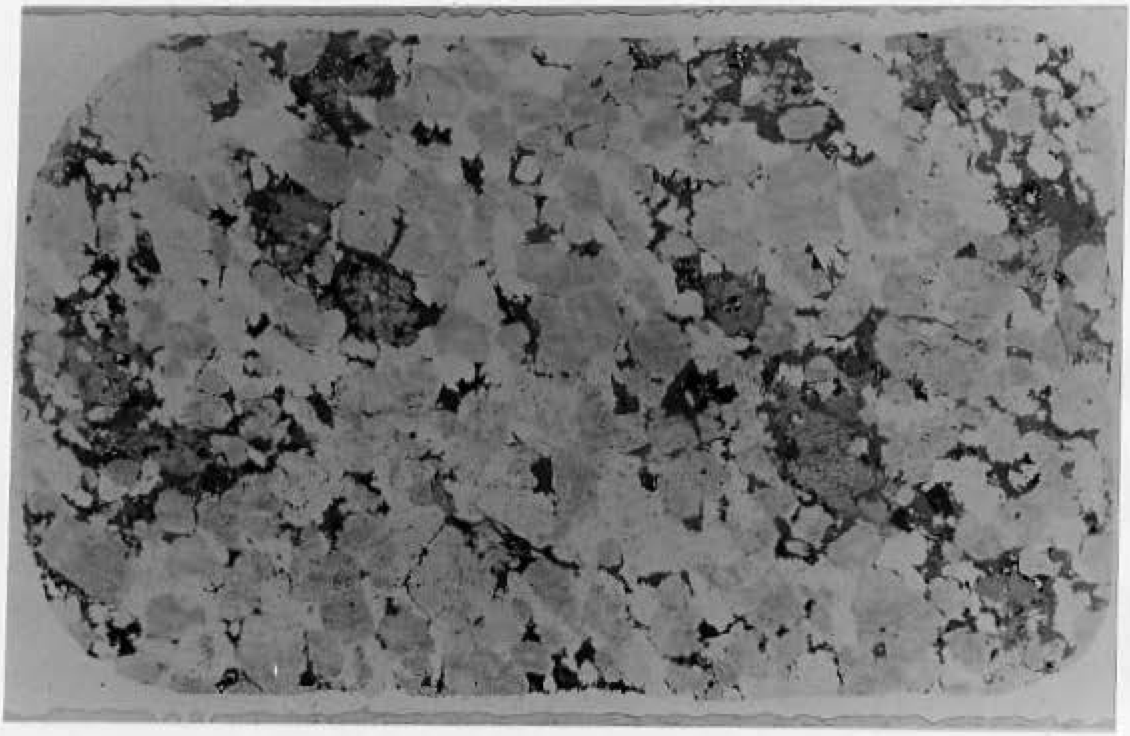
The pluton was sampled at 11 locations (fig. 3-1). Six samples were collected for geochemistry from each of which a petrographic sample was taken. Five other petrographic samples were taken for coverage purposes. Modal values (table 3-1) show a general trend from west to east of a compositional change from granodiorite to tonalite (fig. 3-2).

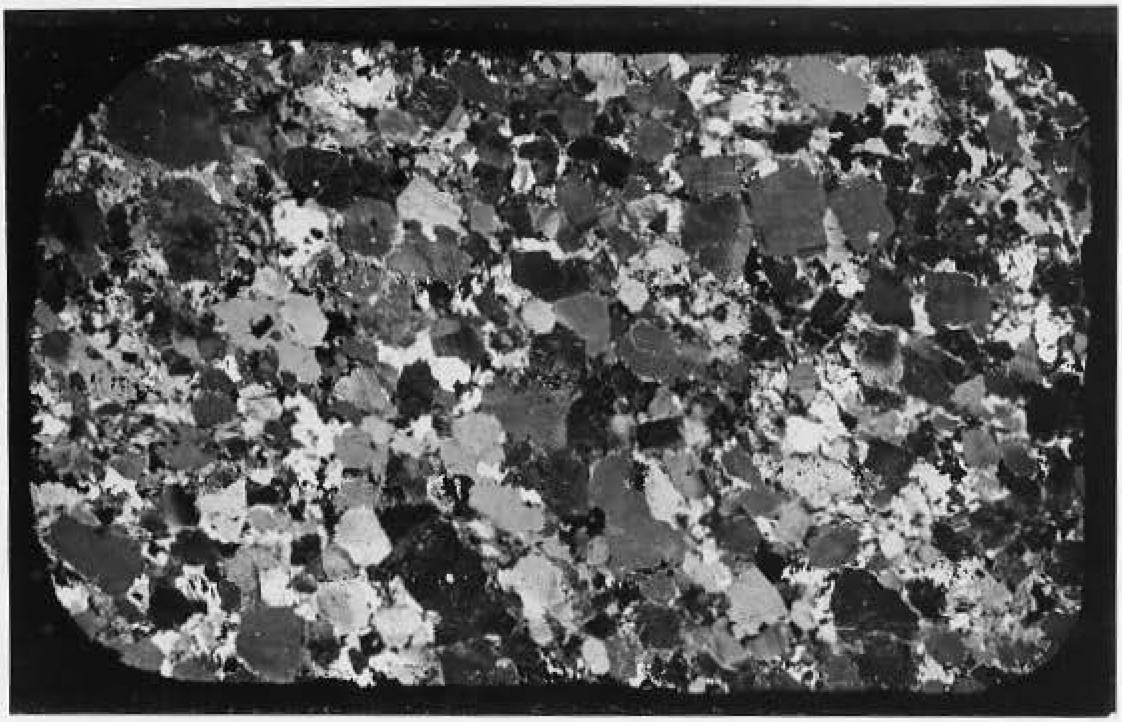
These rocks are predominantly plagioclase, quartz, potassic feldspar biotite, hornblende and clinopyroxene. The overall texture is massive to weakly foliated medium grained subhedral equigranular (plate 2).

Potassic feldspar in the form of perthitic microcline, occurs as coarse phenocrysts and as finer grains, both of which are anhedral. Potassic feldspar varies from less than 1% in the tonalite to 11% in the granodiorite. Fine grained anhedral to subhedral inclusions of plagioclase feldspars, quartz and biotite occur in the potassic feldspar.Alteration to sericite is minor. Occasional epidote and calcite can be found in fractures within the potassic feldspar grains.

Plagioclase feldspar is, in general, finer grained and more subhedral than the potassic feldspar. Michel-Levy tests indicating that the plagioclase composition varies, non-systematically from An_{35} to An_{40} and optically negative biaxial interference figure correspond to andesine plagioclase. The amount of plagioclase ranges from 43%

Plate 2: Macroscopic view of massive texture in the granodiorite-tonalite pluton showing mafic clusters. Plane light at top, crossed polars at bottom (field of view- 2.5 mm x 4.0 mm).





to 52%. Twinning varies from poorly to well developed with albite or pericline twinning occurring most abundantly. Carlsbad twins are rare. Fine grained anhedral to subhedral inclusions of potassic feldspar quartz and biotite occur in the plagioclase. Some plagioclase grains have been fractured or have bent twin lamellae with undulatory extinction. Alteration to sericite varies from very minor and disseminated in some sections to minor but patchy in others. Alteration of plagioclase is always more severe than that of potassic feldspar. Augustithis (1973) noted this type of occurrence as well and attributed it to the greater susceptibility of plagioclase, compared with potassic feldspar, to alteration.

Quartz occurs as anhedral polycrystalline grains of various sizes which are, on average, equal in size to the feldspars. Extinction is always undulatory and quartz to quartz grain boundaries tend to be lobate and sutured. The amount of quartz present varies from 14% to 29%.

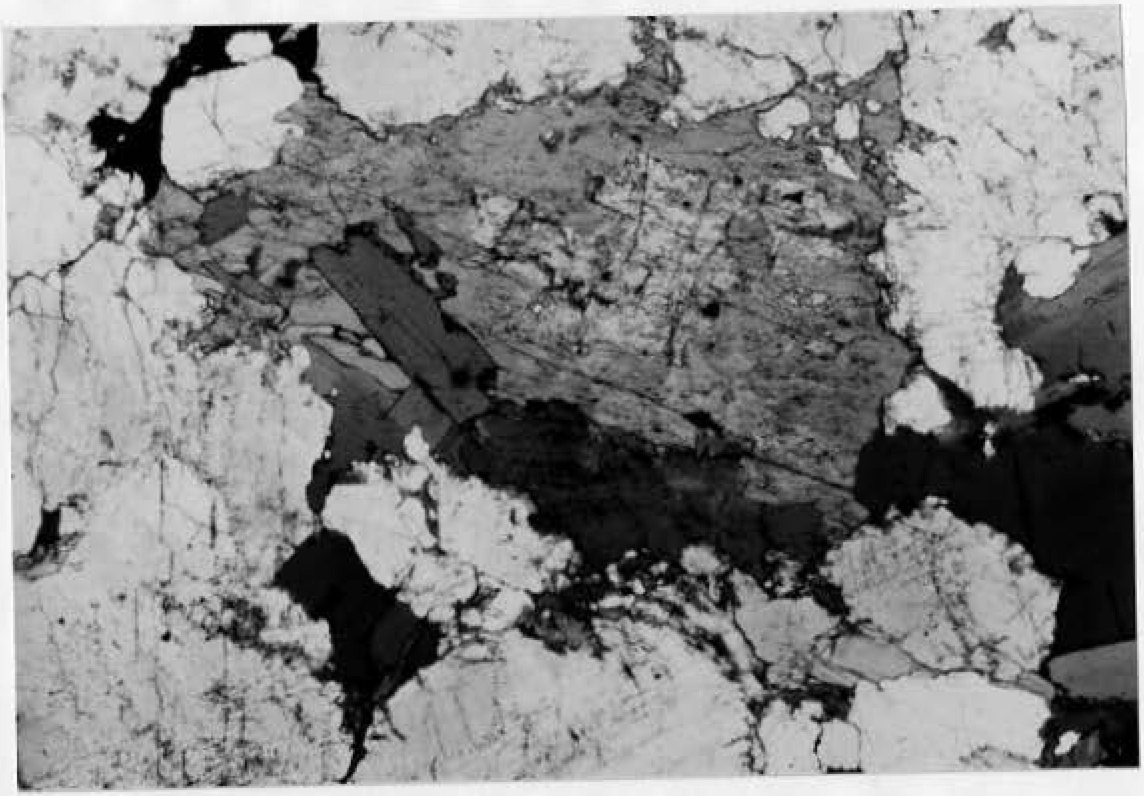
The mafic minerals occur in clusters (plate 3a), typically clinopyroxene cores altered and rimmed by an amphibole which in turn is rimmed by biotite.

