Geological Investigation of a Mineralized Granitic Cupola, Kempt Snare Lake, Yarmouth County, Nova Scotia

Honours Thesis

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Abstract

At Kempt Snare Lake, a leucogranite and leucomonzogranite cupola, with a composition similar to the Davis Lake Pluton, intrudes the metawackes of the Goldenville Group. $^{40}Ar/^{39}Ar$ dating constrains the age of intrusion to a minimum age of ca. 330 Ma. Shear zones and abundant faults and veins have cut the stock during a complex deformation event ca. 300 Ma ago. Hot fluids (>320°C), high in granophile elements, base metals, sulfur, volatiles, and containing varying salinities, metasomatized the wallrocks, and produced greisens with tin-specialized compositions. The fluids also deposited sulphides, scheelite, fluorite, carbonate, and rare tourmaline, mostly in veins, but also in the wallrock. Veining associated with faulting at least 30 Ma after intrusion, highly variable fluid compositions, and a linear trend of mineral deposits in the Kempt Snare Lake area suggest mineralization is related to fluids from a major southwest trending shear zone.

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Chapter 1. Introduction

1.1 General Statement

At Kempt Snare Lake, an altered granitic cupola with W-Pb-Zn-Cu-As-Ag mineralization has intruded the metasedimentary rocks of the Goldenville Formation in the polymetallic tin domain of southwestern Nova Scotia (Chatterjee and Strong, 1985). Falconbridge Limited made drill core from Kempt Snare Lake available to the author. This drill core provides the basis for this investigation which is to determine the relationship of the mineralized cupola to other intrusive rocks and mineral deposits in the area.

1.2 Location, Access, and Topography

The Kempt Snare Lake W-Pb-Zn-Cu-As-Ag prospect on the southwest shore of Kempt Snare Lake, Yarmouth County, is located 40 km northeast of Yarmouth (44° 00' North Latitude and 65° 51' West Longitude; Figure 1). Access to the prospect is via a private road off the provincial highway joining the villages of East Kemptville and Carleton. Mixed forest grows on thick till, and many drumlins occur throughout the area.

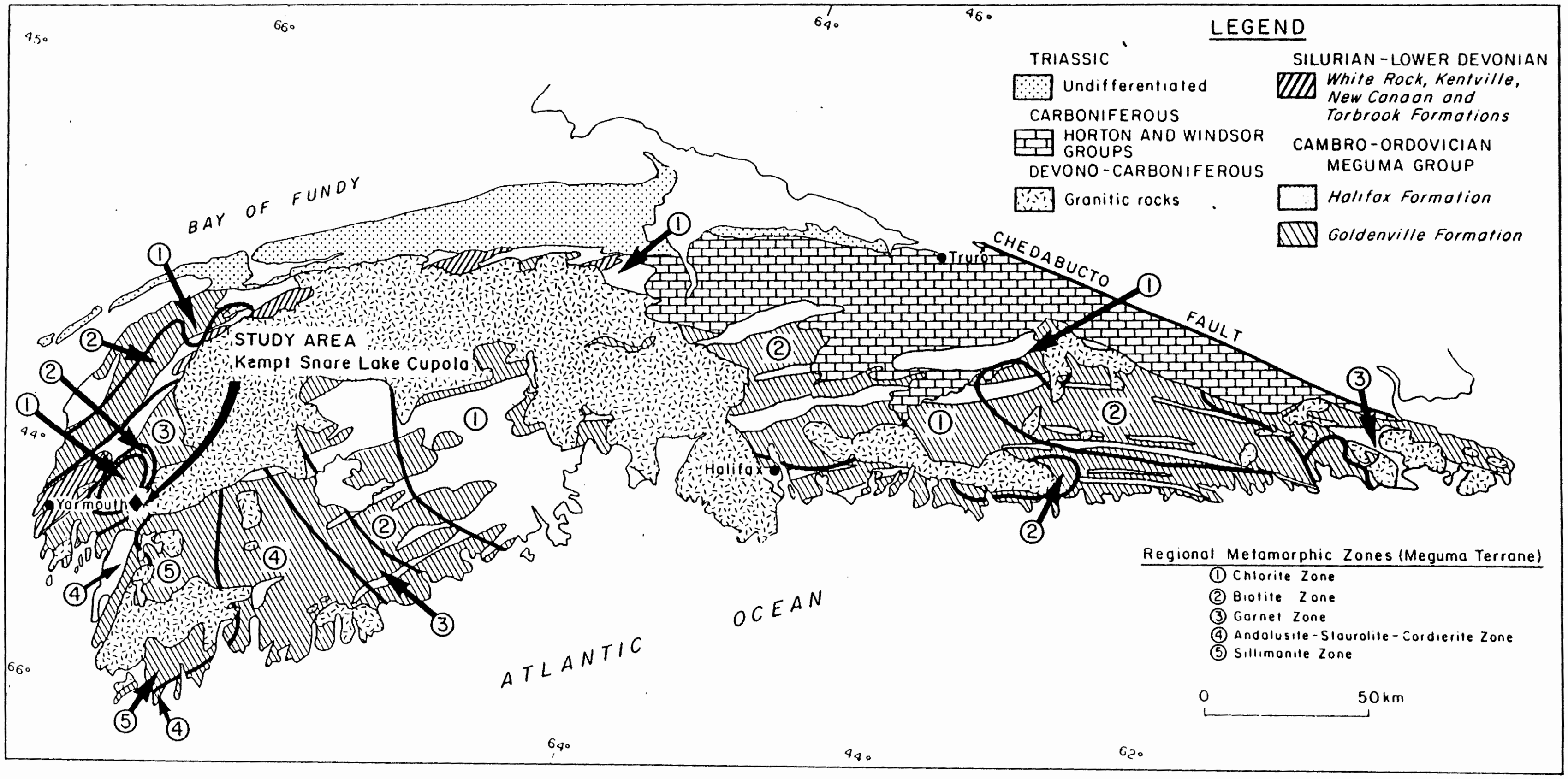

LEGEND
TRIASSIC
Undifferentiated
CARBONIFEROUS
HORTON AND WINDSOR GROUPS
DEVONO-CARBONIFEROUS
Granitic rocks
SILURIAN-LOWER DEVONIAN
White Rock, Kentville, New Canaan and Torbrook Formations
CAMBRO-ORDOVICIAN
MEGUMA GROUP
Halifax Formation
Goldenville Formation
Regional Metamorphic Zones (Meguma Terrane)
① Chlorite Zone
② Biotite Zone
③ Garnet Zone
④ Andalusite-Staurolite-Cordierite Zone
⑤ Sillimanite Zone
0
50km
BAY OF FUNDY
ATLANTIC OCEAN
CHEDABUCTO FAULT
STUDY AREA
Kempt Snare Lake Cupola
Yarmouth
Halifax
Truro
45°
66°
64°
46°
44°
62°

FIG. 1.1

1.3 Regional Geology

Southwestern Nova Scotia is underlain mostly by the metasediments of the Cambro-Ordovician Meguma Group (Figure 1.1). The Meguma Group consists of the metawackes of the Goldenville Formation and the conformably overlying metapelite-dominated Halifax Formation. Folding of the metasediments and regional metamorphism to greenschist and amphibolite facies occurred during the Acadian Orogeny (Fyson, 1966). The peraluminous granites of the Devono-Carboniferous South Mountain Batholith and a number of smaller plutons to the east and south of the batholith intruded and thermally metamorphosed the Meguma Group.

These granites consist chiefly of granodiorite and monzogranite; however, compositions ranging from tonalite to leucogranite occur (Clarke and Muecke, 1985). Age dating (Rb/Sr, K/Ar) established that the South Mountain Batholith intruded 360 - 370 Ma ago (Clarke and Halliday, 1980; Reynolds **et al.**, 1981); however, apparent ages of the smaller southern plutons range from ca. 320 - 370 Ma (Reynolds **et al.**, 1987). The reason for these age differences remains controversial; proposed explanations include (Reynolds **et al.**, 1981):

1. The southern plutons intruded later than the South Mountain Batholith.

2. The southern plutons intruded at the same time, but cooled more slowly than the South Mountain Batholith.

3. The southern plutons intruded at the same time as the South Mountain Batholith, but a later tectonothermal event partially outgassed the southern plutons while leaving the South Mountain Batholith largely unaffected.

1.4 Local Geology

At Kempt Snare Lake, a small altered granitic cupola with Pb-Zn-W-Cu-As-Ag mineralization in quartz veins has intruded the Goldenville Formation approximately 3 km southwest of the Davis Lake Pluton (Figure 1.2). This cupola occurs near a 20 km southwest-trending zone of metasediment-hosted tin mineralization (Duncan, 1986a). Kempt Snare Lake occurs in a 70 x 10 km polymetallic tin domain, which hosts North America's only primary tin producing deposit, East Kemptville, and extends from the Davis Lake Pluton to the Wedgeport Pluton (Figure 1.3). Although metasediments host many of the deposits in this domain, the distributions of trace elements, oxygen isotope, and lead isotope data from the deposits indicate a genetic link with the granitic rocks. Chatterjee and Strong (1985) suggest that cooling of the plutons produced shear joints and faults, which subsequently acted as channelways for the hydrothermal fluids that formed the

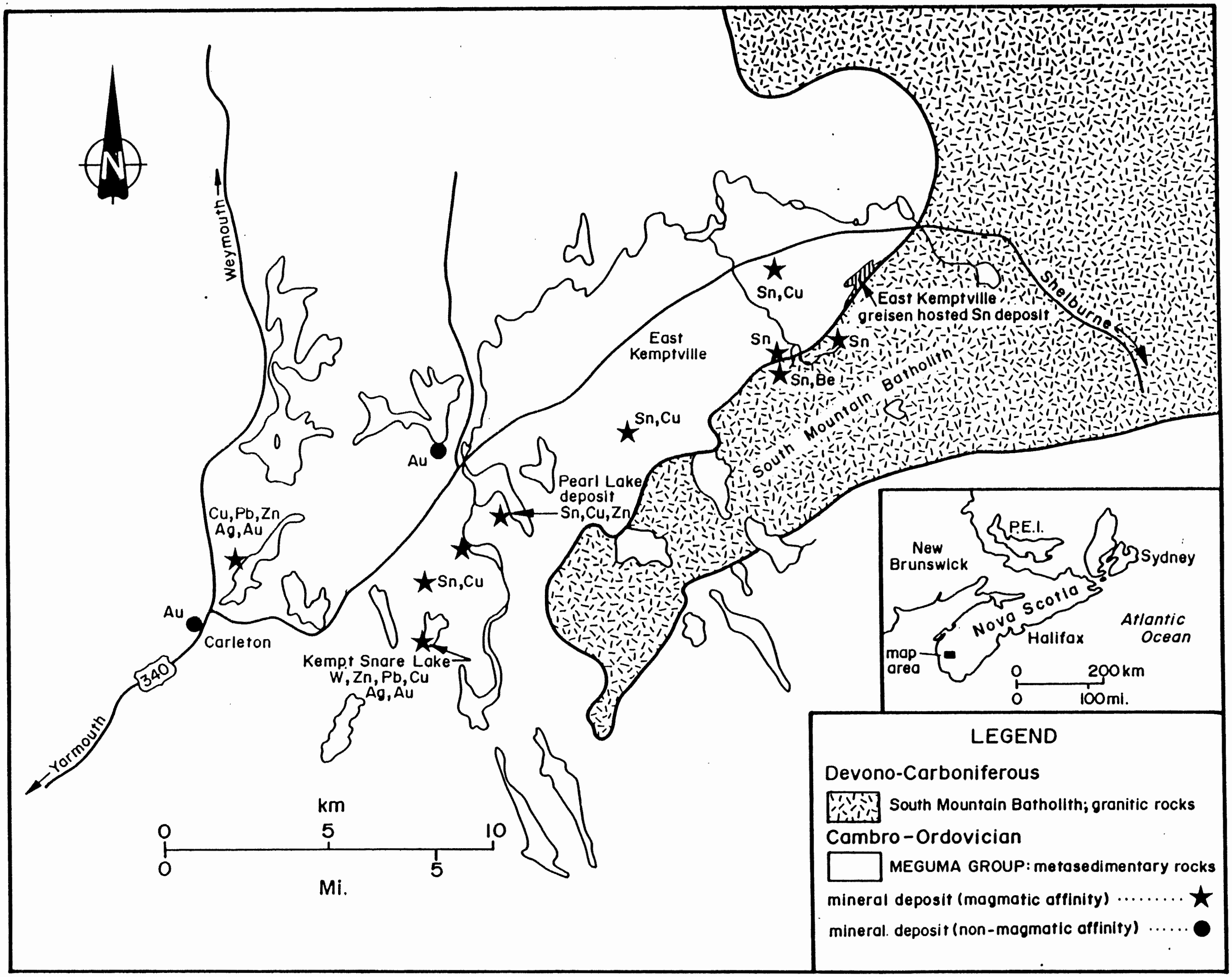

N
Weymouth
Au
Au
Carleton
340
Yarmouth
Cu, Pb, Zn
Ag, Au
Sn, Cu
Kempt Snare Lake
W, Zn, Pb, Cu
Ag, Au
Pearl Lake
deposit
Sn, Cu, Zn
Sn, Cu
East
Kemptville
Sn, Cu
Sn
Sn, Be
Sn
East Kemptville
greisen hosted Sn deposit
Shelburne
South Mountain Batholith
km
0
5
10
0
5
Mi.
New
Brunswick
P.E.I.
Sydney
Nova Scotia
Halifax
Atlantic
Ocean
map
area
0
200 km
0
100 mi.
LEGEND
Devono-Carboniferous
South Mountain Batholith; granitic rocks
Cambro-Ordovician
MEGUMA GROUP: metasedimentary rocks
mineral deposit (magmatic affinity) ·········· ★
mineral. deposit (non-magmatic affinity) ······ ●

FIG. 1.2

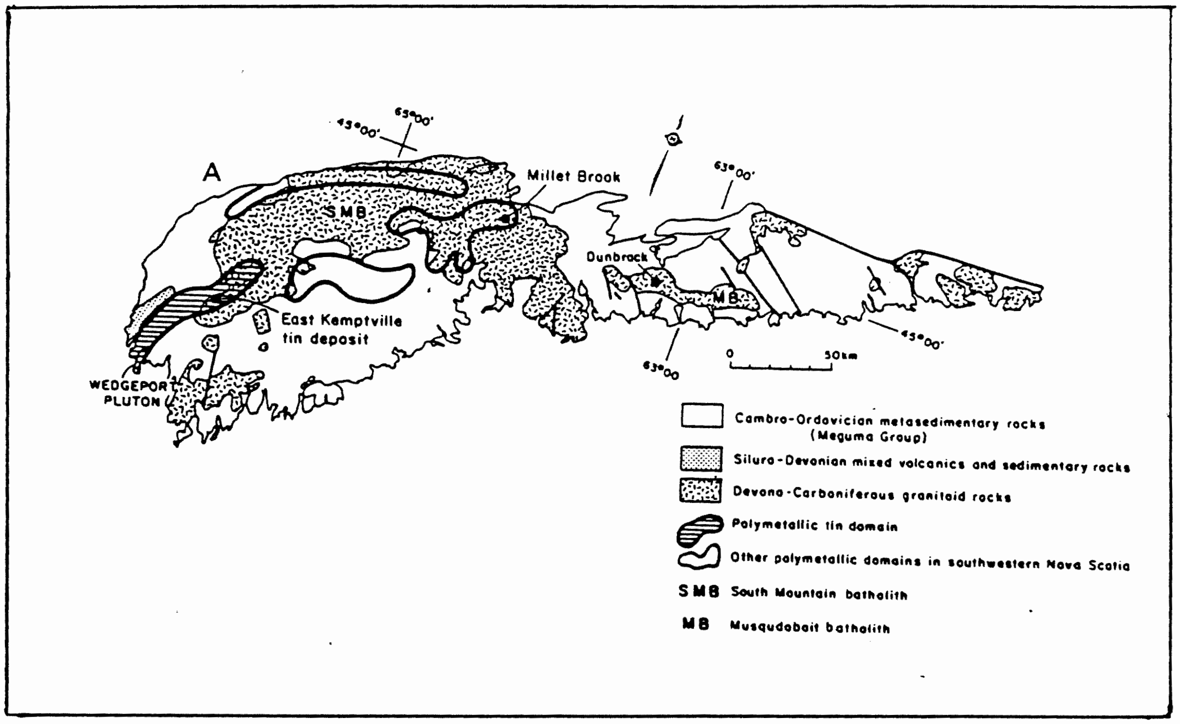

A
45°00'
65°00'
SMB
Millet Brook
63°00'
Dunbrack
MB
East Kemptville tin deposit
WEDGEPORT PLUTON
63°00
45°00'
0
50km
Cambro-Ordovician metasedimentary rocks (Meguma Group)
Siluro-Devonian mixed volcanics and sedimentary rocks
Devono-Carboniferous granitoid rocks
Polymetallic tin domain
Other polymetallic domains in southwestern Nova Scotia
SMB South Mountain batholith
MB Musqudobait batholith

Figure 1.3

metal deposits and altered the host rocks. In the Davis Lake Pluton and Wedgeport Plutons, alteration produced varying degrees of greisenization, albitization, and silicification.