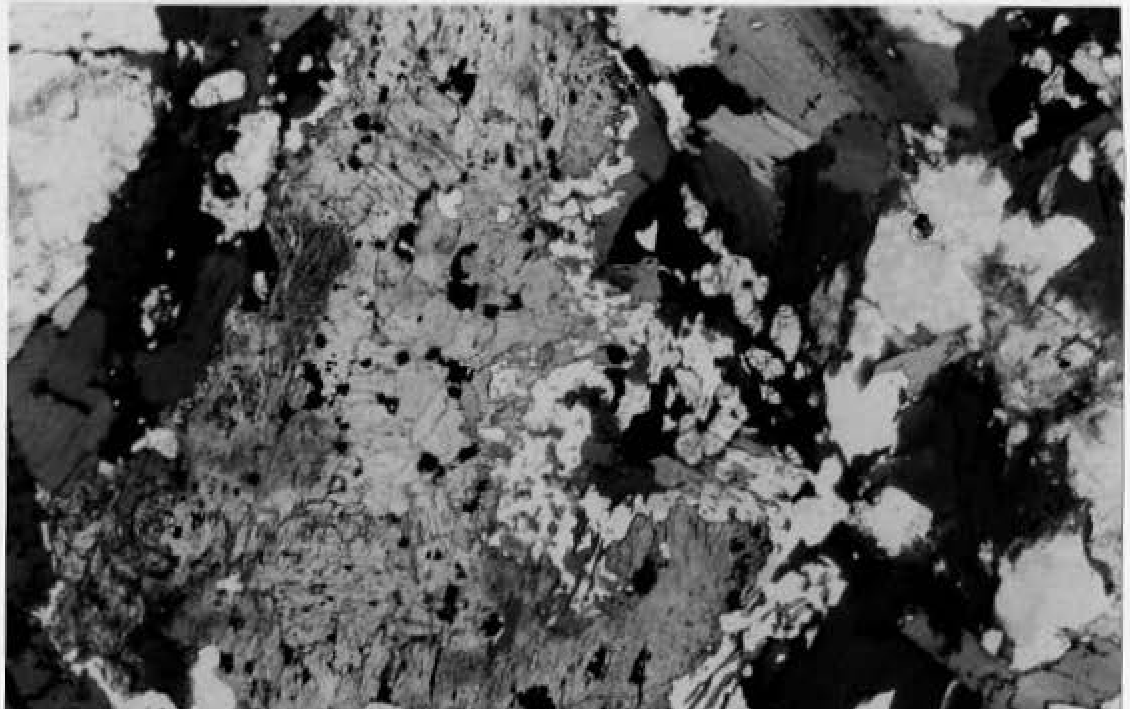
Patchy alteration of the clinopyroxene by the amphibole obscure the former's optical properties. Where unaltered the clinopyroxene is neutral to very pale brown with high relief and middle second order birefringence. Good cleavage in one direction, parallel to the C-axis can be observed with extinction angles, and optically positive biaxial interference figure with a moderate 2V all indicating augite.

Amphibole occurs as alteration products of augite, rims to

Plate 3a: Mafic cluster in the granodiorite-tonalite pluton with the pale green pyroxene core, green hornblende rim and brown biotite (Plane light, field of view - 2.5 mm x 4.0 mm).

Plate 3b: Mafic cluster in the granodiorite-tonalite pluton with neutral to pale green amphibole rimmed by green hornblende, surrounded by brown biotite. Note opaques (Plane light, field of view - 2.5 mm x 4.0 mm).





augite and as individual anhedral grains. Most grains exhibit strong pleochroism from light to dark green, which according to Nockholds (et al, 1978), indicates that the amphibole is an aluminous, fairly Fe-rich hornblende. Basal grains displaying excellent 56° - 124° cleavage occur frequently. Rarely a neutral to pale green amphibole, distinguished from augite by its lower relief, columnar crystal habit and polysynthetic twinning occurs with augite, both of which are altered and rimmed by hornblende (plate 3b).

Biotite occurs as discrete grains and as rims to hornblende and is strongly pleochroic from pale to dark brown, indicating that it is Fe-rich (Nockholds et al, 1978). Basal flakes show no cleavage or pleochroism however do exhibit excellent pseudo-uniaxial, optically negative interference figures. Some grains show excellent cleavage with subparallel extinction. Inclusions of subhedral zircon and apatite with pleochroic halos are quite common. Most biotite grains exhibit exsolution of opaques at grain boundaries and along cleavage traces (plate 4a). Alteration of biotite to chlorite is minor in most cases and severe in samples which have been sheared.

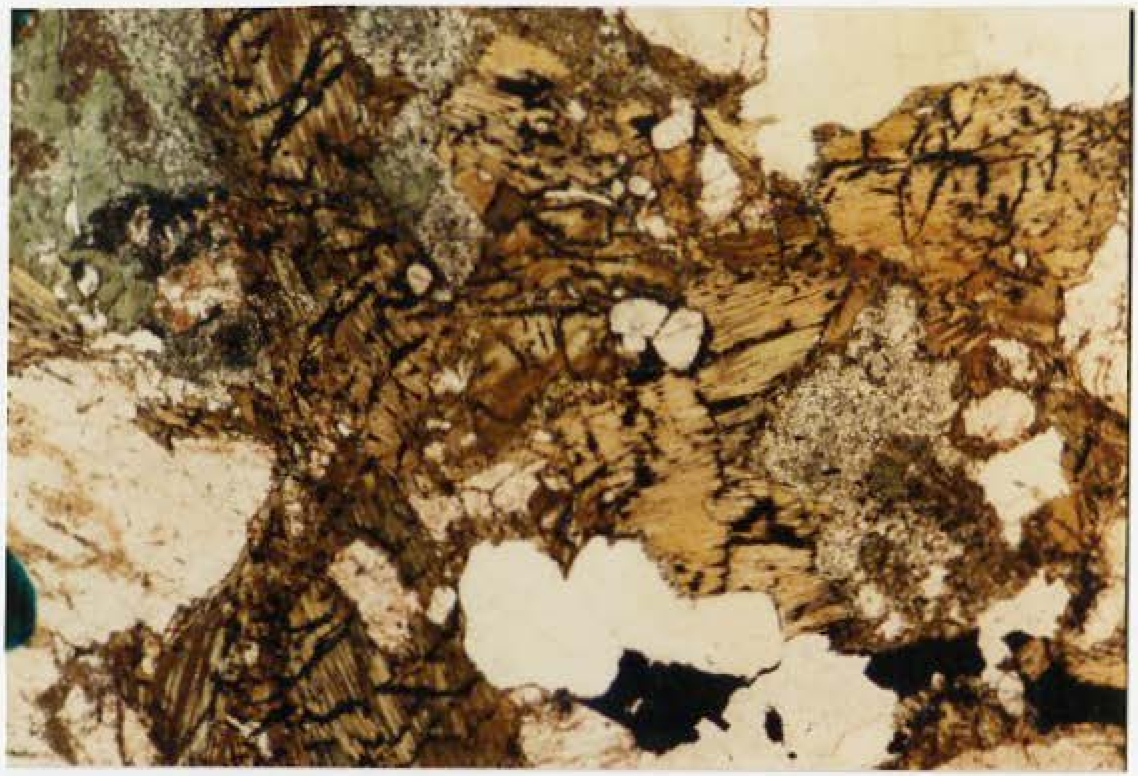
The abundance of mafic minerals as a whole is relatively constant across the pluton at approximately 20% to 25%. However in some clusters only biotite is present. This may reflect local compositional variation within the magma at the time of cooling.

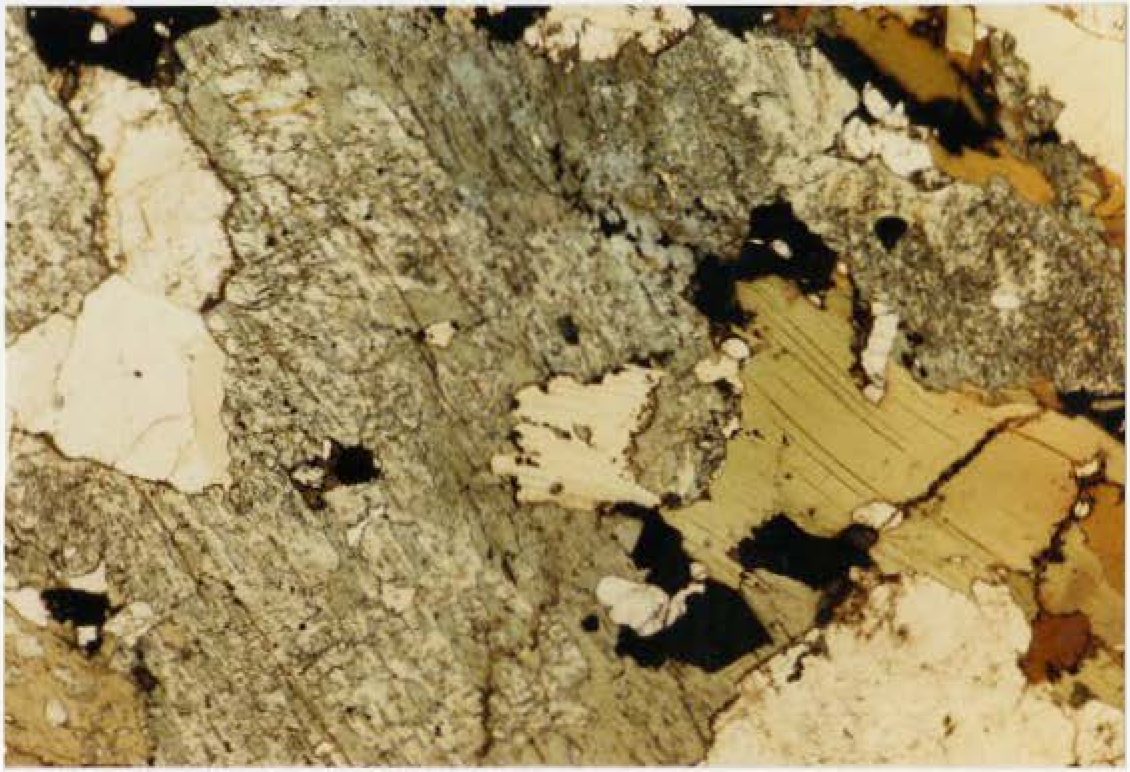
Opaques occur as fine to medium grained anhedral grains associated with mafic minerals, occasionally as exsolution products (plate 4b).

Myrmekitic intergrowths of quartz and plagioclase occur at

Plate 4a: Exsolution of opaques and chloritization of biotite in the granodiorite-tonalite pluton (Plane light, field of view - 2.5 mm x 4.0 mm).

Plate 4b: Opaques in association with mafic minerals in the granodiorite-tonalite pluton (Plane light, field of view - 2.5 mm x 4.0 mm).





potassic feldspar-biotite grain boundaries and at potassic feldspar-plagioclase grain boundaries (plate 5a,b).

3.3 Migmatitic Granite Gneiss

Because the contact with the granodiorite-tonalite pluton is gradational and very little time in the field was available to study it, the migmatitic granitic gneiss is rather poorly defined. It was sampled at 2 locations - station 6 where 2 samples were collected and station 4 where 1 sample was collected (fig. 3-1). Both of these stations were moderately to strongly foliated, with migmatites at station 4 (plate 6) and therefore are texturally different from the granodiorite-tonalite pluton.

Modal values (table 3-1) show samples MN6 to MN6b to be granites while sample MN4 is a granodiorite (fig. 3-2). Compositionally then, station 6 differs from the granodiorite-tonalite pluton while station 4 is quite similar, albeit somewhat quartz rich.

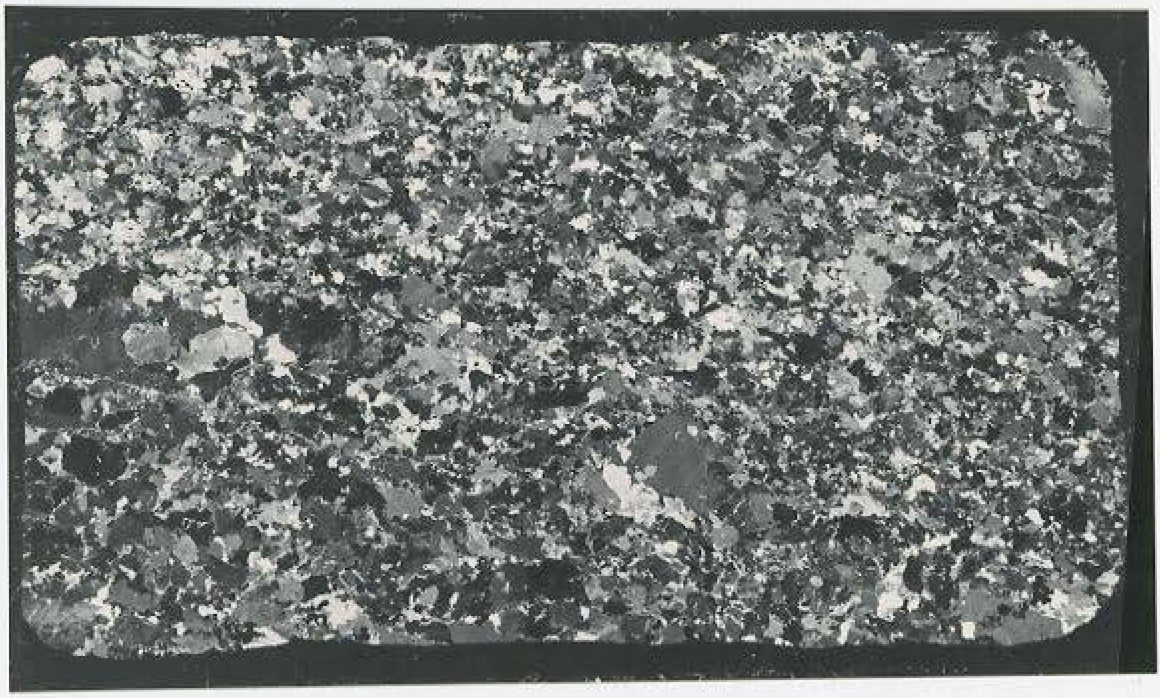
Sample MN4 contains plagioclase, quartz, potassic feldspar, biotite, hornblende and clinopyroxene. It has a considerably different texture than the samples from the granodiorite-tonalite pluton (plate 7a,b). Mafic minerals occur less in clusters and more as individual grains with a preferred orientation defining a weak foliation (plate 8). Feldspars and quartz tend to be slightly finer grained and more anhedral with curved grain boundaries resulting from

Plate 5a: Myrmekite in the granodiorite-tonalite pluton between biotite, upper left, and potassic feldspar, lower right (Crossed polars, field of view - 0.4 mm x 0.6 mm).

Plate 5b: Myrmekite in the granodiorite-tonalite pluton between plagioclase, bottom. and extinct potassic feldspar (Crossed polars, field of view - 1.5 mm x 2.25 mm).

Plate 6: Development of migmatitic texture in the migmatitic granite gneiss at station 4 (knife for scale).

Plate 7: Gneissic texture in sample MN4 from the migmatitic granite gneiss. Plane light at top, crossed polars at bottom (field of view- 2.5 mm x 4.0 mm).



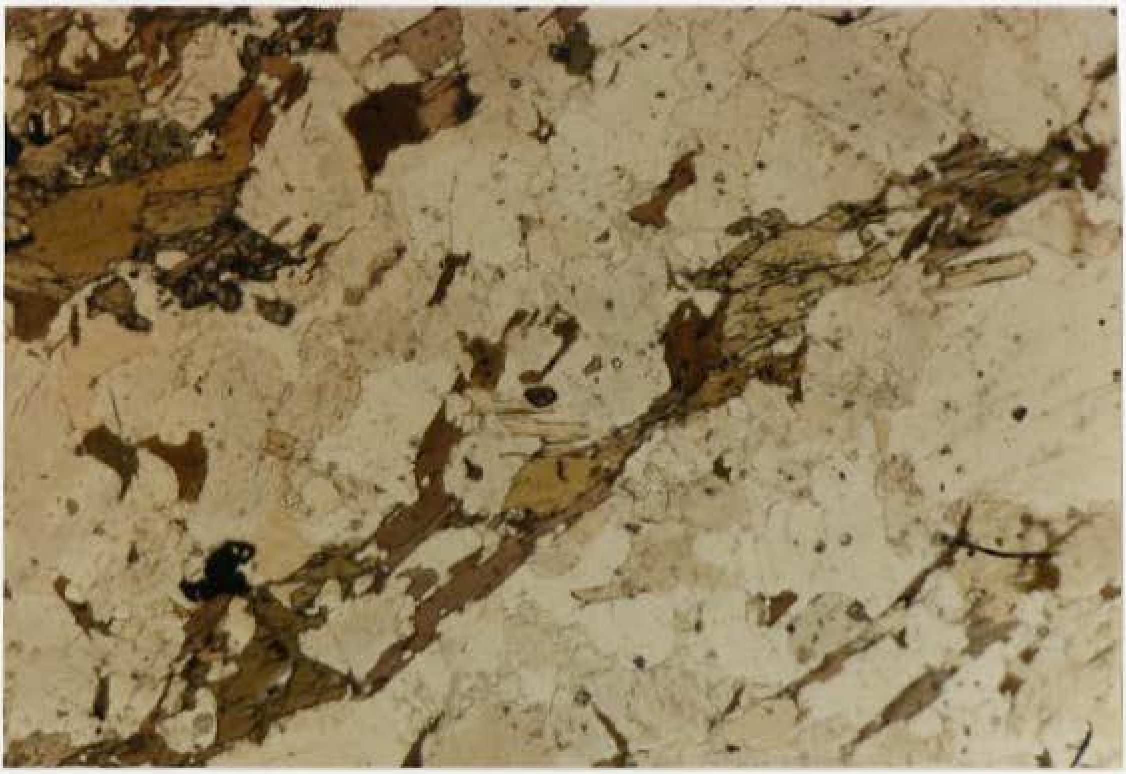


Plate 8: Prefered orientation of mafics in sample MN4 from the migmatitic granite gneiss (Plane light, field of view - 2.5 mm x 4.0 mm).

adjacent grains intruding into one another, in a manner similar to the embryo-like embayments described by Spry (1969).

Samples MN6 and MN6b are predominantly potassic feldspar, quartz, plagioclase and biotite, while MN6b also contains hornblende, cummingtonite and possibly orthopyroxene. They are coarse grained anhedral equigranular with no foliation apparent in thin section.

Potassic feldspar occurs as coarse anhedral grains of perthitic microcline. Inclusions of quartz, biotite and plagioclase occur within the potassic feldspar. Myrmekite occurs at potassic feldspar-plagioclase, and potassic feldspar-biotite grain boundaries. Plagioclase occurs as subhedral grains, and in general is finer grained than potassic feldspar.

Quartz occurs as coarse anhedral undulatory grains, as graphic intergrowths with plagioclase and as fine grained aggregates in the mortar texture (plate 9).

The mafic minerals occur in clusters as in the granodiorite-tonalite pluton. Pyroxene cores are altered and rimmed by amphibole which is rimmed by biotite. The pyroxene is neutral to pale brown with low first order birefringence, parallel extinction and an optically negative biaxial interference figure corresponding to the orthopyroxene--hypersthene. Altering and rimming the pyroxene is green pleochroic hornblende. Also altering the pyroxene is a pale brown, fibrous to columnar amphibole with polysynthetic twinning, second order birefringence and extinction angles of 20° - 22° corresponding to cummingtonite. Cummingtonite tends to occur within the hornblende rims near sub-millimetre fractures in the pyroxene

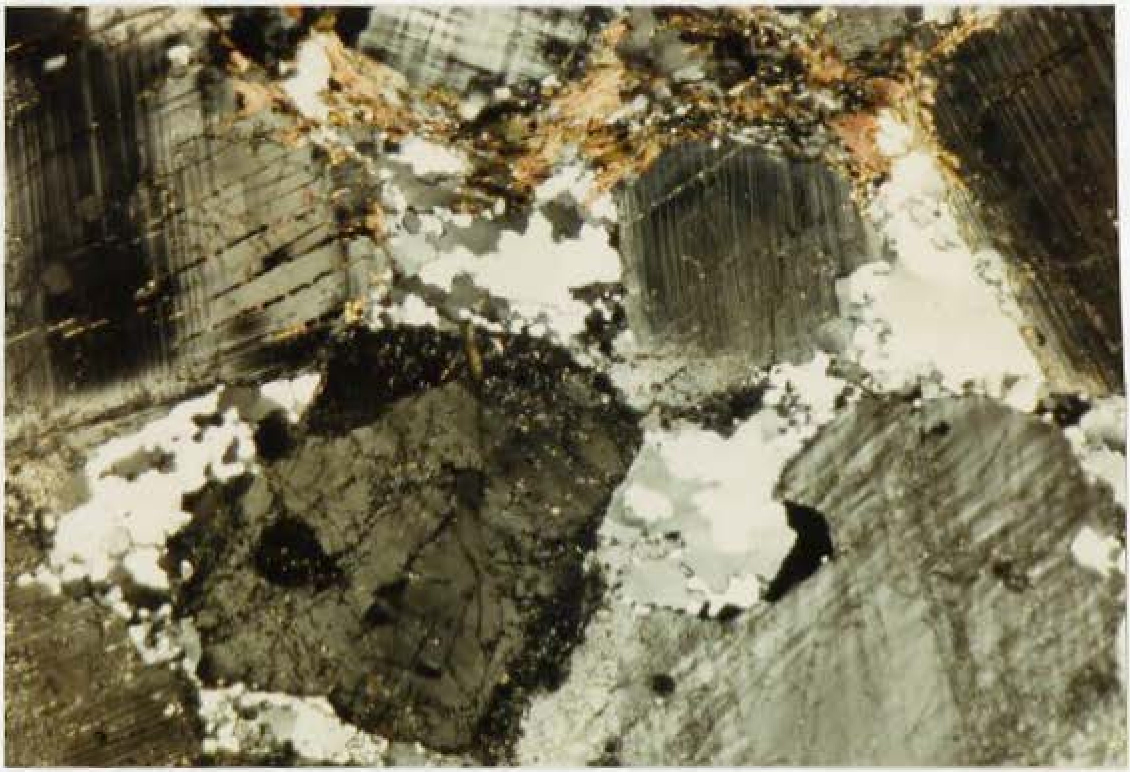


Plate 9: Mortar texture in the migmatitic granite gneiss (Crossed polars, field of view - 2.5 mm x 4.0 mm).

(plate 10a,b).

Biotite exsolves opaques at grain boundaries and along cleavage traces and is chloritized in places. Inclusions of zircon and apatite are abundant.