Kontak (1986) presented field and geochemical evidence indicating that the leucogranites, hosting the East Kemptville deposit, originally believed to belong to the Davis Lake Pluton (Richardson, 1985), differ from the rocks of the Davis Lake Pluton and the South Mountain Batholith. He suggested that the East Kemptville leucogranite formed by partial melting and emplacement along a crustal-scale shear zone.

1.5 Previous Work

In 1927, galena- and sphalerite-bearing black granitic boulders were discovered in the Kempt Snare Lake area. In 1928, a vertical shaft was sunk to a depth of 23 m on a 2 m quartz vein with reported grades of 2.0 % Pb-Zn, 0.5 % Cu, and up to 61 ppm Au and 153 ppm Ag (Grant, 1948; Jensen, 1987). Since then, several people have unsuccessfully attempted to pump out the water-filled shaft (Shea, 1972).

In the 1960's, Taylor (1969) did a regional mapping survey of southwestern Nova Scotia. He examined the tailings at Kempt Snare Lake, and stated that mineralized quartz veins occur in a dark grey quartz feldspar porphyry, possibly representing a diorite porphyry.

In the late 1970's, tin and uranium exploration programs in southwestern Nova Scotia resulted in the discovery of North America's only primary tin producer, East Kemptville, and led to a re-evaluation of the Kempt Snare Lake prospect (Duncan, 1986a).

In 1982, Shell Canada Resources Ltd. cored three short diamond drill holes, which encountered tin mineralization in the Goldenville Formation, just north of Kempt Snare Lake (Duncan 1986b).

In 1984, Falconbridge Limited initiated the Yarmouth Tin Project, and in 1984 and 1985 staked claims in the Kempt Snare Lake area. They concluded from their exploration that the mineralization occurs in a hydrothermally altered, greisenized cupola, which according to Tischendorf's classification (1977), represents specialized granite. Scheelite mineralization was first noted at this time (Duncan, 1986b).

In 1985 and 1986, Falconbridge Limited conducted till geochemistry surveys, in which they measured anomalous values of Sn, W, Zn, and Ag (Duncan, 1986a).

In 1985, an I.P. resistivity survey, conducted by Falconbridge Limited, over the Kempt Snare Lake property, revealed a high chargeability zone near the shaft (Figure 2.1) (Duncan, 1986a).

In 1986, Falconbridge Limited recovered 202.44 m of BQ core from three diamond drill holes on the property. Jensen (1987) logged the core, and noted mineralization, veins, faults, and fractures; but did limited lithological and textural work on the host rocks. Falconbridge Limited analyzed rocks from the drill core primarily for Au and W, but they did not detect economic concentrations of either element. They did, however, detect anomalous Ag values in two of the holes (KS-86-2 and KS-86-3). The source of the Ag is unknown.

Scott (1986) did a mineralogical and petrological study on a number of sulfide-rich samples from the waste rock dump near the shaft at the prospect.

1.6 Purpose of Study

At Kempt Snare Lake, a little studied mineralized cupola has intruded the metawackes of the Goldenville Group. The purpose of this study is to determine the nature and origin of this mineralized cupola, and compare it to other mineralized granites in southern Nova Scotia, particularly the South Mountain Batholith, the Davis Lake Pluton, the Wedgeport Pluton, and the East Kemptville Leucogranite. The following topics are considered:

1. Lithologies
2. Structures
3. Veins and Mineralization

4. Mineral Chemistry
5. Whole Rock Chemistry
6. Ages of the Granite and the Deposit
7. P-T Conditions during Mineralization

Chapter 2. Geology

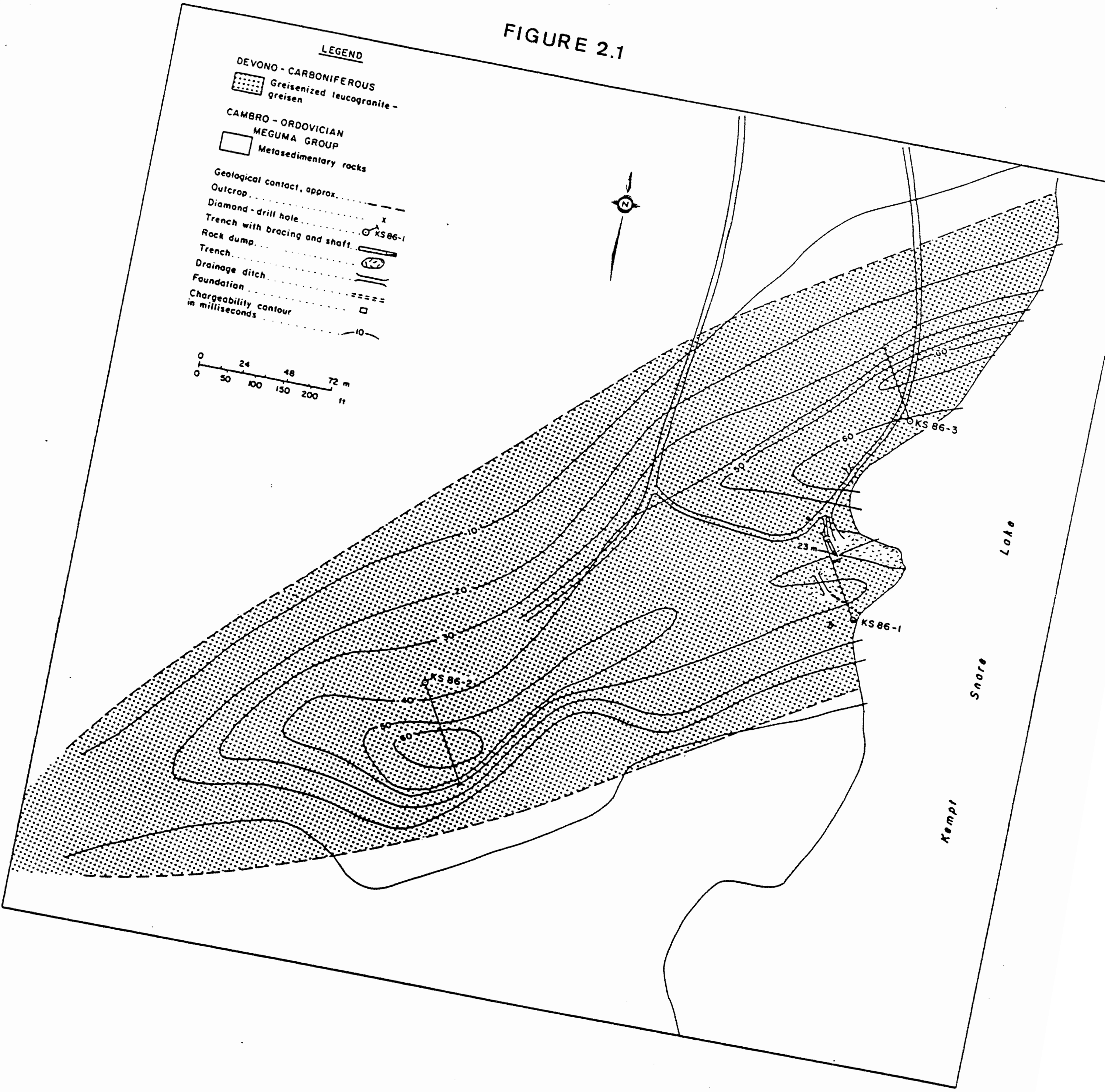
2.1 Introduction

This chapter presents geological work based on studies of waste rock dump samples from the prospect and the drill core. Field relations of Units, veins, and structures are described.

2.2 Field Work

The plane table map of the Kempt Snare Lake prospect (Figure 2.1) shows several trenches, now water-filled, and associated waste rock dumps, and the location of diamond drill holes KS-86-1 to 3. Most of the waste rock material consists of black, fine to medium-grained, porphyritic (3 to 7 mm quartz phenocrysts) greisenized granite. Light grey leucogranite (< 2% mafic minerals) and fine-grained black greisens also occur throughout the dumps, but are less common than the medium-grained greisens. Scheelite, galena, sphalerite, arsenopyrite, chalcopyrite, pyrite, siderite, calcite, fluorite, and tourmaline occur in quartz veins. Many of the rocks have slickensides, indicating that the cupola has been faulted. No outcrops except for one extensively weathered subcrop consisting of 0.5 to 2.0 cm brecciated quartz crystals in a green, vuggy, highly fractured

FIGURE 2.1


LEGEND
DEVONO - CARBONIFEROUS
Greisenized leucogranite - greisen
CAMBRO - ORDOVICIAN
MEGUMA GROUP
Metasedimentary rocks
Geological contact, approx.
Outcrop
Diamond - drill hole
KS 86-1
Trench with bracing and shaft
Rock dump
Trench
Drainage ditch
Foundation
Chargeability contour in milliseconds
10
0
24
48
72 m
0
50
100
150
200
ft
N
10
20
30
40
50
60
60
60
50
KS 86-1
KS 86-2
KS 86-3
23 m
Kempt Snare Lake

matrix of chlorite, muscovite, and clay minerals, occur in the area (Plate 2.1).

2.3 Drill Core

2.3.1 Lithology

All of the rocks from the drill core are variously altered granitic rocks. Based on texture, grain size, and degree of alteration, 5 Units were recognized:

Unit 1 - Black, medium-grained, porphyritic greisen
Unit 2 - Grey - black, fine-grained greisen
Unit 3 - Grey, medium-grained, greisenized granite
Unit 4 - Medium-grained leucogranite
Unit 5 - Coarse-grained leucomonzogranite

(See Plates 2.1 a-f, at back of chapter, for photos of samples stained with Na-cobaltinitrate, Tables in Appendix A for complete descriptions, and back pocket for drill sections showing the distribution of the Units.)

The term greisen is used to describe the highly altered granitic rocks. Because these rocks do not consist mostly of quartz and mica, but have abundant feldspar, they are different from "classic" greisens. However, they are highly altered, very heterogeneous granitic rocks, associated with ore mineralization; therefore, according to the definition by Shcherba (1970), these rocks may be referred to as greisens.

Unit 1, the black medium-grained, porphyritic greisen comprises ca. 50 % of the rocks in the drill core. The presence of 5 - 10 % anhedral, subequant quartz phenocrysts (4 - 10 mm) and the black color distinguish this Unit from other Units. The stained sample shows that K-feldspar has been intensely altered to fine-grained black material, discussed later, and that biotite has been completely replaced by chlorite. The dark color of the feldspars makes it difficult to distinguish individual grains in hand specimen, and makes the quartz "eyes" stand out.

Unit 2, the grey - black, fine-grained greisen comprises < 5 % of the rocks. The fine grain size and rare quartz phenocrysts distinguish the black greisen from Unit 1. The fine-grained grey greisen occurs only at the top of hole KS-86-3. As in Unit 1, the feldspar has been extensively altered, and biotite, completely replaced.

Unit 3, the grey, medium-grained greisenized granite comprises ca. 25 % of the rocks, and occurs in all three drill holes. This Unit has similar textures and grain sizes as Unit 1, but the lighter color, indicating less extensive alteration, distinguish it from that Unit. As in the previous Units, biotite has been completely replaced.

Unit 4, the medium-grained leucogranite, comprises < 5 % of the rocks, and occurs only in holes KS-86-1 and 3 in areas with few veins. Textures and grain sizes are similar to Units 1 and 3, but this Unit is much less altered as indicated by its lighter color, well-defined K-feldspar grains in the stained sample (Plate 2.1e), and only partially replaced biotite. The concentration of biotite is < 2 %; therefore, by the classification used by the Nova Scotia Department of Mines and Energy (MacDonald and Horne, 1985), this rock is a leucogranite.

Unit 5, the coarse-grained leucomonzogranite occurs only in the bottom 30 m of hole KS-86-2. This Unit is coarse-grained with abundant K-feldspar phenocrysts as large as 2 cm. Only partially-replaced biotite, comprises ca. 5 % of this Unit, and therefore, by the classification used by the Nova Scotia Department of Mines and Energy, this rock is a leucomonzogranite. In areas with few veins, this Unit looks relatively "fresh"; however, as veins and faults increase upward in the drill core, alteration increases until feldspars are black, and biotite, totally replaced.

Gradational contacts between Units 1 - 4 and heterogeneity within Units, made the subdivison of these rocks very difficult. The only abrupt contact, a fault contact, occurs between Units 5 and 4.

2.3.2 Structures

Faults with slickensides occur on average every 3 - 5 m; however, some zones as wide as 15 m, with faults every 10 - 100 cm are present (See drill sections; back pocket). Orientations vary from 10 - 85° relative to the axis of the drill core, but faults at 45°, i.e. vertical or horizontal, are most common.

Shear zones, some several metres wide, with moderate to strong foliations defined by mica and chlorite, quartz ribbons, and K-feldspar occur in all three holes. Younger faults cut these shear zones.

Small (< 1mm), irregular fractures, at all orientations, are abundant throughout the drill core. These fractures often transect each other, and small (< 1 cm) displacements along them are common.

2.3.3 Veins

Two major zones, with quartz veins every 5 - 20 cm, occur in all three drill holes (See drill sections, back pocket). The veins range in size from 1 mm to 1 m, and consist mostly of massive, milky quartz, although small quartz carbonate veins, containing siderite ± calcite ± dolomite, and usually fluorite are common. Most veins have sharp, irregular margins, containing abundant black selvages of wall rock, but many small veins (< 5 cm) with straight boundaries are present. Smoky quartz and small vugs with open-space filling are uncommon in the veins. Cross-cutting relationships of the veins are complex, and pre-, syn-, and post-fault veins of all types occur. The veins are variously mineralized with arsenopyrite, sphalerite, galena, scheelite, chalcopyrite, fluorite, carbonate, minor amounts of pyrrhotite and pyrite, and rare tourmaline.

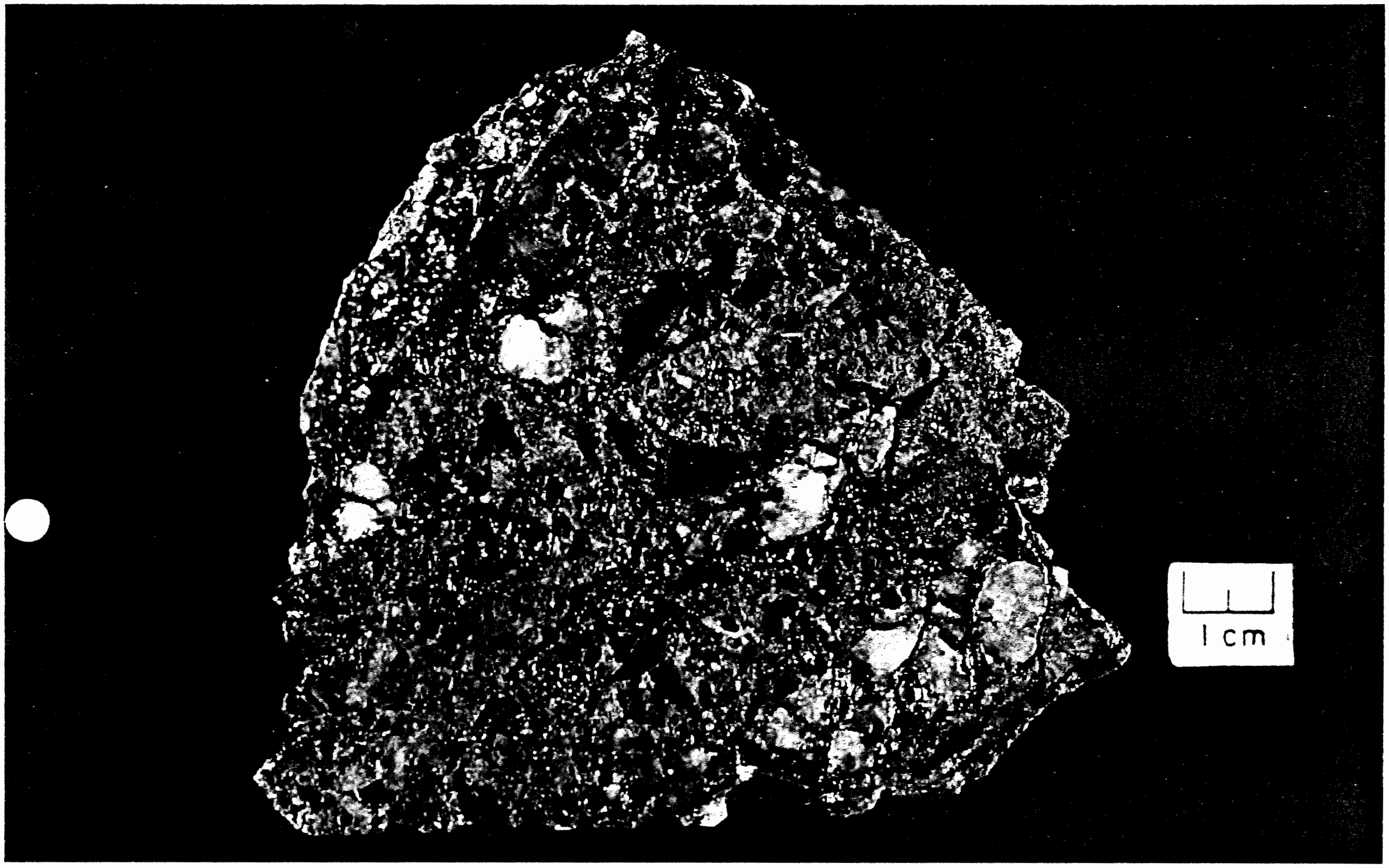


Plate 2.1

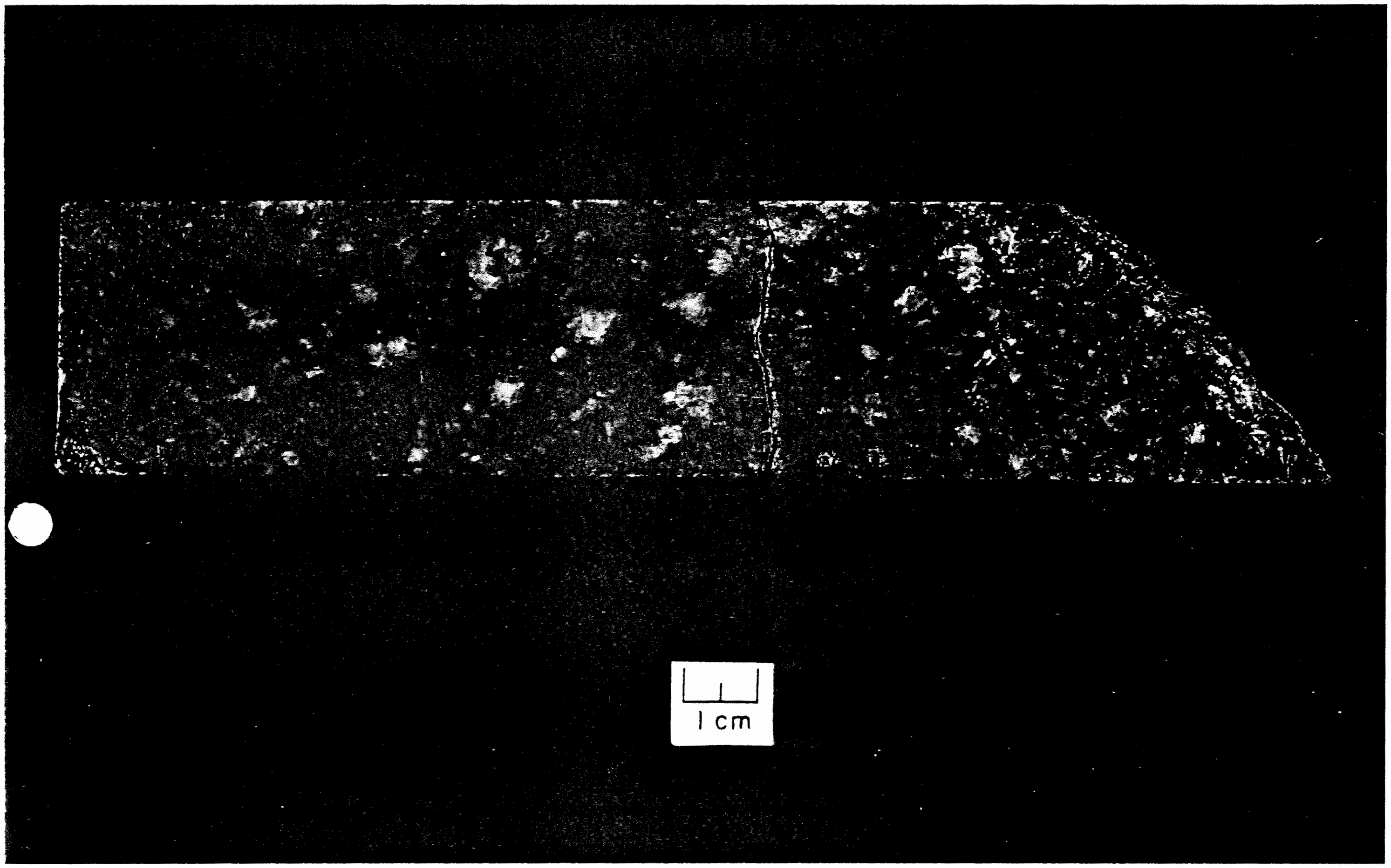


Plate 2.2a

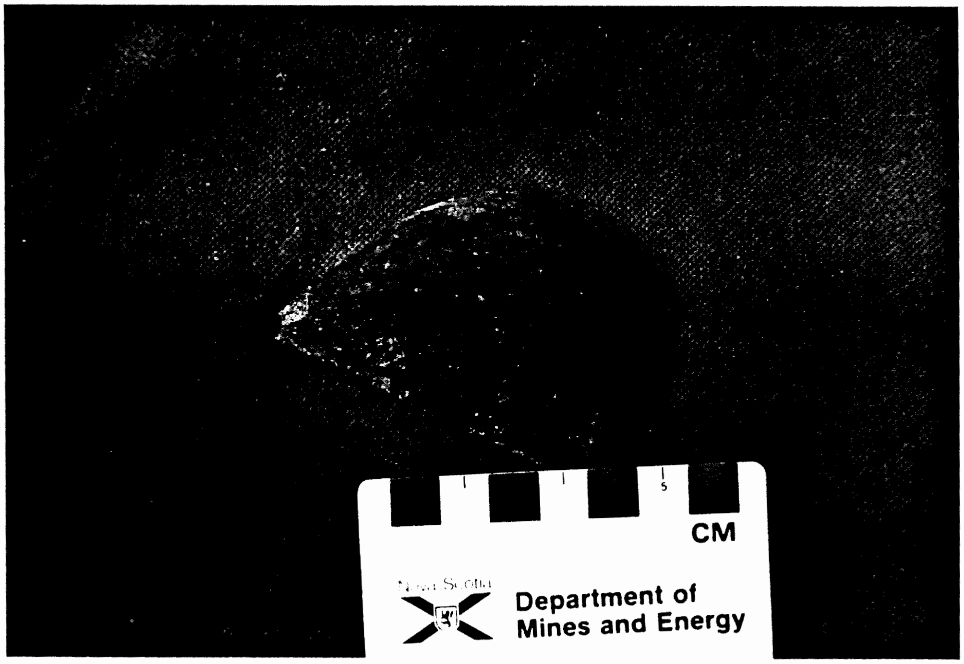


Plate 2.2b

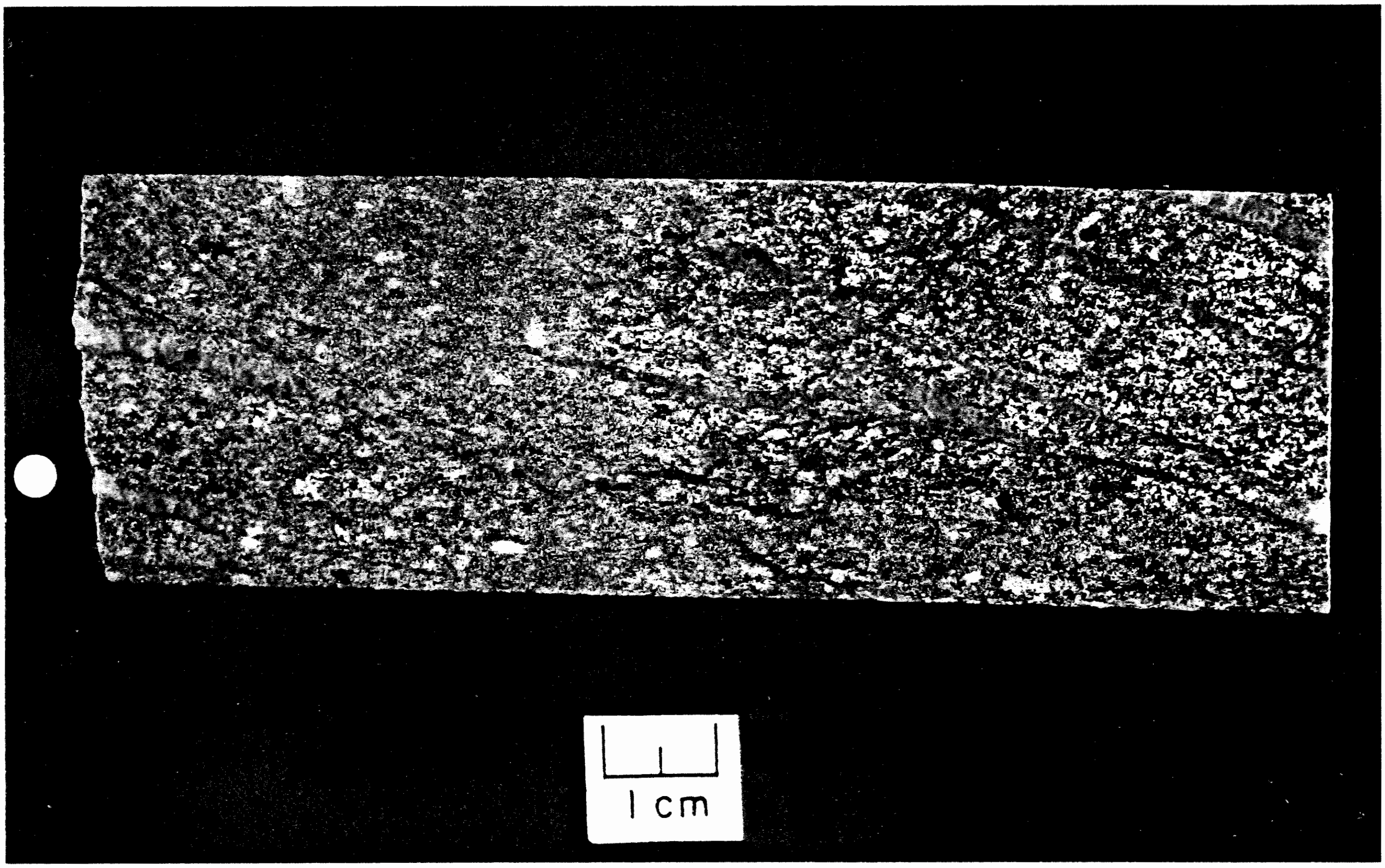


Plate 2.2c

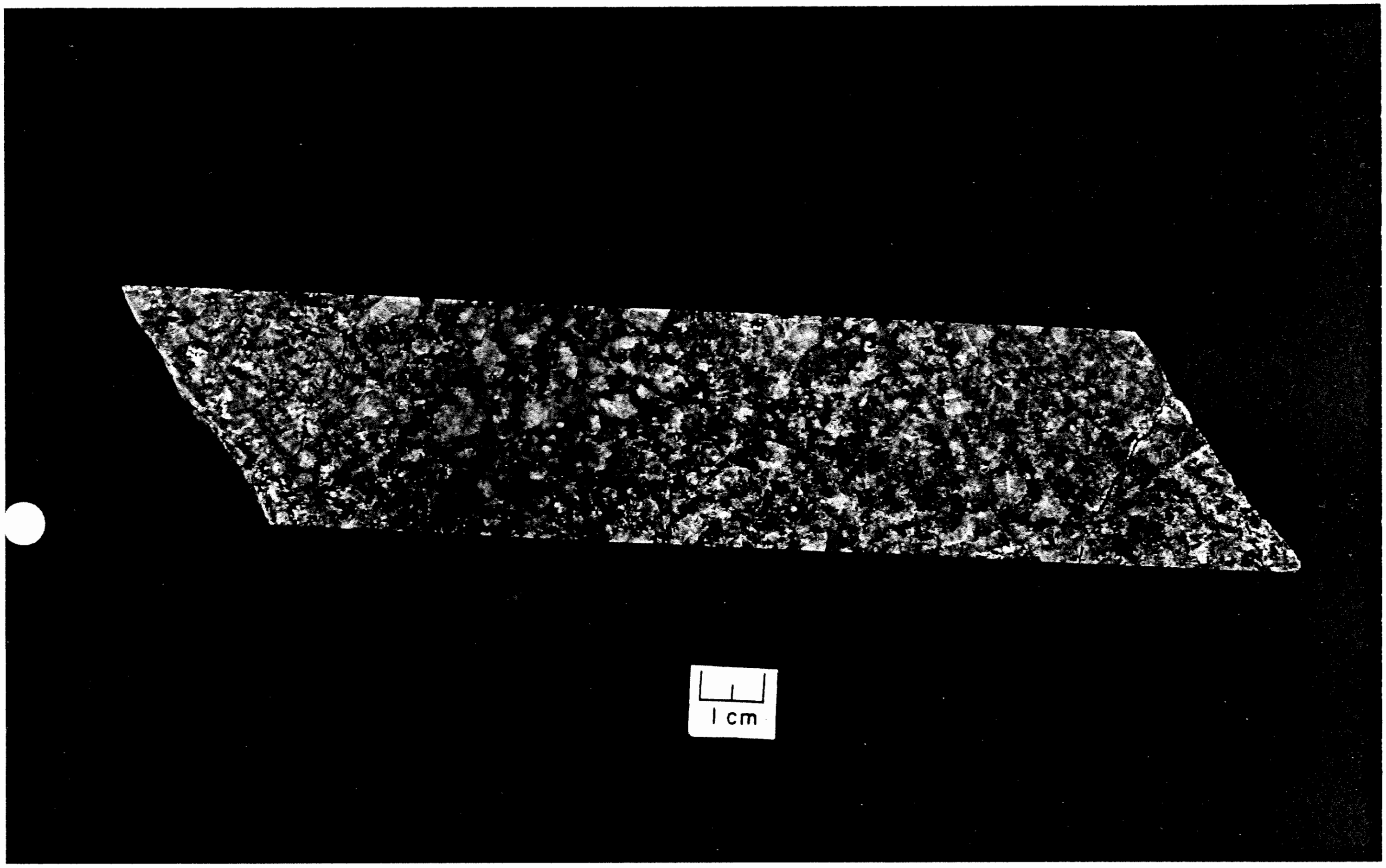


Plate 2.2d

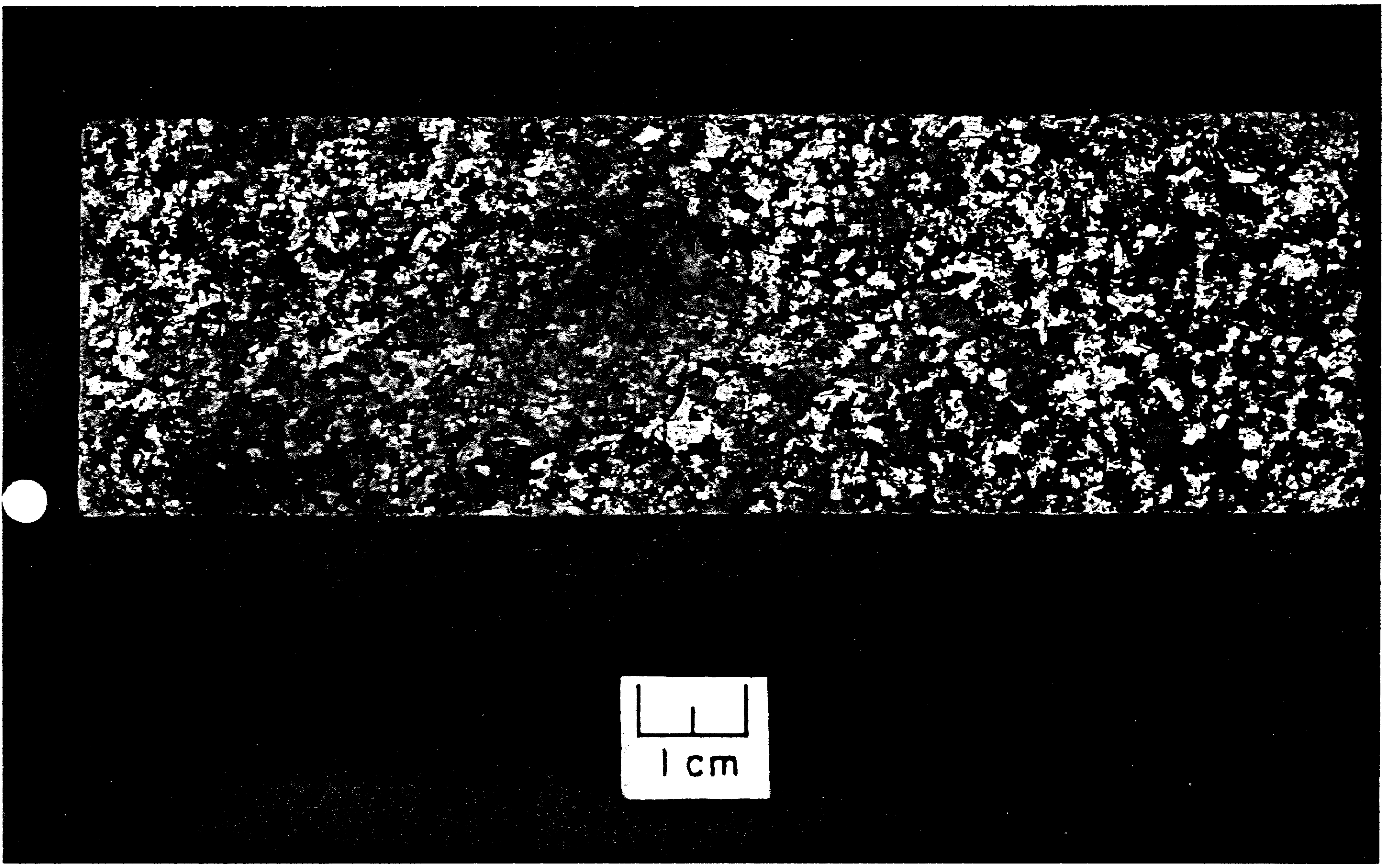


Plate 2.2e

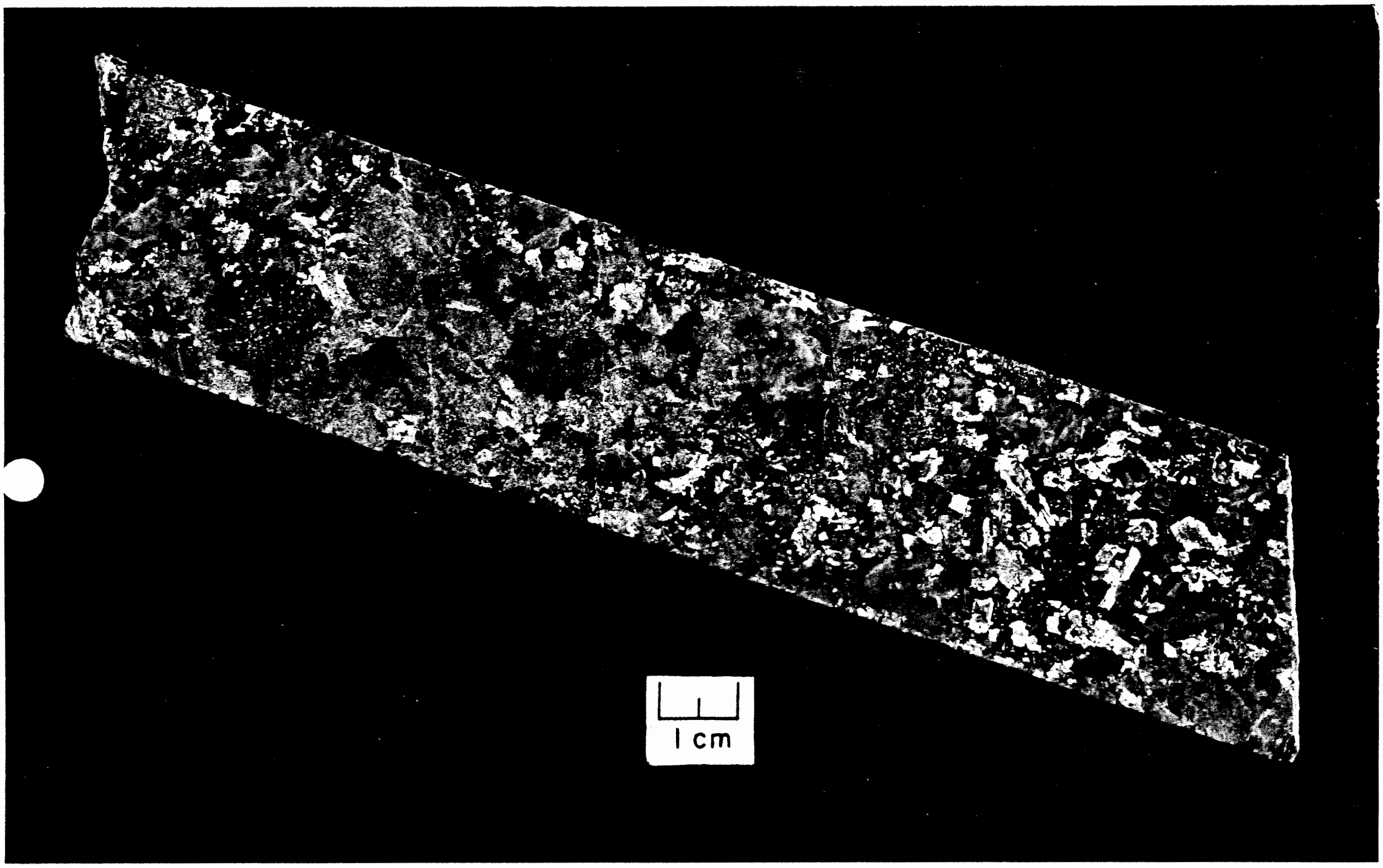


Plate 2.2f

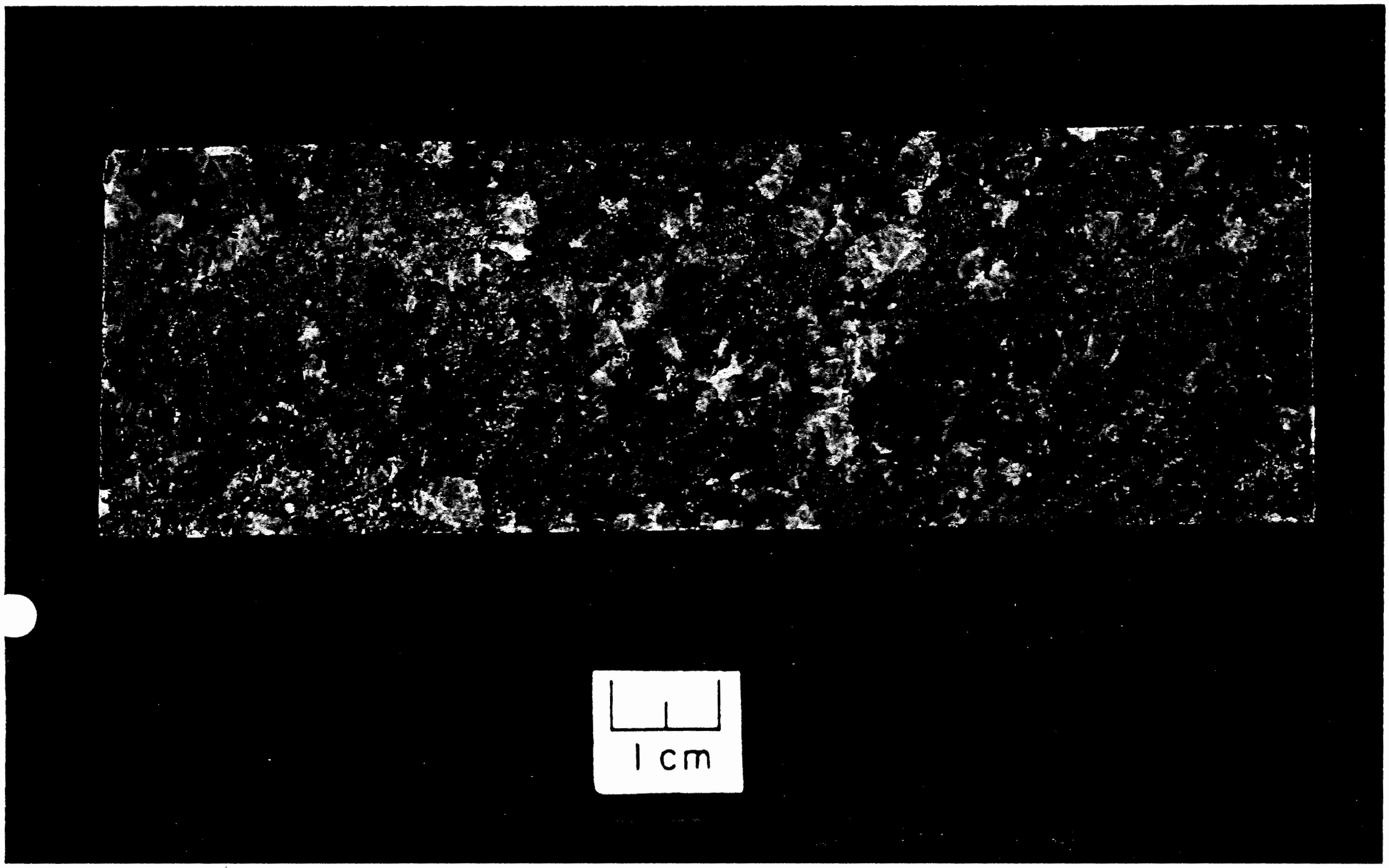


Plate 2.2g

Chapter 3. Petrography

3.1 Introduction

Petrographical studies were carried out on 82 thin sections of samples from the drill core and the waste rock dump. This chapter describes the mineralogy, textures, and microstuctures of the host granitoid rocks and the mineralogy of the mineralized veins.

As all units have similar mineralogies, this chapter does not give individual petrographical descriptions; see tables in Appendix A for those.

3.2 Mineralogy

3.2.1 Quartz

Quartz typically occurs as subequant, anhedral, phenocrysts with undulose extinction, and varying degrees of subgrain development and recrystallization. Recrystallization produced fine-grained aggregates of sub-polygonal strain-free grains.

3.2.2 K-feldspar

K-feldspar, in these rocks, occurs as medium-grained perthitic (3-10 mm), anhedral, phenocrysts (Units 1-4), and perthitic coarse-grained (10-20 mm), subhedral phenocrysts (Unit 5). Albite inclusions with a variety of textures (Plate 3.1) commonly occur:

1. Irregular strings
2. Replacement patch albite
3. Incipient chessboard
4. Euhedral-subhedral crystals

Similar textures occur in the altered granitic rocks of the East Kemptville tin deposit, where Richardson (1985) interpreted types 1, 2, and 3 as exsolution, replacement-modified exsolution, and replacement textures, respectively. The euhedral-subhedral inclusions do not have crystallographically-controlled orientations, and are more altered than the replacements, indicating trapping of the euhedral grains as inclusions during K-feldspar growth.

Alteration of K-feldspar varies from < 5% to 100%; three alteration products have formed:

1. Albite

Albite occurs both rimming and growing as replacements in the K-feldspar (Plate 3.1a).

2. Sericite

Sericite occurs as stringers in early stages of alteration and disseminated throughout the K-feldspar in more advanced stages (Plate 3.2).

3. "Black Sericite"

Extremely fine-grained black inclusions replace up to 50% of the K-feldspar (Plate 3.3). In early stages of alteration, these inclusions occur as stringers, similar to the sericite stringers, in buff K-feldspar. In more advanced stages of alteration, the inclusions become disseminated thoughout the grains, causing the black colour of the K-feldspar in hand specimen.

3.2.3 Plagioclase

Plagioclase typically occurs as subhedral 0.25 to 3.0 mm primary blocky plates or prismatic laths. Abundant Albite twins and rare pericline twins occur. Alteration, as in K-feldspar, to sericite and "black sericite" has occurred; however, small plagioclase grains may overgrow the larger plates and laths (Plate 3.4).

3.2.4 Biotite

Biotite is not common (<2%) in Units 1-4, where it occurs as highly altered 1-3 mm anhedral grains in the groundmass (Plate 3.5a). In Units 1, 2, 3 complete replacement by chlorite, fine-grained muscovite, and oxides has occurred. In Unit 5, biotite is more abundant (5%), commonly subhedral, and more coarse-grained (2-5 mm) (Plate 3.5b).