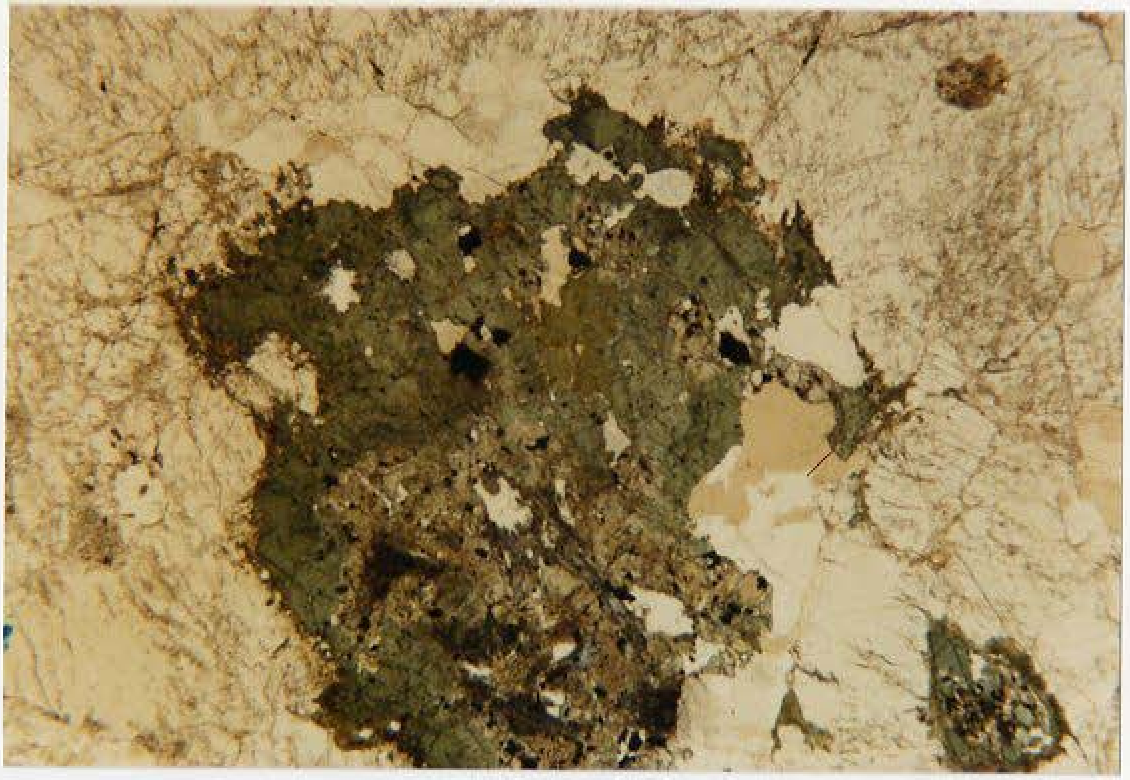
3.4 Interpretation of Textures

In some cases in the granodiorite-tonalite pluton there is a texture whereby fine grained recrystallized quartz aggregates form a matrix in which sit coarse undulose quartz and feldspar grains, with deformed twin lamellae (plate 11a). This texture is similar to the mortar texture of Spry (1969) and is indicative of slight post-crystallization deformation. Other textural features also resulting from this deformation are lobate and sutured quartz to quartz grain boundaries, and undulose plagioclase grains with fractured and bent twin lamellae (plate 11b).

Within the shear zones, more severe deformation features are observed. Quartz occurs as recrystallized polycrystalline lense-shaped grains with abundant 120^{o} triple junctions; coarse grains show undulatory extinction. Biotite shows distinct preferred orientation, grain size reduction and alteration to chlorite. Feldspars occur as anhedral, fractured and severely sericitized grains with bent twin lamellae (plate 12). Calcite and epidote occasionally can be found in fractures within the feldspars, and with sericite, probably represent a late volatile rich stage of the deformation event.

Plate 10a: Mafic cluster in the migmatitic granite gneiss with pale green-brown fibrous cummingtonite, pale brown pyroxene and green hornblende rim (Plane light, field of view - 2.5 mm x 4.0 mm).

Plate 10b: Twinning in cummingtonite in the migmatitic granite gneiss (Crossed polars, field of view - 0.4 mm x 0.6 mm).



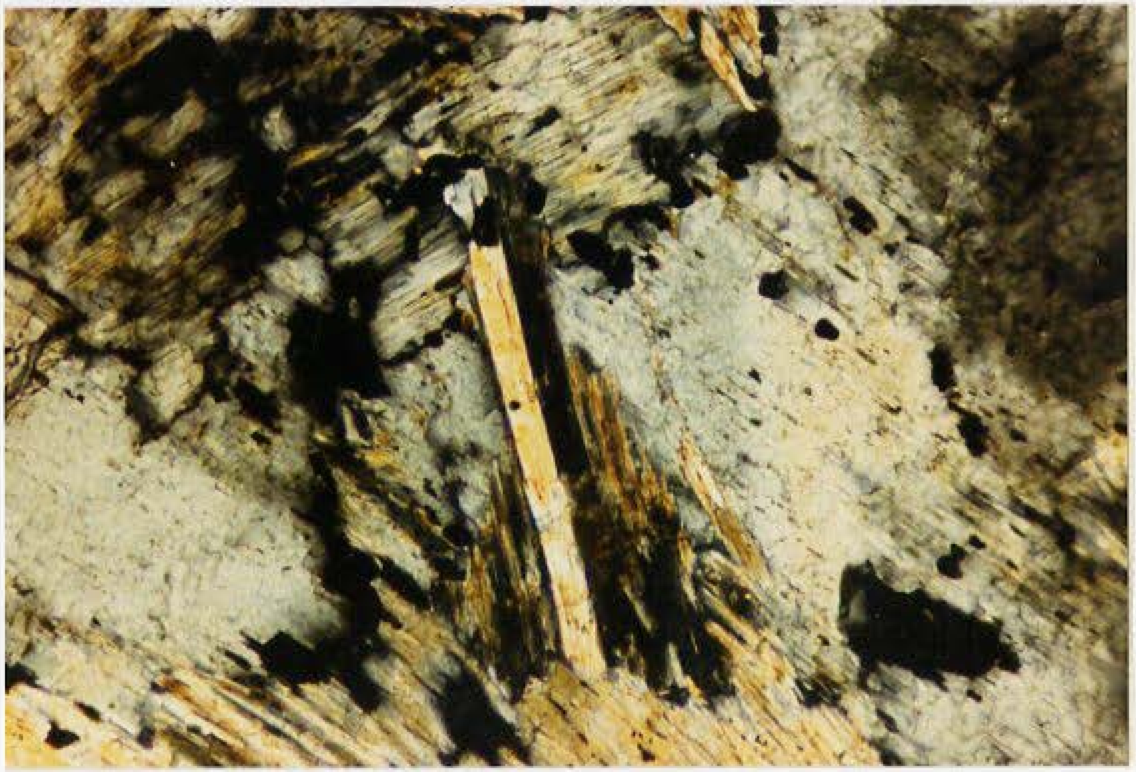
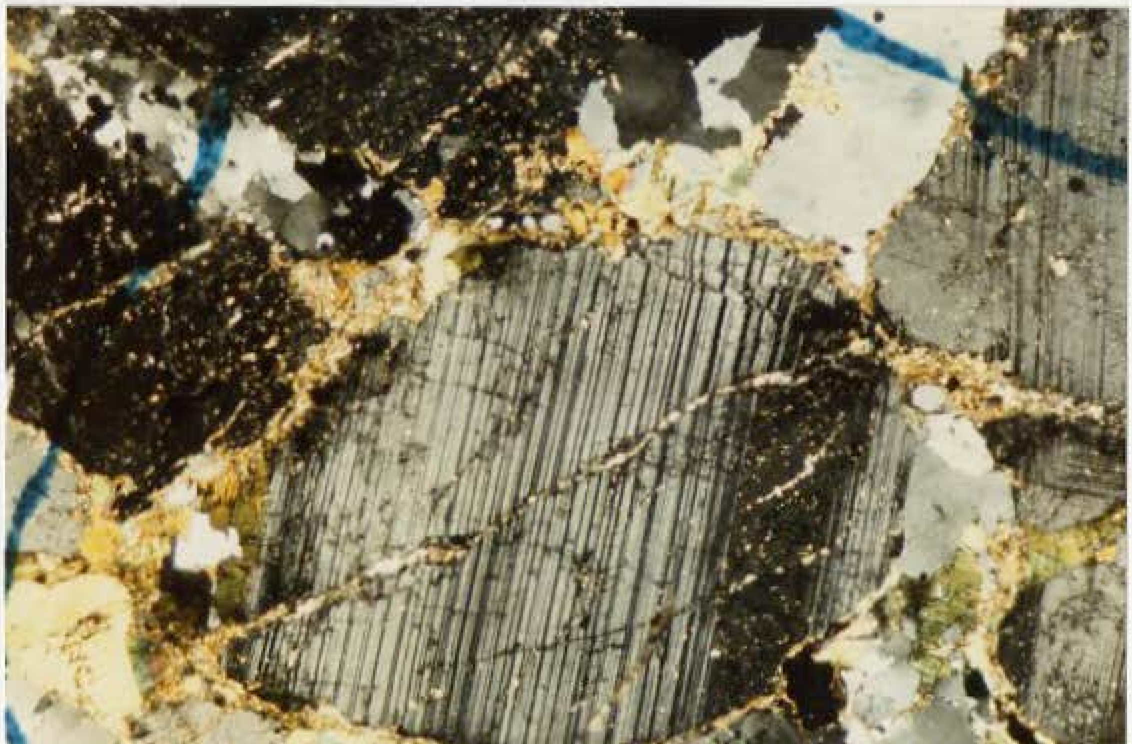


Plate 11a: Mortar texture in the granodiorite-tonalite pluton (Crossed polars, field of view - 2.5 mm x 4.0 mm).

Plate 11b: Fractured and deformed twin lamellae in plagioclase in the granodiorite-tonalite pluton (Crossed polars, field of view - 2.5 mm x 4.0 mm).



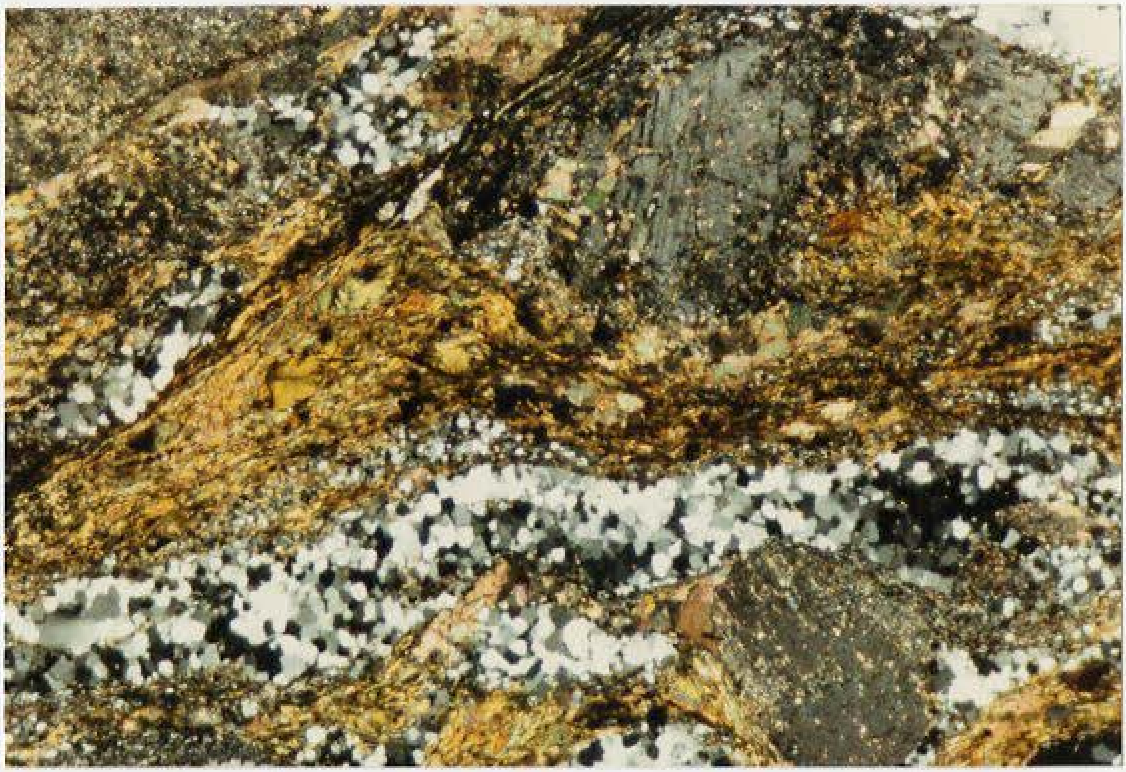


Plate 12: Polygonalized quartz, chloritized biotite, sericitized feldspar, and calcite in shear zone within the granodiorite-tonalite pluton (Crossed polars, field of view - 2.5 mm x 4.0 mm).