3.2.5 Muscovite

Several varieties of muscovite occur in the cupola (Plate 3.6). Most muscovite occurs as fine to medium grained (0.25-2 mm) subhedral to anhedral grains, which have grown interstitially between other major phases, but some muscovite is associated with quartz veins where it grew as medium-grained (1-3 mm) radiating sheaf-like aggregates. Fine-grained muscovite (sericite), as stated earlier, also occurs as alteration products of feldspar and biotite.

3.3 Microstructures

The rocks have undergone ductile and brittle deformation. The following observations are evidence for ductile deformation:

1. Localized shear zones with foliations defined by aligned white micas and chlorite stringers (Plate 3.7a).
2. Quartz with subgrain development.
3. Recrystallized quartz.
4. Kinked muscovite (of the interstitial type).
5. Albite with bent twin planes.

The following are evidence for brittle deformation (Plate 3.8):

1. Microfractures
2. Boudinaged feldspar in shear zones

3.4 Textures

Igneous textures, represented by interlocking subhedral K-feldspar phenocrysts, subhedral albite, irregular quartz, subhedral altered biotite, and interstitial muscovite are common in all units (Plate 3.6a, 3.8a). However, abundant anhedral angular grains, extensive alteration, and common deformation features give the granites a cataclastic appearance (Plate 3.8b).

3.5 Vein Mineralogy

Quartz veins and adjacent wallrock are variously mineralized with arsenopyrite, sphalerite, galena, scheelite, chalcopyrite, fluorite, carbonate, minor pyrite and pyrrhotite, and rare tourmaline.

3.5.1 Arsenopyrite

Arsenopyrite, the most abundant sulphide, occurs typically near vein margins, but also within veins, or disseminated in the wallrock. Crystals are euhedral, inclusion-free with abundant fractured faces. Small subhedral pyrite grains may occur around, and galena commonly rims, arsenopyrite (Plate 3.9).

3.5.2 Sphalerite

Dark brown, often submetallic sphalerite occurs in veins as massive rounded blebs as large as 5 cm. Zones of yellow sphalerite occur near the rims of some grains. Sphalerite is highly gractured, and typically contains inclusions of chalcopyrite and pyrrhotite, has pyrite and chalcopyrite at the margins, and is rimmed by galena (Plate 3.10). Inclusions in siderite are rare.

3.5.3 Galena

Galena occurs in veins as irregular masses, which have filled fractures in the veins and the wallrocks. It commonly rims arsenopyrite and sphalerite, and occurs as intergrowth with chalcopyrite (Plate 3.9b, 3.11) and inclusions in siderite.

3.5.4 Scheelite

Scheelite occurs mostly in veins in and around dark selvages of incorporated wallrock (Plate 3.12); however, significant amounts of scheelite also occur as disseminations within the most altered Units (1 and 2). The relationships between scheelite and other phases were not established.

3.5.5 Chalcopyrite

Chalcopyrite occurs mostly as inclusions in sphalerite, or at sphalerite grain margins with pyrite (Plate 3.10). Some intergrowths with galena (Plate 3.11) and inclusions in siderite occur as well.

3.5.6 Pyrite

Pyrite occurs as small euhedral–subhedral grains around arsenopyrite and spalerite (Plates 3.9a, 3.10b).

3.5.7 Pyrrhotite

Pyrrhotite occurs mostly as rounded blebs in sphalerite (Plate 3.10a).

3.5.8 Fluorite

Fluorite occurs in all vein types, but is particularly abundant in the small carbonate veins. When in contact with sulphides, fluorite always appears to have grown last.

3.5.9 Carbonate

Siderite is the most common carbonate phase. Buff euhedral crystals occur mostly in small (<1 cm) veins where they are commonly associated with fluorite. Siderite may contain inclusions of arsenopyrite, galena, sphalerite, and chalcopyrite. Calcite and possibly dolomite also occur in siderite-bearing veins.

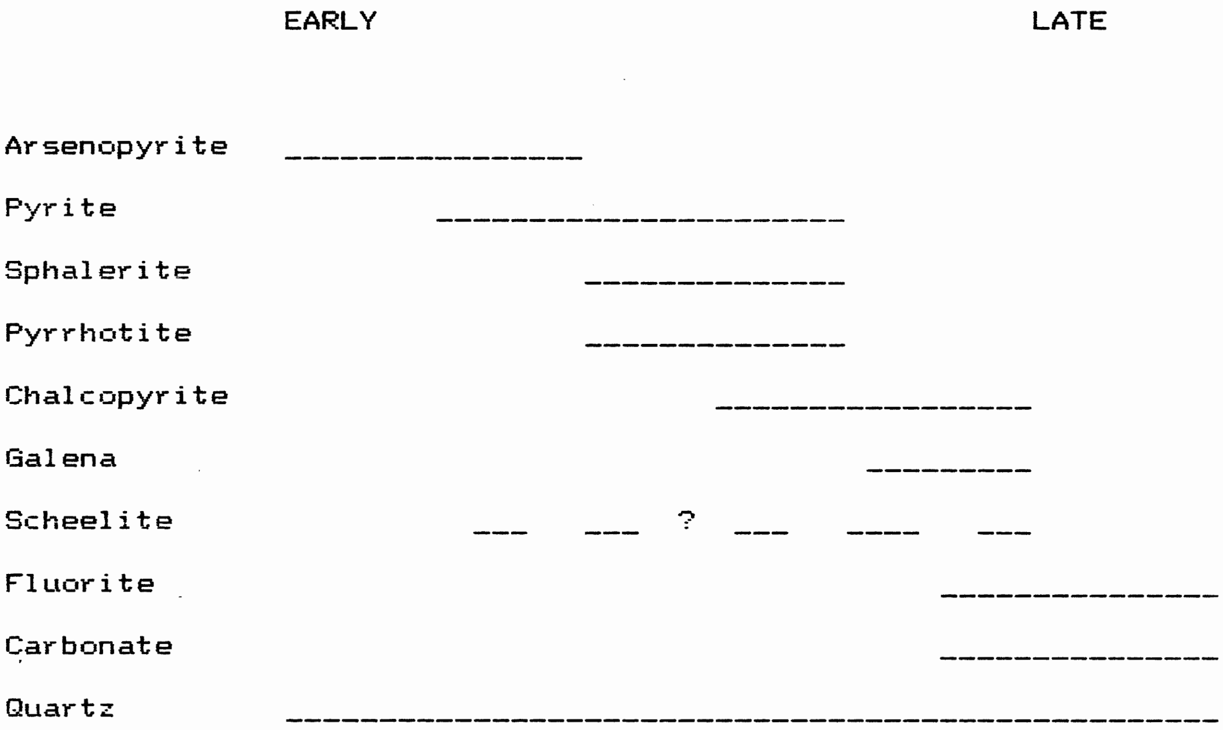
3.5.10 Tourmaline

Tourmaline is a rare phase, and no work was done on it.

3.6 Paragenesis

Based on the textures of the ore minerals, a paragenetic sequence was established (Figure 3.1). Arsenopyrite formed early, while carbonate and fluorite marked late stages of mineralization; however, for the other phases considerable overlap in the paragenetic sequence is probable.

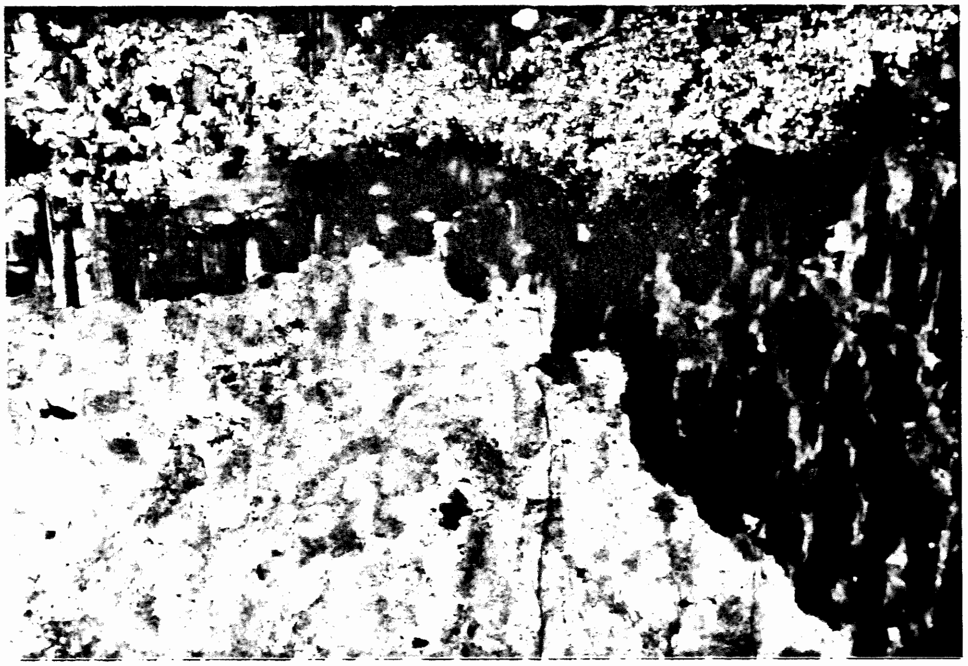
Figure 3.1


EARLY
LATE
Arsenopyrite
Pyrite
Sphalerite
Pyrrhotite
Chalcopyrite
Galena
Scheelite
?
Fluorite
Carbonate
Quartz

Plates

Note: All scale bars = 1mm.

Plate 3.1a



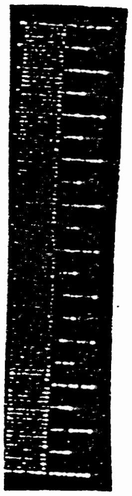
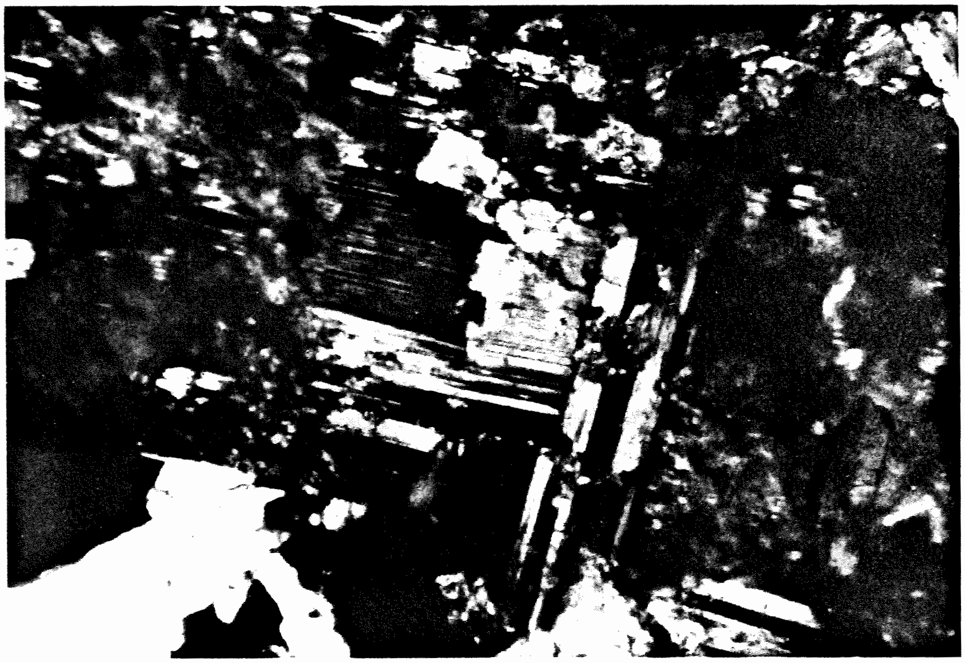
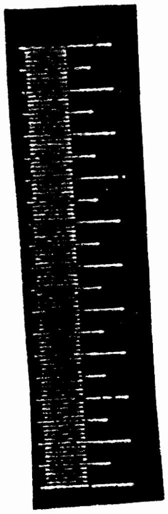


Plate 3.1b

Plate 3.1c





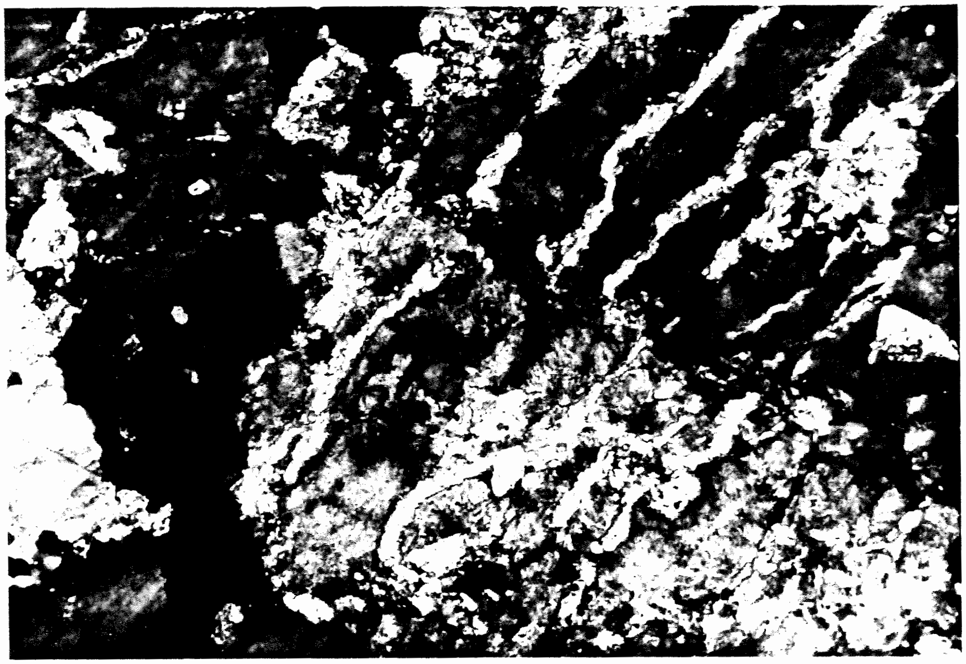
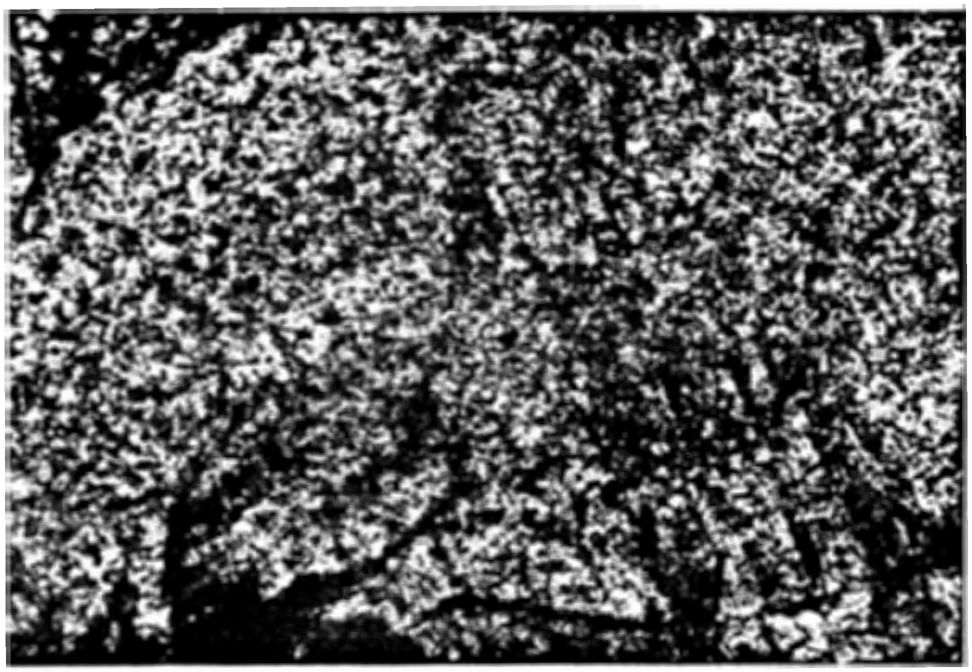