Controversy exists concerning the nature of the mafic clusters. Thompson (et al, 1986) suggests that hornblende rims on clinopyroxene and late biotite represent evidence for a metamorphic origin of said clusters. However, Nockhold (et al, 1978) sites the occurrence of hornblende-biotite granodiorite plutons in Southern California with pyroxene cores in some of the hornblende crystals while White and Chappell (1983) interpreted pyroxene cores in hornblende crystals in granitoids of the Lachlan Fold Belt as being a restite component of a granitoid and therefore an igneous phenomenon. Therefore, the mafic clusters in the pluton of this study may be either an igneous cooling feature or a metamorphic feature.

Other features in the pluton which according to Spry (1969) suggest a metamorphic history are sericitization and clouding of feldspars, chloritization of biotite, solid solution exsolution by feldspar, and strained extinction or polygonalization of quartz grains.

Conversely, Nockholds (et al, 1978) suggests that all of the above features except polygonalization of quartz can be attributed to igneous cooling phenomena involving residual fluids rich in water.

From regional field evidence, including surrounding map sheets (Thompson and Henderson, 1983), Thompson (et al, 1986) has suggested that a regional low grade (greenschist to lower amphibolite facies), high strain event has occurred. Spry (1969) points out that plutonic rocks are extremely resistant to thermal metamorphism except at high grades, and therefore Thompson's metamorphic event may only be displayed as deformational features. However, the majority of the pluton has not suffered high strain as evidenced by the lack of polygonalized quartz indicating that its texture is igneous. The shear zones within the pluton may be a localized manifestation of this low grade, high strain metamorphic event.

The presence of orthopyroxene in thin section and migmatitic textures in the field supports the supposition that the migmatitic granite gneiss correlates with Thompson's "orthopyroxene/ migmatite/ charnockite" unit (Thompson et al, 1985). Extensive mortar like texture as described by Spry (1969) throughout the samples indicates that post crystallization deformation has occurred. The textural relationships between the orthopyroxene, hornblende and cummingtonite suggest that the orthopyroxene cores and hornblende rims were derived from a high grade event which preceded the growth of the cummingtonite. The occurrence of cummingtonite and mortar texture correlates with Thompson's (et al, 1986) regional metamorphic event.

Within the massive to gneissic granite, exsolution of opaques, chloritization of biotite, and sericitization of feldspars represents a later hydrothermal alteration by residual fluids. This hydrothermal alteration may have been caused by the intrusion of the pluton adjacent to the east.

CHAPTER 4 GEOCHEMISTRY

4.1 Elemental Geochemistry

Major element analyses of six samples from the granodiorite-tonalite pluton are listed in table 4-1. A gradational change from granodiorite to tonalite is indicated by a decrease in K_2O content and a slight increase in Al_2O_3 content. This trend conforms with the modally determined trend (fig. 3-2).

As compared with the average granodiorite, tonalite and ferrogranodiorite of Nockolds et al (1978) the pluton appears to be a ferrotonalite. The SiO_2 and total Fe values of the pluton are characteristic of the ferrogranodiorite, although they are somewhat depleted. The Al_2O_3, CaO and MgO values of the pluton are characteristic of the tonalite, although they are somewhat enriched, especially the latter. The Na_2O values are distinctly low across the pluton averaging 2.4%. The high CaO and Al_2O_3 values are reflected in the high normative plagioclase content. Consequently, in terms of the molecular proportions, $Al_2O_3 > CaO + Na_2O + K_2O$ for all six samples and the pluton is classified as peraluminous (Carmichael et al, 1974). The SiO_2 content varies from approximately 61% to 65% which correlates with an intermediate rock.

Table 4-2 contains normative values for the six granodiorite-tonalite samples of table 4-1 as calculated using the mesonorm of Shaw (1969). Two norms per sample were determined with total Fe as Fe_2O_3 and total Fe as FeO representing minimum and maximum normative

TABLE 4-1 MAJOR ELEMENT DATA FOR THE GRANODIORITE-TONALITE PLUTON AND AVERAGE GRANITOIDS (FROM NOCKOLDS ET AL, 1978)

Element	MN2	MN11	MN10	MN9	MN8	MN7	Gd.	Ton.	Fgd.
SiO_2	61.12	62.53	64.24	64.58	60.67	62.20	66.88	66.15	64.90
Al_2O_3	15.50	16.56	16.37	15.83	17.04	16.85	15.66	15.56	13.33
Fe_2O_3	7.65	6.67	5.88	5.96	7.90	7.65	3.92	4.78	8.46
MgO	3.57	2.25	2.07	2.50	3.30	1.95	1.57	1.94	0.52
CaO	5.72	5.39	5.05	4.31	4.95	5.55	3.56	4.65	3.52
Na_2O	2.12	2.38	2.35	2.52	2.56	2.38	3.84	3.90	3.74
K_2O	3.31	3.17	3.19	3.38	2.49	2.37	3.07	1.42	3.38
TiO_2	0.66	0.66	0.57	0.61	0.59	0.69	0.57	0.62	0.89
MnO	0.14	0.11	0.10	0.09	0.16	0.11	0.07	0.08	0.14
P_2O_5	0.19	0.20	0.18	0.21	0.35	0.18	0.21	0.21	0.23

Gd.- Granodiorite

Ton.- Tonalite

Fgd.- Ferrogranodiorite

From Nockolds et al, 1978.

All values in wt. %

TABLE 4-2 NORMATIVE VALUES FOR THE GRANODIORITE-TONALITE PLUTON

	MN2		MN11		MN10		MN9		MN8		MN7	
	A	B	A	B	A	B	A	B	A	B	A	B
Quartz	22.42	23.11	24.88	25.48	26.93	27.53	27.18	27.75	25.60	26.33	27.06	27.78
K-spar	13.92	9.58	10.42	6.70	11.40	8.03	10.32	6.95	-	-	5.15	0.60
Plag.	41.05	42.20	44.95	46.05	43.90	44.80	41.30	42.20	43.95	45.30	46.50	47.90
	Ab_{47}	Ab_{47}	Ab_{49}	Ab_{49}	Ab_{49}	Ab_{49}	Ab_{56}	Ab_{56}	Ab_{53}	Ab_{53}	Ab_{47}	Ab_{47}
Biot.	9.65	17.55	9.20	15.84	8.00	13.87	9.52	15.52	12.72	20.75	7.60	15.39
Hb.	5.70	5.70	-	-	-	-	-	-	-	-	-	-
Hem.	5.44	-	4.71	-	4.18	-	4.23	-	5.61	-	5.52	-
Sphene	1.41	1.44	1.41	1.44	1.23	1.23	1.29	1.32	1.26	1.29	1.47	1.53
Apat.	0.40	0.43	0.56	0.56	0.37	0.40	0.45	0.45	0.75	0.77	0.40	0.40
Musc.	-	-	3.89	3.92	3.99	4.13	5.71	5.81	9.87	3.40	6.30	6.41
Cor.	-	-	-	-	-	-	-	-	0.24	2.15	-	-

A - total Fe as Fe_2O_3

B - total Fe as FeO

mafic mineral content respectively. The normative values reflect the decrease in K_2O content as a decrease in potassic feldspar, and therefore, conform to the modally determined trend (fig. 3-2). The presence of normative corundum and muscovite in sample MN8 reflects the high Al_2O_3 and slightly lower K_2O contents at that point, which is typical of tonalite.

Table 4-3 lists concentrations of the trace elements Rb and Sr as well as major elements K and Ca for the six samples from the granodiorite-tonalite pluton and for the average basaltic, high-Ca granitic, and low-Ca granitic rocks according to Faure (1977). Comparison of concentrations and K/Rb, Ca/Sr, Rb/Sr ratios indicates that the granodiorite-tonalite pluton is similar to the average high-Ca granitic rocks of Faure (1977) in all respects, except Ca content, in which the pluton is relatively enriched (fig. 4-1,2,3).

4.2 Geochronology

An attempt to determine the age of the granodiorite-tonalite pluton was made employing the Rb-Sr whole rock isochron method.

To produce a geochronologically meaningful age one must collect samples that have been isotopically closed since their time of formation. Therefore, samples should be isolated from fractures and weathered surfaces which may represent isotopic contamination. If possible, samples collected should vary compositionally from one to the next while still representing a comagmatic rock suite. Compositional variation results in a greater spread in $^{87}Rb/^{86}Sr$ and

TABLE 4-3 Rb, K, Sr, Ca DATA FOR THE GRANODIORITE-TONALITE PLUTON

AND SELECTED AVERAGE IGNEOUS ROCKS

Element	MN2	MN7	MN8	MN9	MN10	MN11	B	HCG	LCG
Rb	104	96	120	124	107	115	30	110	170
K	27478	19675	20671	28059	26482	26316	8300	25200	42000
Sr	410	389	343	404	451	458	465	440	100
Ca	40881	39666	35378	30804	36092	38522	76000	25300	5100
K/Rb	264	205	172	226	247	229	277	229	247
Ca/Sr	100	102	103	76	80	84	163	58	51
Rb/Sr	0.254	0.248	0.350	0.306	0.238	0.250	0.065	0.250	1.700

B - Basalt

HCG - High-Ca granite

LCG - Low-Ca granite

From Faure (1977).

All values in ppm.

Figure 4-1: Weight % K versus Rb (ppm) for the granodiorite-tonalite pluton and selected average igneous rocks from Faure (1977).