Plate 3.2a

Plate 3.2b



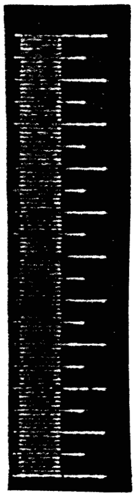


Plate 3.3

Plate 3.4

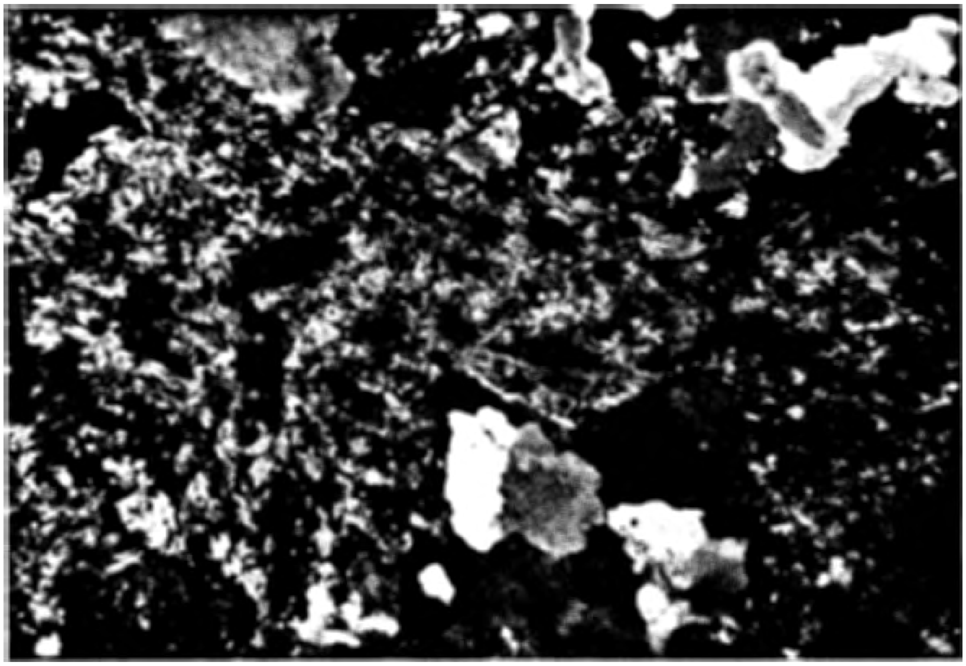


Plate 3.5a

Plate 3.5b

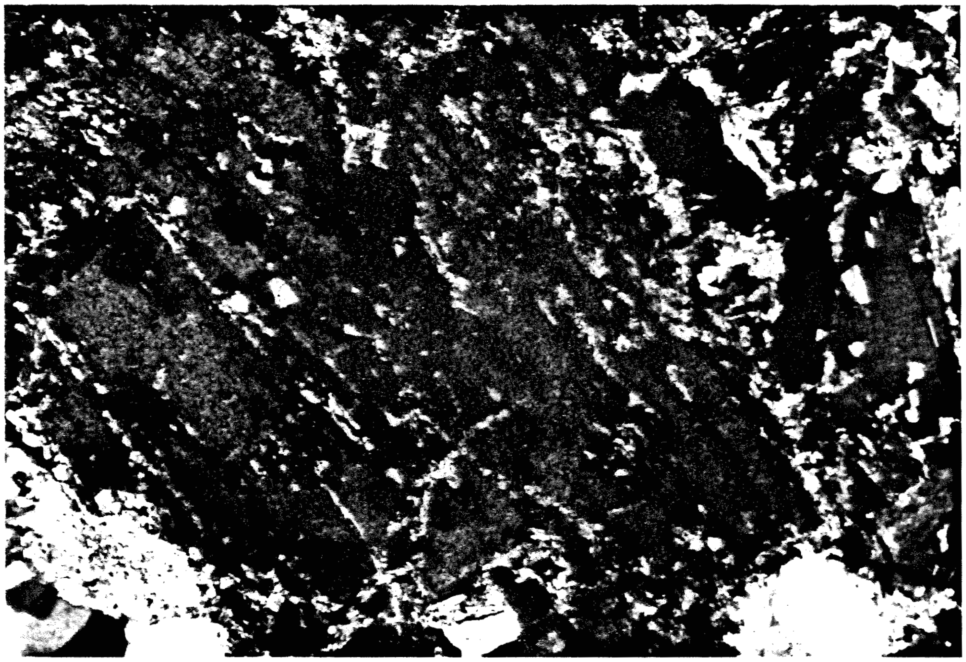


Plate 3.6a

Plate 3.6b

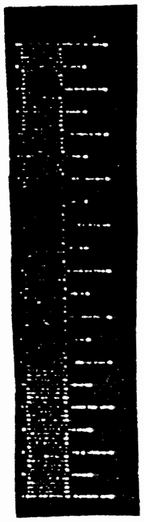
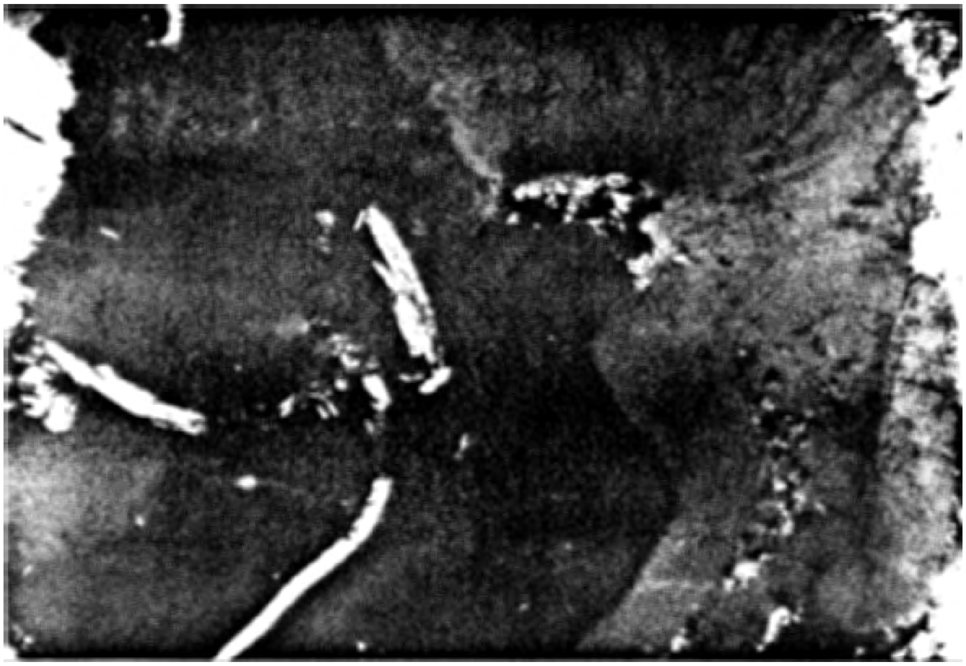
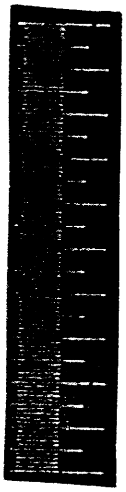


Plate 3.7a

Plate 3.7b





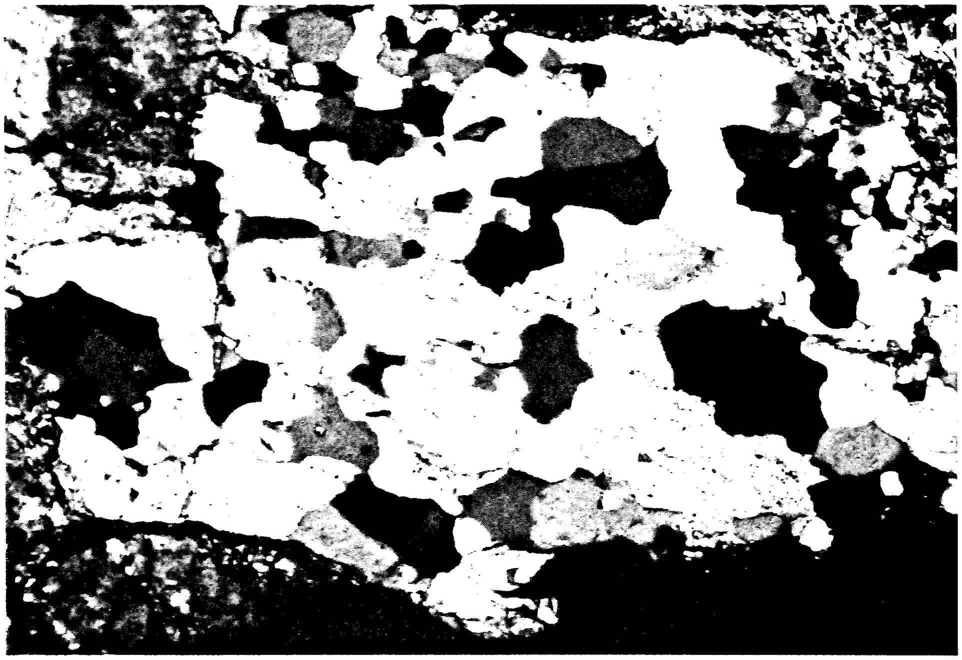
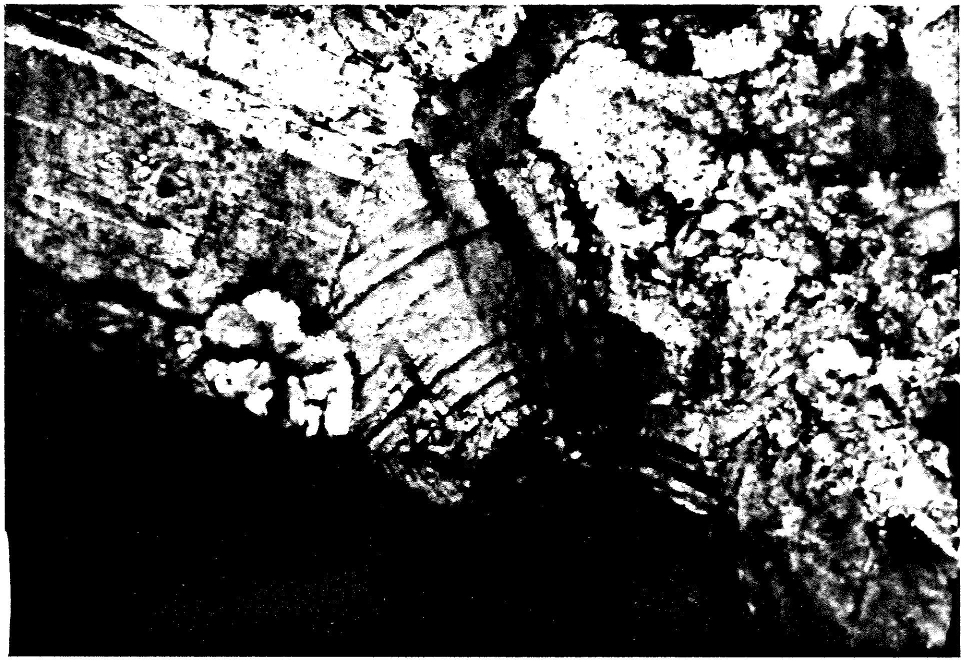


Plate 3.7c

Plate 3.7d



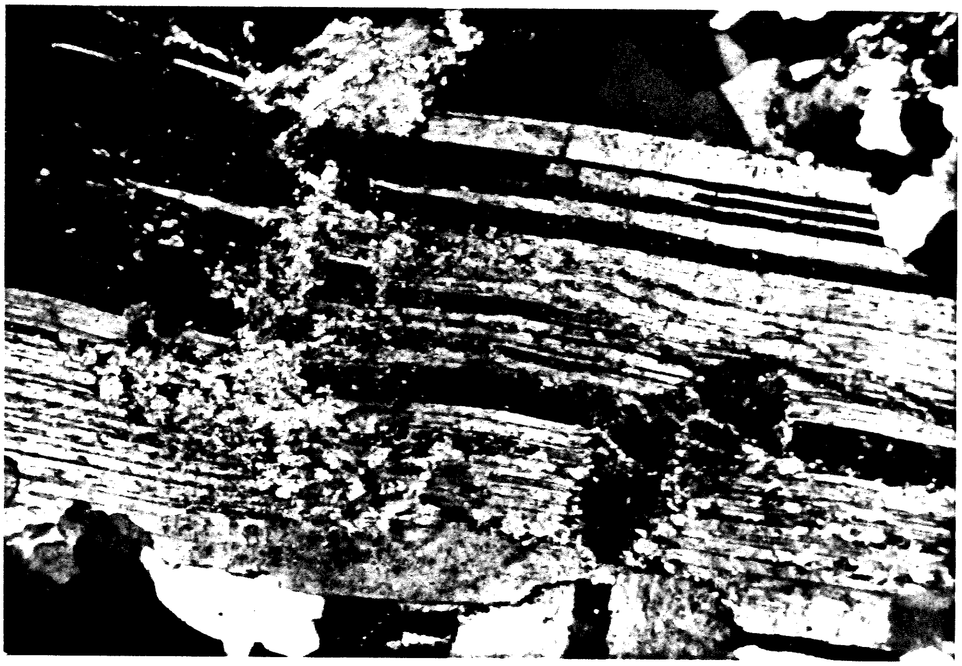
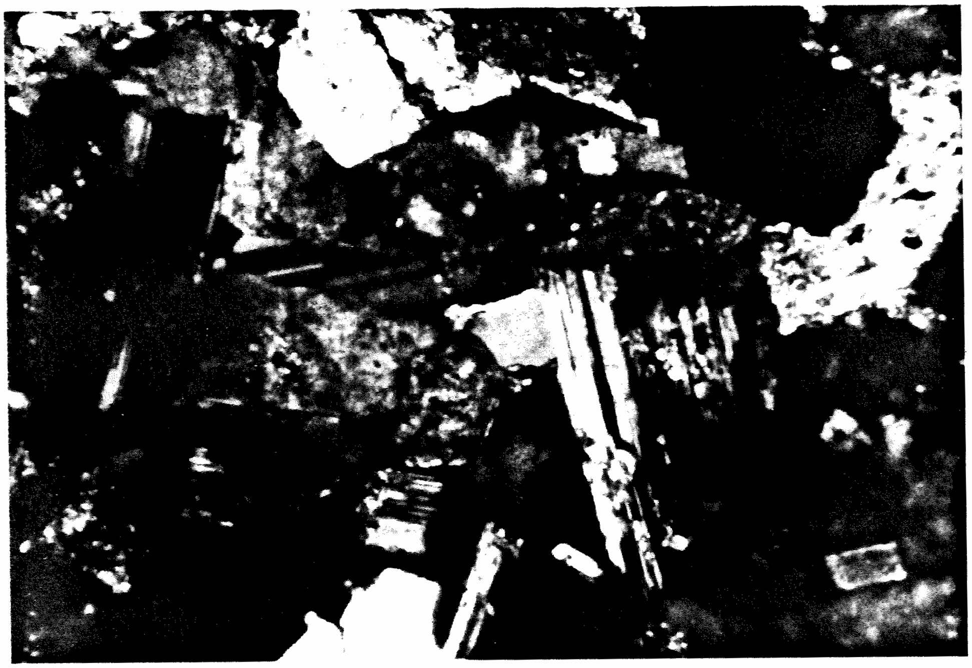
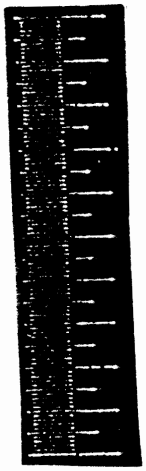


Plate 3.7e

Plate 3.8a





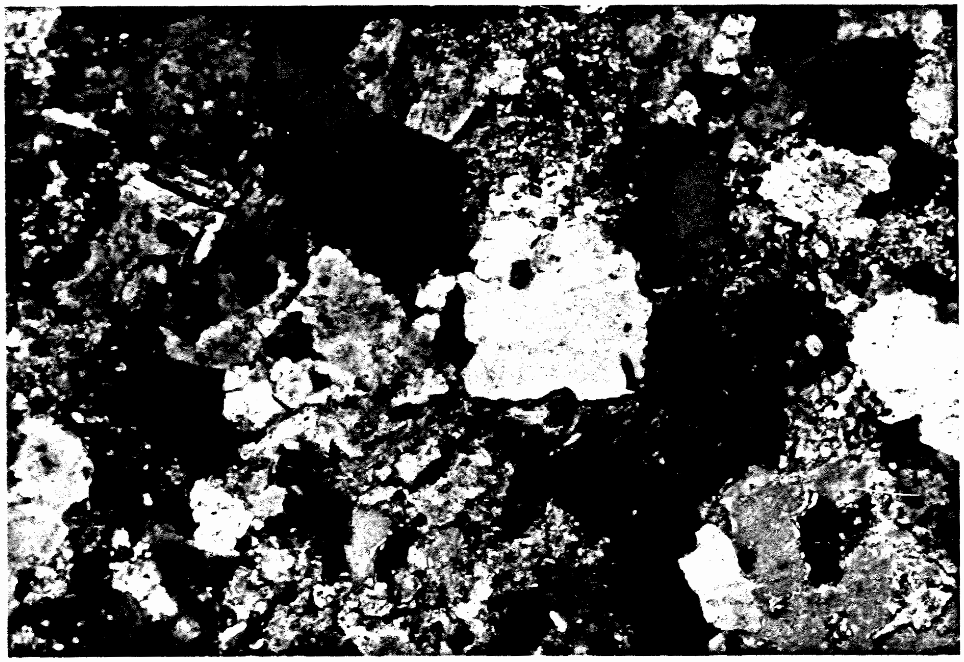


Plate 3.8b

Plate 3.9a

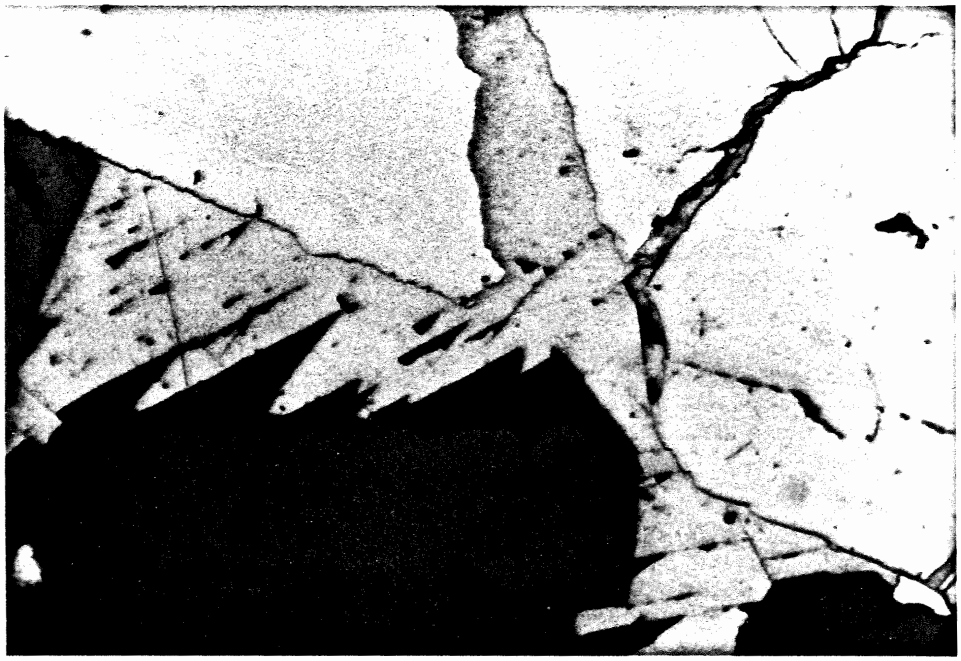


Plate 3.9b

Plate 3.10a

Plate 3.10b

Plate 3.11

PLATE 3.12

Chapter 4. Mineral Chemistry

4.1 Introduction

Mineral compositions were determined using the JEOL 733 electron microprobe at Dalhousie University. This chapter presents the compositions of plagioclase, muscovite, "black sericite", oxides replacing biotite, galena, arsenopyrite, sphalerite, and pyrite.