▲ - Granodiorite-tonalite pluton

● - B- Basalt
LCG- Low Ca-granite
HCG- High Ca-granite

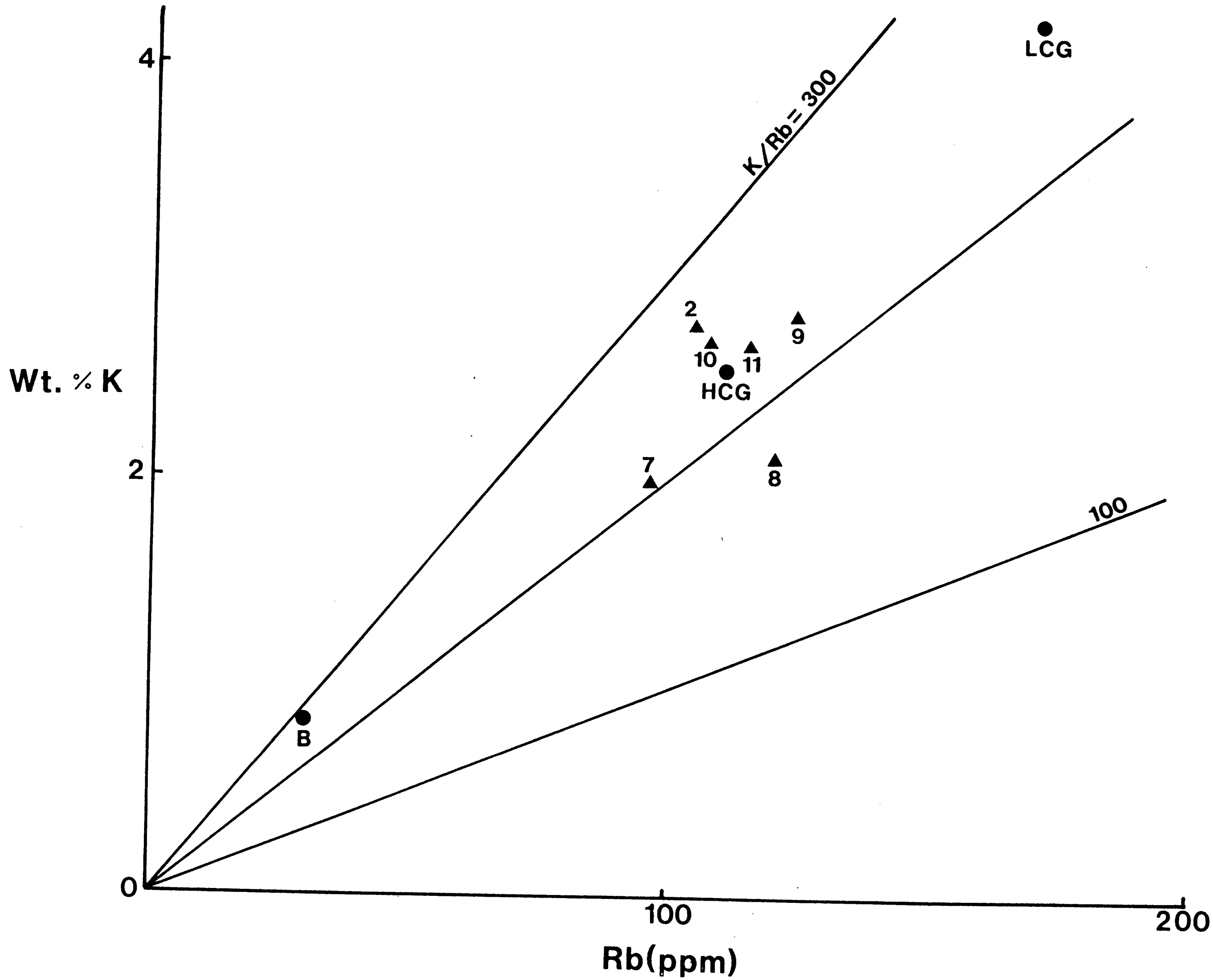
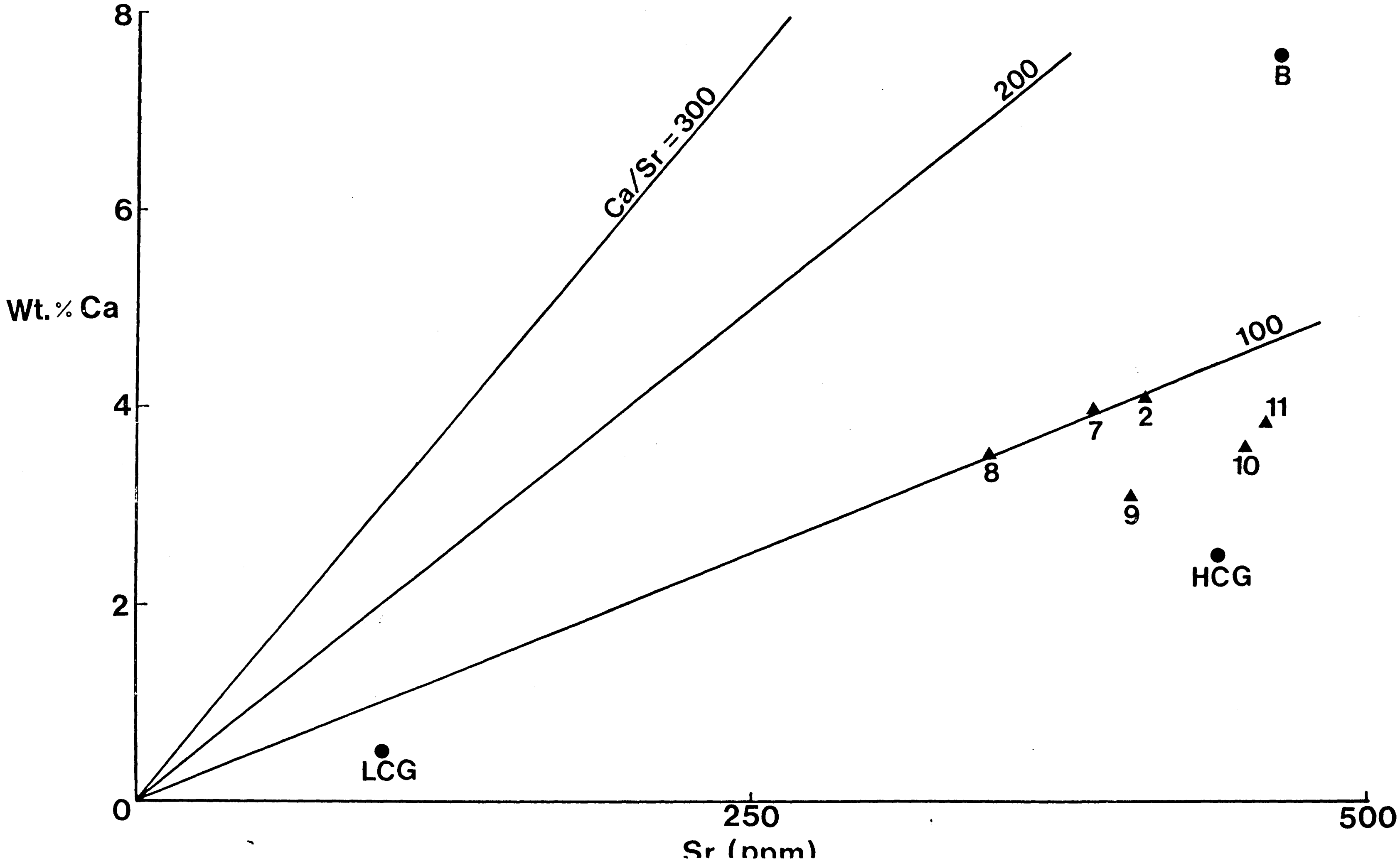

Wt. % K
4
2
0
100
200
Rb(ppm)
K/Rb = 300
100
LCG
HCG
B
2
10
11
9
7
8

Figure 4-2: Weight % Ca versus Sr (ppm) for the granodiorite-tonalite pluton and selected average igneous rocks from Faure (1977).

▲ - Granodiorite-tonalite pluton

● - B- Basalt
LCG- Low Ca-granite
HCG- High Ca-granite

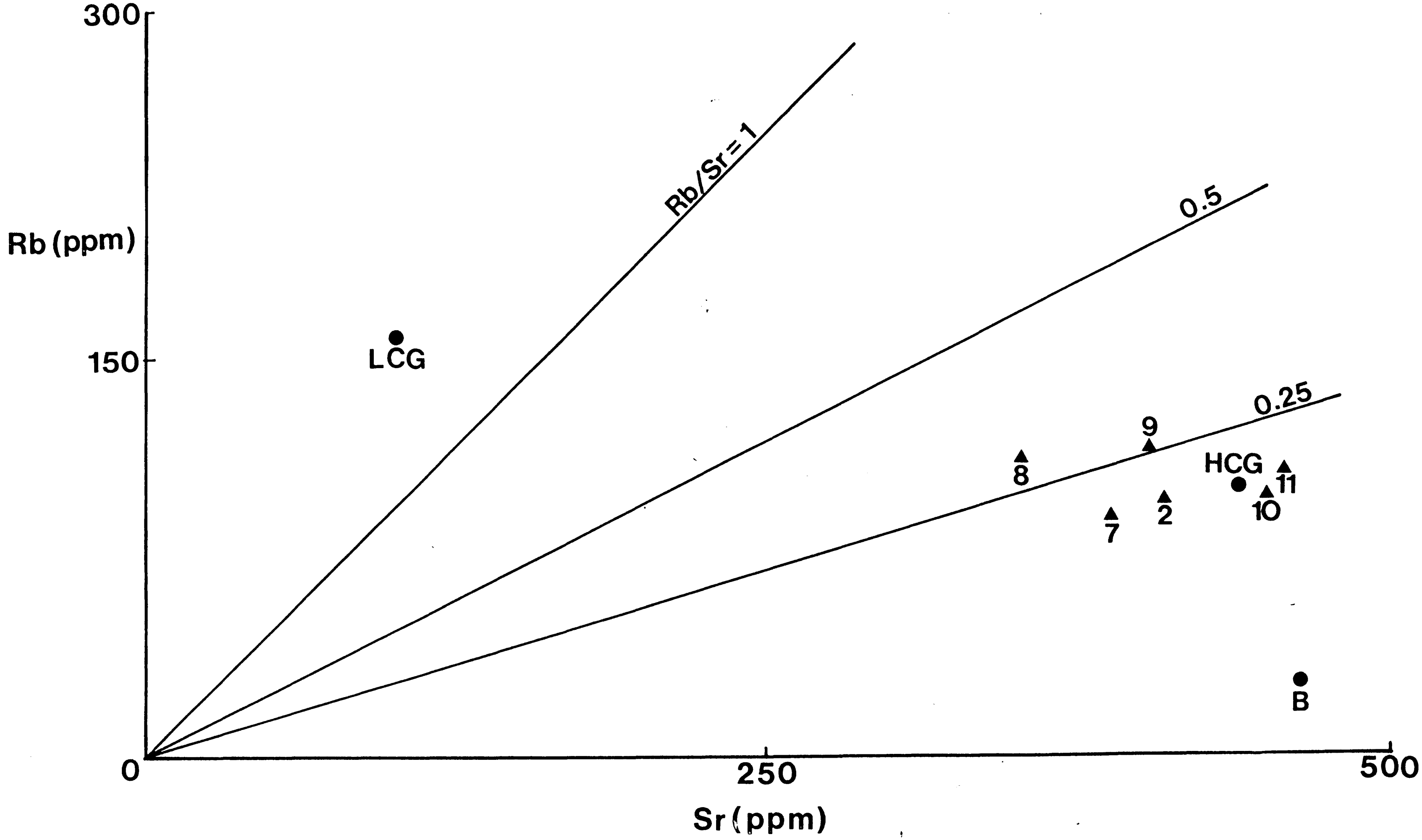


Ca/Sr = 300
200
100
B
7
2
11
8
10
9
HCG
LCG
Wt. % Ca
8
6
4
2
0
250
500
Sr (ppm)

Figure 4-3: Rb-Sr diagram for the granodiorite-tonalite pluton and selected average igneous rocks from Faure (1977).

▲ - Granodiorite-tonalite pluton

● - B- Basalt
LCG- Low Ca-granite
HCG- High Ca- granite



300
150
0
Rb (ppm)
250
500
Sr (ppm)
Rb/Sr = 1
0.5
0.25
LCG
HCG
B
8
9
7
2
10
11

$^{87}Sr/^{86}Sr$ ratios enhancing statistical validity. Normally, 20-30 samples should be collected to date a body such as the granodiorite-tonalite pluton using Rb-Sr geochronology, to ensure that 10-15 samples can be analyzed to form an isochron (R. H. McNutt, pers. comm. 1986).