4.2 Plagioclase

All of the plagioclase grains, including primary-looking subhedral laths and plates, subhedral inclusions in K-feldspar, and exsolution/replacement patches in K-feldspar have albitic compositions. Compositions vary from 0 to 4.4 atomic % An (see Figure 4.1), and different types of grains can not be distinguished by their compositions.

4.3 Muscovite

The probing of interstitial muscovites within the granite, in veins, altering biotite, and sericite revealed significant

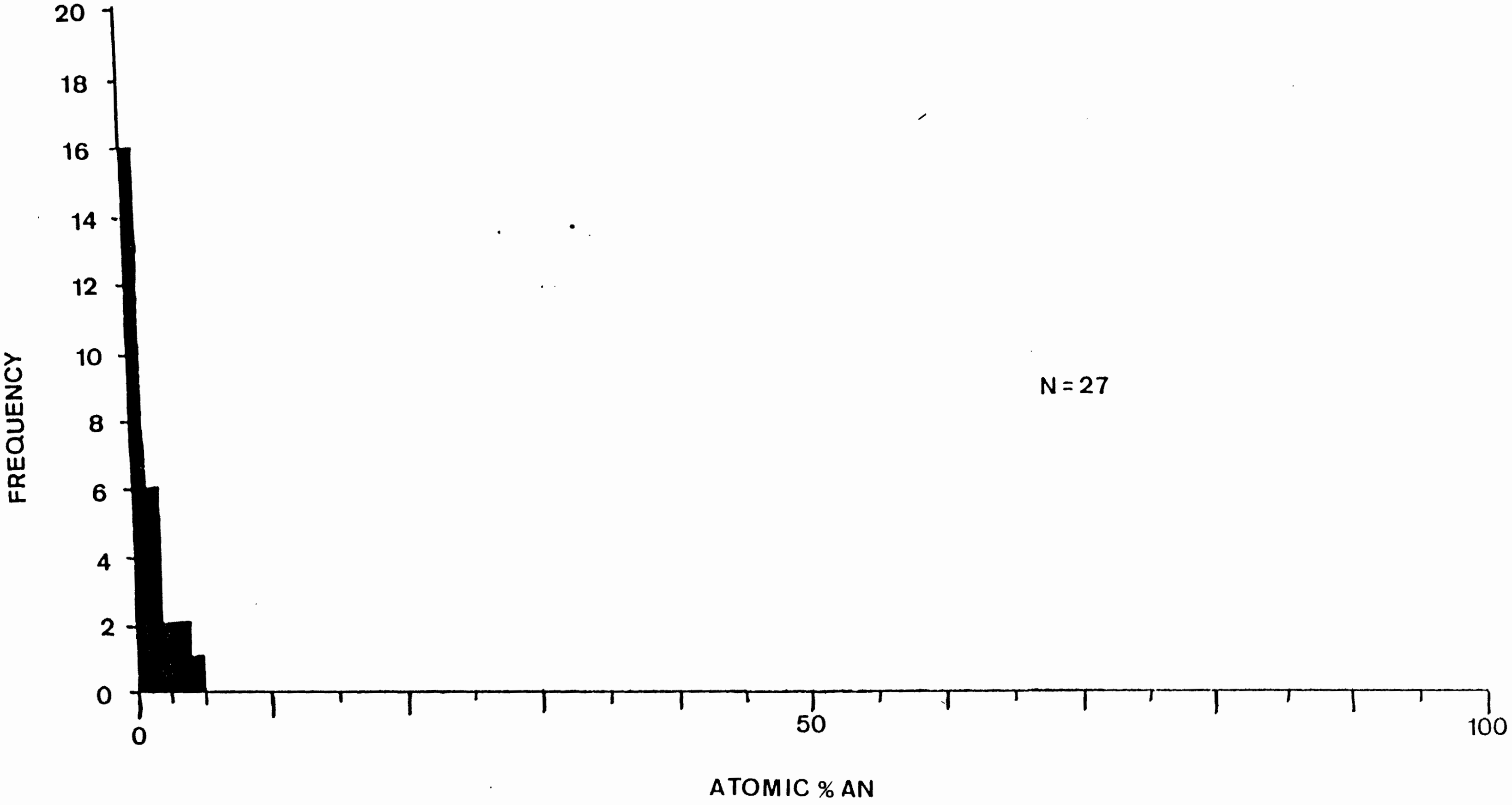


FIGURE 4.1

chemical variability, particularly in the FeO contents. The FeO/TiO_2/MgO plot (Figure 4.2) of selected analyses shows that compositions do not appear to vary systematically. Monier et al. (1984) have found that magmatic, late to post-magmatic and hydrothermal muscovites from the Massif Central, France fall in different fields on this type of plot. The muscovites from Kempt Snare Lake fall into the late to post-magmatic field; however, studies of muscovite compositions in the South Mountain Batholith (Ham, 1987) showed that little correlation exists between muscovite composition and origin.

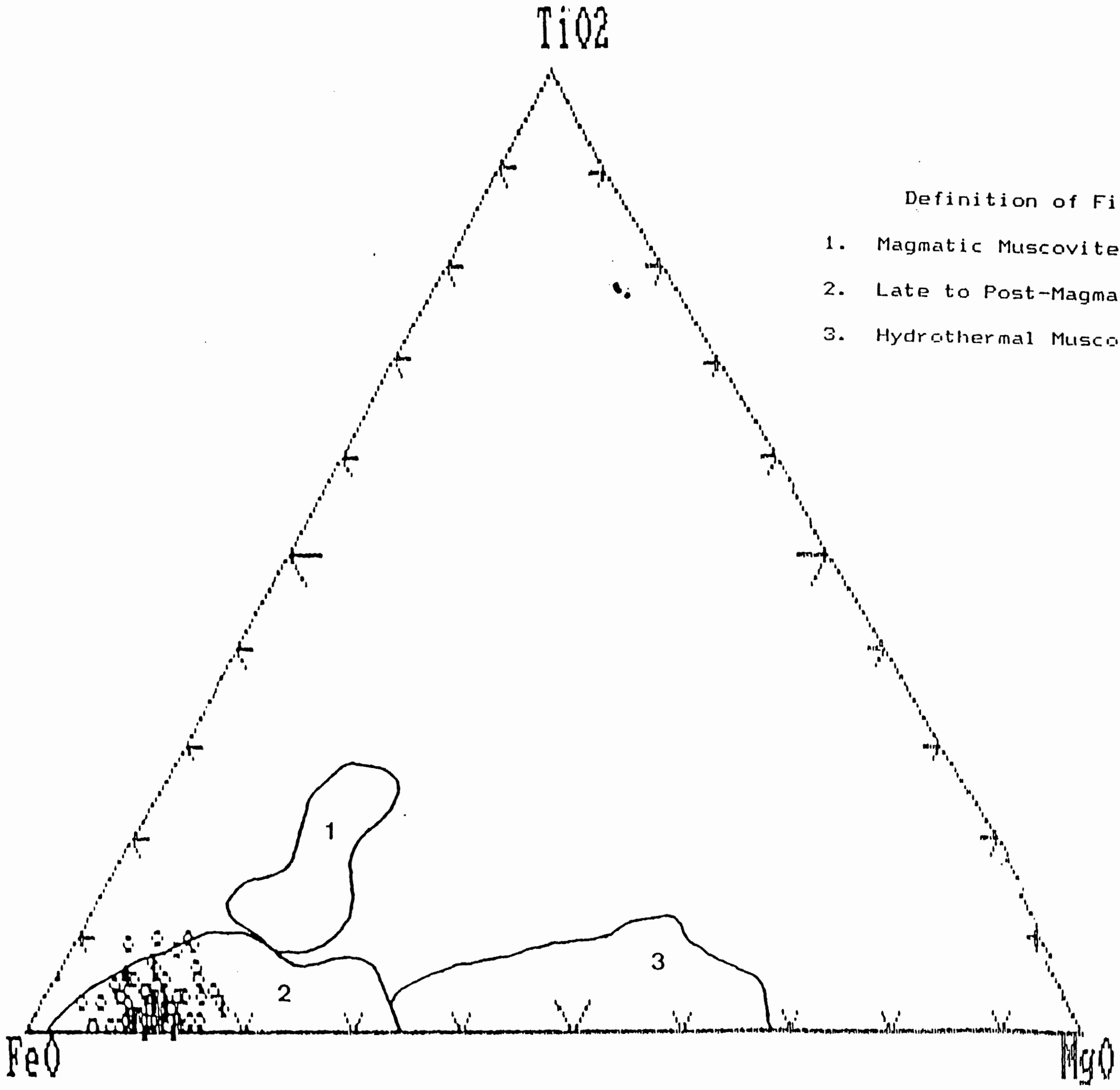
4.4 "Black Sericite"

Where feldspar has been extensively replaced, probing of "black sericite" was possible. The analyses show compositions equivalent to muscovites thus justifying the term "black sericite". The cause of the dark colour remains unknown.

4.5 Oxides replacing Biotite

Probe data for the oxides replacing biotite show that these contain varying amounts of TiO_2 and Fe, and therefore are Fe-Ti oxides.

FIGURE 4.2



Definition of Fields (Monier et al., 1984):

1. Magmatic Muscovite
2. Late to Post-Magmatic Muscovite
3. Hydrothermal Muscovite

4.6 Galena

Analyses of galena show that silver concentrations as high as 0.21 wt.% occur.

4.7 Arsenopyrite

Arsenic levels in arsenopyrite vary from 30.5 to 33.5 atomic %. Some grains show zoning with increases of arsenic as high as 1.5 atomic % from core to rim.

4.8 Sphalerite

Analyses show that most dark spalerites contain 6.5 to 7.5 atomic % Fe; however, analyses of yellow zones near the edges of some grains have Fe contents of 1 to 2 atomic % Fe.

4.9 Pyrite

Microprobe work confirmed the presence of pyrite around sphalerite and arsenopyrite. Anomalous arsenic contents as high as 2.85 atomic % were detected in two small pyrite grains at an arsenopyrite grain margin.

Chapter 5. Geochemistry

5.1 Introduction

Geochemical analyses were done on 10 whole-rock samples, representative of the different units, recognized in the drill core. The samples were analyzed for major elements, loss on ignition, and the following trace elements: F, B, Li, Ba, Rb, Sr, Y, Zr, Nb, Th, Pb, Ga, Zn, Cu, Ni, V, Cr, Mo, Sb, Cs, La, Ce, Hf, Ta, W, Au, U, As, Ag, Sn, and Bi (see Table 5.1 for analyses).

This chapter examines variations between units and the geochemical aspects of alteration, using both variation diagrams of selected elements and an isocon diagram. (Grant, 1986). The geochemistry of the Kempt Snare Lake cupola is compared with available geochemical data for the South Mountain Batholith, the host rocks of the East Kemptville tin deposit, the Wedgeport Pluton, the Davis Lake Pluton and tin-specialized granites in southern Nova Scotia.

5.2 Geochemical Variation among Units

5.2.1 Variation Diagrams

TABLE 5.1

SAMPLE NO UNIT	86-1-6 1	86-1-1 1	86-1-2 4	86-1-4 3	86-2-3 2	86-2-4 1	86-2-8 5	86-3-9 2	86-3-1 1	86-3-3 4
SiO_2	70.02	75.20	75.81	75.64	74.34	74.75	76.69	75.43	73.31	76.17
TiO_2	0.09	0.06	0.07	0.04	0.07	0.05	0.10	0.04	0.07	0.06
Al_2O_3	15.70	13.50	12.88	13.59	13.59	13.51	12.46	13.39	14.59	12.89
Fe_2O_3	0.69	0.30	0.36	0.36	0.74	0.45	0.43	0.44	0.79	0.35
FeO	1.27	0.57	0.67	0.47	0.70	0.70	0.60	0.70	0.87	0.60
MnO	0.12	0.07	0.05	0.02	0.03	0.14	0.09	0.04	0.07	0.05
MgO	0.80	0.78	0.72	0.71	0.83	0.72	0.69	0.73	0.76	0.61
CaO	0.06	0.39	0.49	0.32	0.05	0.19	0.49	0.31	0.11	0.32
K_2O	6.63	5.40	4.50	4.50	5.86	5.50	4.55	4.54	6.06	4.24
Na_2O	1.42	2.91	3.50	3.62	2.33	2.84	2.95	3.39	2.03	3.57
P_2O_5	0.09	0.09	0.08	0.09	0.08	0.08	0.08	0.09	0.08	0.09
TOTAL	97.03	99.33	99.21	99.41	98.70	99.01	99.20	99.18	98.84	99.02
FE_2O_3 TOT	2.10	0.93	1.11	0.88	1.52	1.23	1.10	1.22	1.76	1.02
L.O.I	2.7	1.5	1.3	1.0	1.3	1.7	1.2	0.9	2.0	0.9
TRACES (ppm)										
As	1020	158	124	63	331	210	18	58.6	200	275
Ba	99	87	74	54	73	58	60	23	69	78
Bi	0.04	0.04	7.3	0.04	0.07	0.04	0.04	0.05	0.04	0.04
Cu	1	1	1	1	1	6	4	1	1	1
F	2020	950	1963	820	1600	1260	4080	2350	1200	1380
Mo	3	2	2	2	1	2	2	6	2	2
Pb	6	18	16	3	43	20	41	26	27	22
Rb	901	603	540	518	695	626	522	625	778	465
Sn	16	8.2	5.7	5.8	8.5	8.6	5.7	5.2	12	4.9
Sr	14	29	61	48	16	21	43	20	15	31
Ga	31	22	22	23	23	22	19	26	27	21
Zn	436	50	30	28	124	94	60	45	95	142
U	30	23.9	28.5	31.8	30.2	28.8	26.4	33.7	27.3	25.9
W	25	13	6	22	13	10	11	22	19	6
B	55	32	12	12	28	37	14	12	55	11
Y	75	57	44	40	43	55	60	44	66	47
Li	228	92	125	129	199	147	133	154	226	135
Th	20	19	24	16	23	24	25	16	25	15
Ta	4.2	6.7	3.3	5.2	3.8	3	3.2	5.5	4.6	5
Hf	4	3	3	3	3	4	5	3	5	3
La	2	10	7	4	3	8	17	5	6	9
Nb	16	14	11	12	13	10	12	14	13	13
Cs	13	10	13	11	11	9.4	10	12	12	8.3
Ce	10	27	24	16	14	23	42	19	19	28
Zr	79	66	63	55	67	66	76	49	65	55
Ag	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Au (ppb)	<4	<2	<2	<2	<2	<2	<2	<2	<2	<2
Rb/Sr	64.36	20.79	8.85	10.79	43.44	29.81	12.14	31.25	51.87	15.00
K/Rb	61	74	69	72	70	73	72	60	65	76
Th/U	0.67	0.79	0.84	0.50	0.76	0.83	0.95	0.47	0.92	0.58