Six samples of the granodiorite-tonalite pluton were collected and analyzed, however at the time of collection, geochronology was not the aim of the collection. Of the six samples, four - MN2, MN7, MN10, and MN11 were quite homogeneous isotopically (refer to table 4-4), and subsequently plotted as a tight cluster, essentially representing one point. Therefore, the isochron generated by these six samples is basically a three point plot (fig. 4-4). From this plot two distinct lines of best fit can be drawn. Inclusion of all points yields an age of approximately 2200 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.702. Exclusion of point MN8 yields an age of approximately 1650 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.708. These ages represent the maximum and minimum limits, respectively, on the age range of the granodiorite-tonalite pluton determinable by this study.

A sample collection of inferior quality and statistical size, in terms of geochronology, is probably the main cause of the generation of such a wide age range instead of a single age.

TABLE 4-4: ISOTOPIC DATA

Sample	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$*	Rb (ppm)	Sr (ppm)
MN2	0.725438+/-24	0.7372	104	410
MN7	0.724669+/-22	0.7173	96	389
MN8	0.735017+/-24	1.0148	120	343
MN9	0.729181+/-24	0.8876	124	404
MN10	0.723974+/-22	0.6883	107	451
MN11	0.724745+/-24	0.7241	115	458

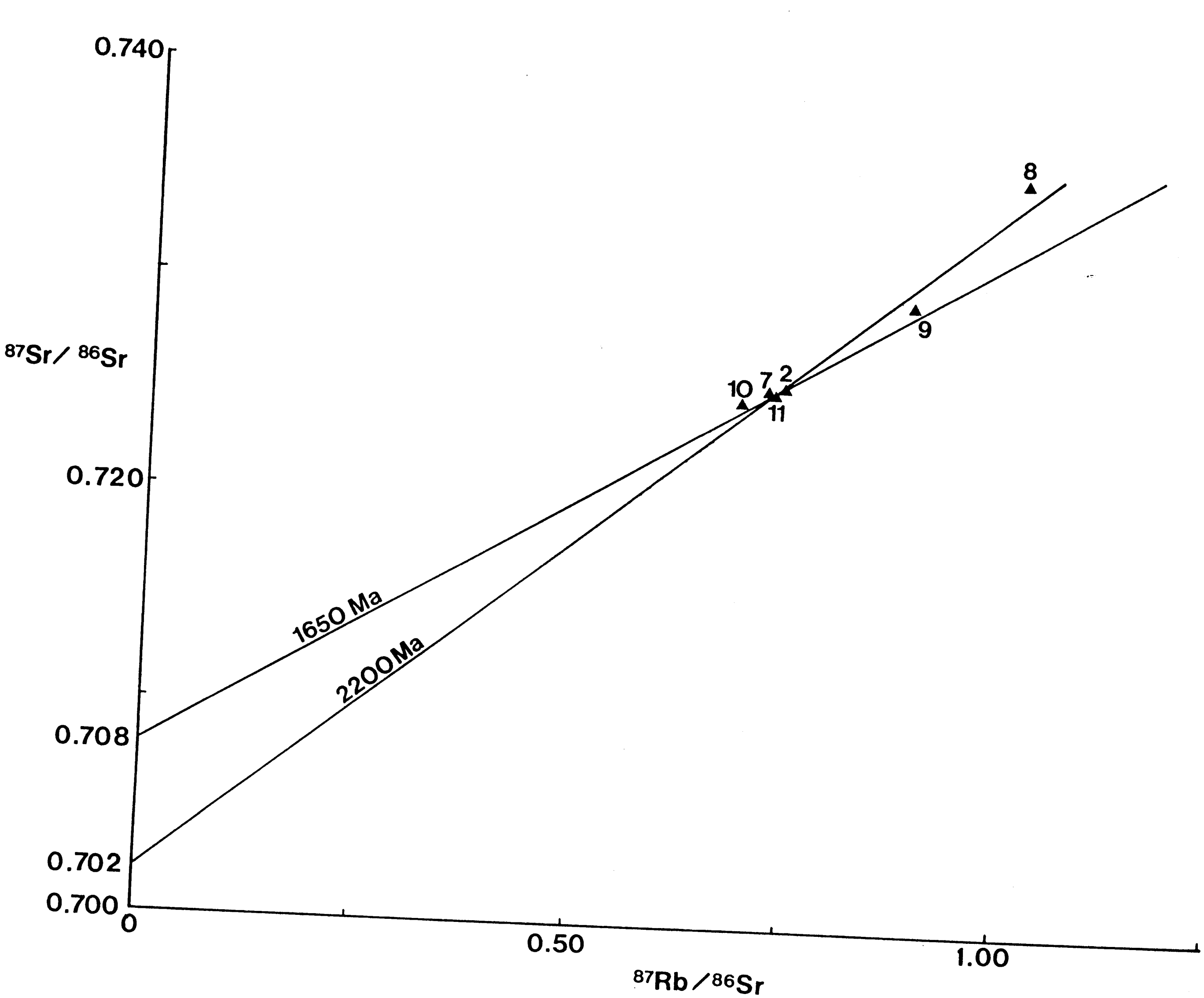
*$^{87}Rb/^{86}Sr$ ratio calculated from Faure (1977),

$^{87}Rb/^{86}Sr = (Rb/Sr)_{XRF} \times (Ab^{87}Rb \times WSr)/(Ab^{86}Sr \times WRb)$

- using the computer program in the appendix

Figure 4-4: Rb-Sr whole rock isochron for the granodiorite-tonalite pluton.

1650 Ma - Minimum age reference line.
2200 Ma - Maximum age reference line.


0.740
0.720
0.708
0.702
0.700
$^{87}Sr/^{86}Sr$
0
0.50
1.00
$^{87}Rb/^{86}Sr$
1650 Ma
2200 Ma
8
9
10
7
2
11

CHAPTER 5 DISCUSSION

From major element chemistry and petrographic analyses the pluton of this study can be classified as ferrogranodiorite-tonalite in composition. These analyses delineated a gradational change from granodiorite to tonalite. This trend was not noted in the field, not surprising given the subtleness of the transition from granodiorite to tonalite. Gradational trends as such may represent a sequence of rocks derived by partial melting and/or fractional crystallization similar to those observed and interpreted by Longstaffe (et al 1980). However, insufficient samples were collected to positively determine this.

Granitoids can be subdivided into suites, each of which has distinctive chemical, mineralogical and isotopic characteristics. Variation of these characteristics within a suite can be attributed to either partial melting or fractional crystallization. Variation of these characteristics between suites is the basis for sub-division of granitoids derived from sedimentary and igneous source rocks, the S- and I- types of White and Chappell (1983).

Within the suite of rocks of this study there is insufficient chemical and isotopic variation to obtain interpretable trends from Harker variation diagrams due to an insufficient data base. Therefore, it is not possible to make petrogenetic inferences. However average elemental and isotopic compositions can be used to compare the rocks of this study to similar rocks from various other areas (Gill, 1981).

The average analysis of the six granodiorite-tonalite pluton samples is compared to the average S- and I- type granitoid analyses of White and Chappell (1983), and the average quartz monzodiorite analysis of the Gillis Mountain pluton of Barr and Pride (1986), the latter being chosen because of its similarity to the pluton of this study (table 5-1). Distinct chemical differences between the granodiorite-tonalite pluton of this study, and the S-type granitoid of White and Chappell (1983) are apparent. Relative to the pluton, S- type granitoids are low in CaO, Na_2O and Sr, and high in K_2O and Rb. These differences, coupled with the similarities between the I- type granitoid and the granodiorite-tonalite pluton suggest that the latter is an I- type granitoid. Significant differences in CaO, Al_2O_3 and Sr content between the average I- type granitoid and the granodiorite-tonalite pluton are probably due to the high anorthite/albite ratio of the plagioclase in the pluton (table 4-2).

The quartz monzodiorite of the Gillis Mountain pluton is typical of I- type granitoids in a subduction-related, continental margin environment according to Barr and Pride (1986). Comparison of the Gillis Mountain pluton to the granodiorite-tonalite pluton of this study reveals considerable similarity between the two although the former is slightly depleted in SiO_2, CaO and K_2O and slightly enriched in Fe_2O_3 and Na_2O. Therefore, the granodiorite-tonalite pluton of this study may also be typical of a subduction-related, continental margin environment.

TABLE 5-1: COMPARISON OF AVERAGE ANALYSES OF THE GRANODIORITE-TONALITE PLUTON, S- AND I- TYPE GRANITOIDS AND THE GILLIS MONTAIN PLUTON

Element (wt.%)	MN	I-Type	S-Type	G.M.P.
SiO_2	62.53	67.98	69.08	60.14
TiO_2	0.64	0.45	0.55	1.39
Al_2O_3	16.43	14.49	14.30	16.29
Fe_2O_3	6.87*	1.27	0.73	7.77
FeO	-	2.57	3.23	-
MnO	0.11	0.08	0.06	0.11
MgO	2.57	1.75	1.82	2.60
CaO	5.21	3.78	2.49	4.81
Na_2O	2.39	2.95	2.20	3.64
K_2O	3.02	3.05	3.63	2.28
P_2O_5	0.24	0.11	0.13	0.36
Ba (ppm)	1033	520	480	797
Rb	111	132	180	101
Sr	409	253	139	465
Zr	203	143	170	160
Nb	8	9	11	-
Y	24	27	32	-
La	33	29	31	-
Ce	64	63	69	-
Nd	34	23	25	-

* Total Fe is Fe_2O_3
G.M.P.- Gillis Mountain Pluton, quartz monzodiorite (Barr and Pride,1986)
I- and S- Type granitoids (White and Chappell, 1983)
MN- Average analysis from the granodiorite-tonalite pluton

Further evidence to support this environmental interpretation is obtained by combining Rb and Sr data with Ca and K data to determine K/Rb, Ca/Sr and Rb/Sr ratios. When compared to similar data from average igneous rocks, the granodiorite-tonalite pluton is most similar to the average high-Ca granitoid, which occurs most commonly in subduction-related, continental margins.

From this study, it is concluded that the granodiorite-tonalite pluton is typical of I- type granitoids, and is similar to plutonic rocks typical of a subduction-related, continental margin environment. This conforms to the tectonic model for the Thelon Orogen proposed by Hoffman (et al, 1986). Hoffman interprets the Churchill margin, within which the granodiorite-tonalite pluton is situated, as being a magmatic arc that was deformed during emplacement, circa 1.98 - 1.90 Ga.

Petrographic evidence indicates that the granodiorite-tonalite pluton was emplaced and subsequently deformed to a limited extent by a regional metamorphic event. Thompson reports a preliminary U-Pb age for the emplacement of the pluton of 1.95 Ga (P. H. Thompson, pers. comm. 1986), which lies within the age range determined by this study using Rb-Sr geochronological methods. This age data, combined with deformational and chemical features, suggest that the emplacement of the granodiorite-tonalite pluton was associated with Hoffman's magmatic arc. Subsequent deformation, by continued subduction, is interpreted as a manifestation of the early Proterozoic regional metamorphic event described by Thompson (et al, 1986).

CONCLUSIONS

The pluton of this study can be classified as ferrogranodiorite-tonalite, with typical I-type granitoid chemical characteristics.

The age range for the emplacement of the pluton as determined by Rb-Sr geochronological methods, is 1.65-2.20 Ga which approximately correlates with a U-Pb age of 1.95 Ga and suggests that emplacement of the pluton was related to a magmatic arc circa 1.98-1.90 Ga.

Petrographic deformation features indicate that the pluton suffered post-crystallization strain during a late Proterozoic metamorphic event.

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APPENDIX- ANALYTICAL PROCEDURES

APPENDIX ANALYTICAL PROCEDURES

1 Sampling Technique

Both petrographic and geochemical samples were collected for this study. All samples were collected using a standard 1.5 lb. rock hammer. Petrographic samples, roughly fist sized, were selected to be as representative as possible of the local outcrop. Geochemical samples were collected as to avoid fractures and weathered surfaces. However, because of severe logistical restraints, in some cases, the quality of sample location was compromised to enhance ease and speed of collection.

2 Sample Crushing

To obtain a homogeneous and representative powder from each sample for geochemical work, four stages of crushing were conducted. First, samples were crushed by hand using a hammer to remove any weathered surfaces and to reduce them to chip size. These sample chips were then crushed using a jaw crusher followed by a Bico ceramic disk pulverizer. The final stage of crushing was by a Spex tungsten carbide shatterbox using a ring and puck assembly. To prevent contamination, each piece of crushing equipment was cleaned using a wire brush, acetone and compressed air, including the shatterbox which was washed with hot water between samples. At each stage of crushing precontamination, using a small amount of sample, was carried out to reduce contamination. Crushed samples were stored in airtight plastic containers.

3 XRF Sample Preparation

For X-ray fluorescence spectrographic analyses both pressed pellets and fused beads were used, the former for trace element analyses and the latter for major element analyses.

To produce pressed pellets, approximately 5g of each finely crushed sample was thoroughly mixed with approximately 1 ml of an organic binding agent, Mowiol, in a small clean glass vial. This mixture was placed in a 30 mm diameter Chemplex aluminum pellet cup and compressed by a Spex 30 ton press to 25 tons pressure.

To produce fused beads, 0.5000 g of each finely crushed sample was thoroughly mixed with 3.000 g of anhydrous lithium metaborate in a clean glass vial. This mixed powder was heated to approximately 1200°C in a Pt/Au crucible until melted to a homogeneous liquid. This liquid was then poured into a Pt/Au 30 mm diameter mold and allowed to cool.

All major and trace element analyses were performed on a Phillips, Model PW1450 AHP, automatic, sequential X-ray fluorescence spectrometer. Refer to table 4-1 for major element analyses and tables A-1 and A-2 for trace elements.

TABLE A-1: Rb-Sr REPLICATE DATA

Sample	Rb (ppm)	Sr(ppm)	Rb/Sr
MN2	106	420	0.25178
	103	411	0.25148
	105	415	0.25365
	101	398	0.25320
	100	397	0.25271
	103	405	0.25508
	107	413	0.26033
	105	409	0.25694
	107	421	0.25443
	104	410	0.25301
	106	418	0.25406
	103	408	0.25372
	105	413	0.25398
	105	408	0.25727
Mean	104+/-2	410+/-7	0.25440+/-237
MN7	95	384	0.24802
	98	394	0.24944
	95	389	0.24389
	98	395	0.24783
	95	385	0.24752
	97	390	0.24810
	95	382	0.24783
	98	388	0.25172
	96	391	0.24459
	97	394	0.24659
	95	387	0.24539
	96	388	0.24808
	95	385	0.24689
	98	391	0.24979
Mean	96+/-1	389+/-4	0.24755+/-206
MN8	121	346	0.34856
	121	345	0.35200
	123	350	0.35132
	115	330	0.34791
	115	328	0.34911
	121	345	0.35040
	119	345	0.34568
	122	348	0.35207
	119	342	0.34709
	121	345	0.35047
	121	340	0.35489
	120	344	0.34861
	121	346	0.35056
	120	343	0.34945
Mean	120+/-2	343+/-6	0.34986+/-234
MN9	122	403	0.30419
	123	406	0.30368

Element	Rb(ppm)	Sr(ppm)	Rb/Sr
MN9	124	407	0.30500
	123	398	0.30915
	124	405	0.30519
	122	402	0.30236
	124	406	0.30409
	124	405	0.30680
	126	408	0.30817
	123	400	0.30708
	125	404	0.30892
	125	407	0.30671
	123	401	0.30790
	125	406	0.30768
Mean	124+/-1	404+/-3	0.30621+/-212
MN10	108	457	0.23708
	105	449	0.23416
	107	457	0.23502
	103	433	0.23700
	105	438	0.23885
	110	462	0.23748
	108	454	0.23721
	109	460	0.23602
	105	443	0.23791
	107	451	0.23809
	107	451	0.23778
	107	446	0.23994
	109	454	0.23939
	108	452	0.23962
Mean	107+/-2	451+/-8	0.23754+/-167
MN11	113	457	0.24643
	116	463	0.25092
	113	457	0.24706
	114	453	0.25087
	118	462	0.25477
	116	463	0.24549
	115	467	0.24689
	113	454	0.24899
	115	455	0.25233
	117	451	0.25866
	113	459	0.24652
Mean	115+/-2	458+/-5	0.24990+/-411

TABLE A-2: XRF TRACE ELEMENT DATA

Element	MN2	MN7	MN8	MN9	MN10	MN11
Rb	102	91	117	121	108	110
Sr	398	370	339	393	451	451
Y	25	22	26	24	22	22
Zr	213	214	70	240	236	243
Nb	7	7	9	7	7	11
La	17	25	37	33	53	33
Ba	1380	650	420	1180	1290	1280
Ce	53	60	65	65	79	62
Nd	35	23	39	37	43	27

All values in ppm.

4 Mass Spectrometry: Sample Preparation and Analyses

For mass spectrometric analysis, finely crushed samples were prepared according to the technique of Beakhouse and Heaman (1980) in the geochronology laboratory of the Geology Department at McMaster University.

Strontium isotopic analyses were performed on a VG 354, 27 cm radius, 90^{o} magmatic sector single focusing mass spectrometer with data analysis controlled by a Hewlett-Packard computer. The data is listed in Table 4-4.

5 Precision and Accuracy

To monitor XRF machine error, standards JG-1, MAG-1 and GSP-1 were analyzed, the latter two for trace elements, the former for major elements. Comparison of these analyses with literature values is in table A-3. Standards JB-2 and JA-1 were analyzed for the replicate runs of Rb and Sr and are listed in Table A-4.

To establish precision, replicate analyses were made on all powdered pellets for Rb-Sr analysis and the means of these replicates were used (Table A-1). Sample MN11 was run for major and trace elements as triplicates (Table A-5). According to Prevec (1985) individual XRF analyses are assumed to have a built in error of +/- 1%. For mass spectrometry, NBS 987 and E & A standards were analyzed to monitor machine error. This standard data is listed in Table A-6.

TABLE A-3: COMPARISON OF XRF STANDARD ANALYSES TO LITERATURE VALUES

A: Majors - all values in wt. %

	JG-1	
Element	Lit. value	07/01/86
SiO_2	72.75	72.52
Al_2O_3	14.27	14.51
Fe_2O_3	2.18	2.10
MgO	0.76	0.87
CaO	2.18	2.13
Na_2O	3.41	3.38
K_2O	3.98	4.10
TiO2	0.27	0.26
MnO	0.07	0.05
P_2O_5	0.09	0.10

B: Trace Elements - all values in ppm

	MAG-1			GSP-1	
Element	Lit. value	07/01/86	Element	Lit. value	07/01/86
Rb	152	159	La	195	180
Sr	140	143	Ba	1300	1280
Y	27	31	Ce	400	380
Zr	130	131	Nd	190	180
Nb	10	14			

TABLE A-4: XRF STANDARD ANALYSES OF JB-2 AND JA-1

Sample	Rb(ppm)	Sr(ppm)	Rb/Sr
JB-2			
literature	6.2	173	0.03584
11/02/86	7	179	0.03635
"	5	179	0.02909
12/02/86	7	180	0.04125
25/03/86	6	177	0.03403
Mean	6+/-1	179+/-1	0.03518+/-505
JA-1			
literature	11.8	268	0.04403
11/02/86	11	255	0.04199
"	10	256	0.03992
12/02/86	11	254	0.04289
25/03/86	11	262	0.04288
Mean	11+/-0.3	257+/-3	0.04192+/-140

TABLE A-5: REPLICATE MAJOR ELEMENT DATA FOR SAMPLE MN11

	MN11				
Element	A	B	C	Mean (+/- std. dev.)	
wt. %					
SiO_2	62.53	62.33	62.57	62.48	(0.13)
Al_2O_3	16.56	16.64	16.61	16.60	(0.04)
Fe_2O_3	6.67	6.62	6.58	6.62	(0.05)
MgO	2.25	2.63	2.28	2.39	(0.21)
CaO	5.39	5.35	5.35	5.36	(0.02)
Na_2O	2.38	2.32	2.47	2.39	(0.08)
K_2O	3.17	3.11	3.13	3.14	(0.03)
TiO_2	0.66	0.65	0.66	0.66	(0.01)
MnO	0.11	0.10	0.09	0.10	(0.01)
P_2O_5	0.29	0.24	0.26	0.26	(0.03)
Rb (ppm)	110	108	111	110	(1.5)
Sr	451	458	457	457	(0.6)
Y	22	21	21	21	(0.6)
Zr	243	241	239	241	(2.0)
Nb	11	9	8	9	(1.5)
La	33	33	34	33	(0.6)
Ba	1280	1300	1310	1297	(15.3)
Ce	62	60	60	61	(1.2)
Nd	27	23	24	25	(2.1)

TABLE A-6 MASS SPECTROMETRY STANDARDS

Standard	Date	87Sr/86Sr Value
E & A	19/03/86	0.708025+/-13
NBS	18/03/86	0.710253+/-13
	8/03/86	0.710238+/- 9
	18/02/86	0.710194+/- 8

```
10 CLS:PRINT "THIS PROGRAM CALCULATES THE STRONTIUM 86 ISOTOPE PERCENTAGE BASED
ON THE INPUT  OF THE 87/86 ISOTOPE RATIO AND BASED UPON THE FOLLOWING CONSTANTS:
"
11 RAT=.0056795131#
12 RAT2=8.373225152#
13 GG=.278346
20 PRINT "84/86=0.0056795131"
21 SR84=83.91326
22 SR86=85.90935
23 SR87=86.90899
24 SR88=87.90601
25 WTRB=85.46796
30 PRINT "88/86=8.373225152"
35 LPRINT "Sr/Sr(87/86)   RB/Sr(87/86)"
40 INPUT "ENTER THE Sr87/Sr86 RATIO:";XX
42 INPUT "ENTER THE Rb/Sr TOTAL RATIO:";TT
50 YY=.0056795131#+1+8.373225152#+XX
60 X=100/YY
62 CC=1/YY
63 WSR=(CC*SR86)+(RAT*CC*SR84)+(XX*CC*SR87)+(RAT2*CC*SR88)
70 PRINT "THE PERCENTAGE OF THE 86 ISOTOPE IS:";X
80 GWR=(TT*GG*WSR)/(CC*WTRB)
90 PRINT "THE Rb/Sr (87/86) RATIO, BASED ON Rb 87 OF 27.85% AND A Sr 86 OF ";X"%
 IS:";GWR
100 LPRINT XX,GWR
110 GOTO 40
2184 SR=83.9134
2286 SR=85.9092
2387 SR=86.9088
```