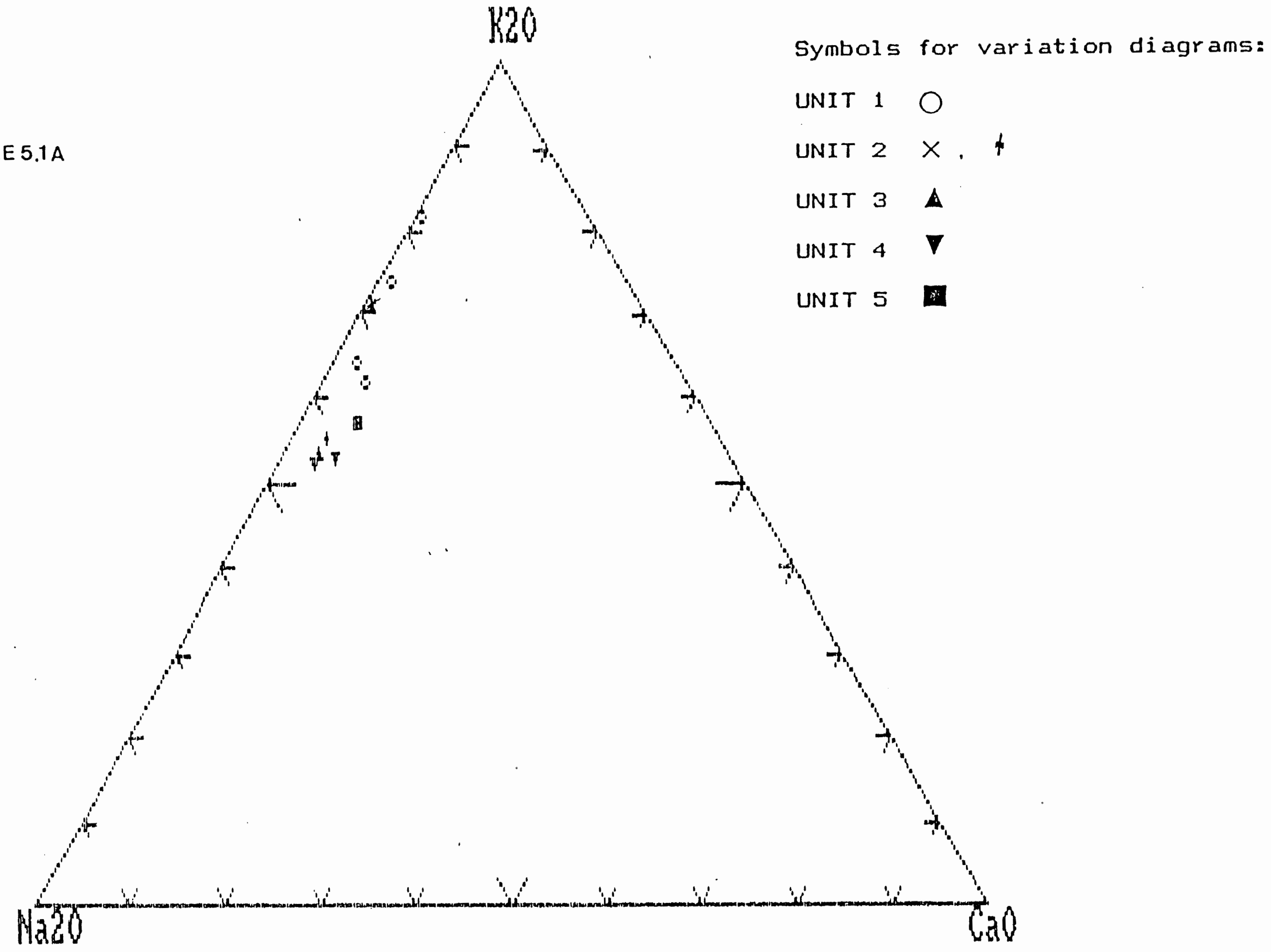
Variation diagrams of selected elements (Figures 5.1a-d, 5.2) show that the altered units (1 and 2) contain higher Al_2O_3, K_2O, and Rb and lower SiO_2, Na_2O, and, CaO concentrations than the less altered units (3,4,5). These elements appear to vary in a linear manner. Unit 5 appears to be distinct from the other unaltered units in that it is enriched in Zr, TiO_2, Ce, and La. These elements show no systematic trends for progressive alteration, suggesting that they remained immobile, and reflect original igneous variation. Therefore, Unit 5 may represent a different intrusion.

5.2.2 Isocon Diagram

An isocon diagram is a graph of the concentrations of elements of an altered rock vs. its unaltered equivalent. An isocon is defined by a line passing through the origin and the components whose concentrations remained unchanged during alteration, i.e. immobile elements. This diagram is useful because the position of an element relative to the isocon indicates whether that element was enriched or depleted during alteration (Grant, 1986).

The isocon diagram of highly altered rocks (Unit 1) vs. relatively unaltered rocks (Unit 4) (Figure 5.3) shows that Zr, TiO_2, Ta, Cs, P_2O_5, Al_2O_3, and SiO_2 define a line passing through

FIGURE 5.1A


K2O
Na2O
CaO
Symbols for variation diagrams:
UNIT 1 ○
UNIT 2 × , +
UNIT 3 ▲
UNIT 4 ▼
UNIT 5 ■

Symbols for variation diagrams:

UNIT 1 ○

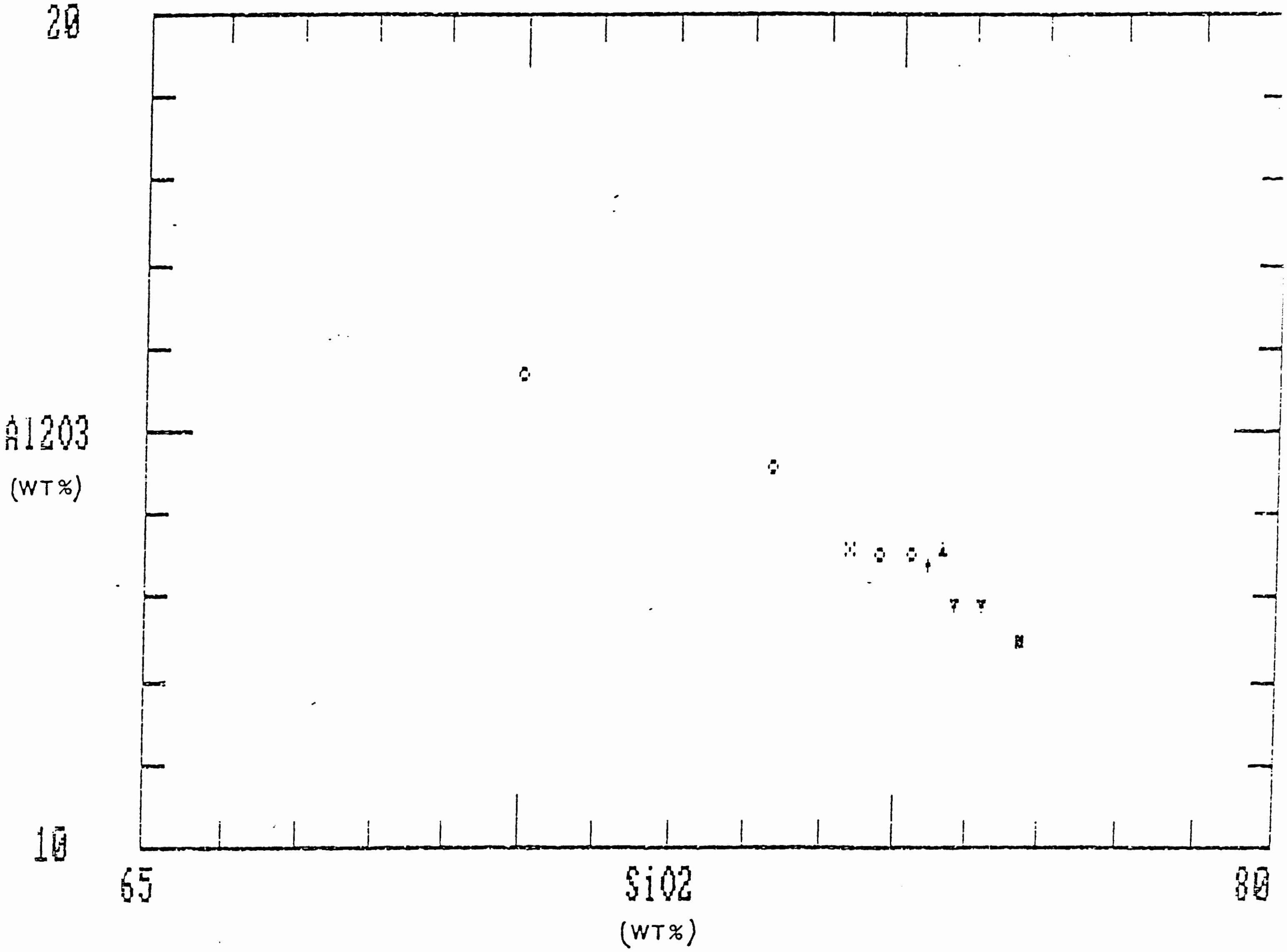
UNIT 2 × , +

UNIT 3 ▲

UNIT 4 ▼

UNIT 5 ■

Figure 5.1b



Symbols for variation diagrams:

UNIT 1 ○

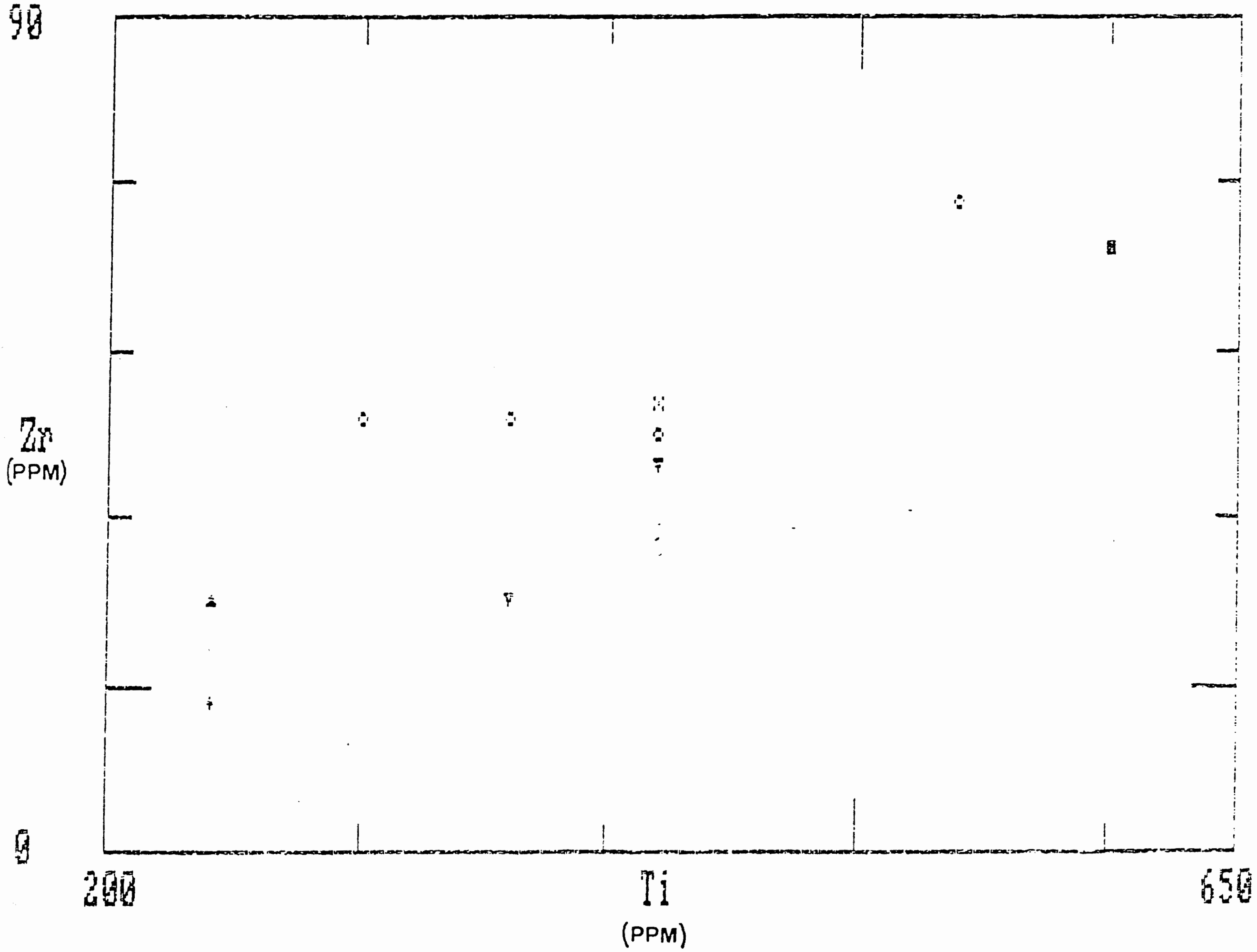
UNIT 2 × , +

UNIT 3 ▲

UNIT 4 ▼

UNIT 5 ■

Figure 5.1c



Symbols for variation diagrams:

UNIT 1 ○

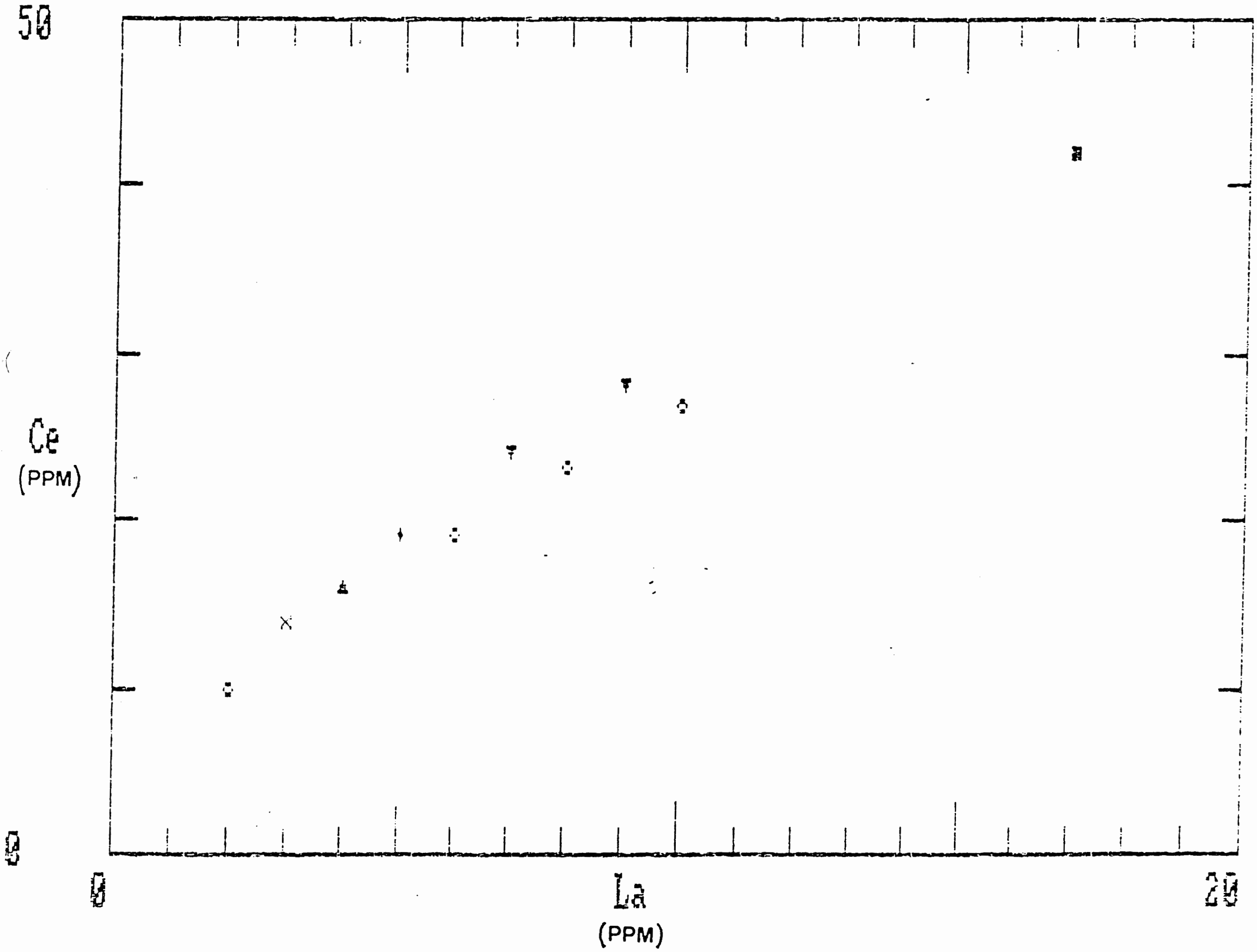
UNIT 2 × , †

UNIT 3 ▲

UNIT 4 ▼

UNIT 5 ▣

Figure 5.1d



KSL : Kempt Snare Lake

SMBM : South Mountain Batholith Monzogranite (McKenzie and Clarke, 1975)

DLL : Davis Lake Leucogranite (Chatterjee et al., 1983)

EKL : East Kemptville Leucogranite (Kontak, 1986)

Wedge: Wedgeport Monzogranite (Wolfson, 1983)

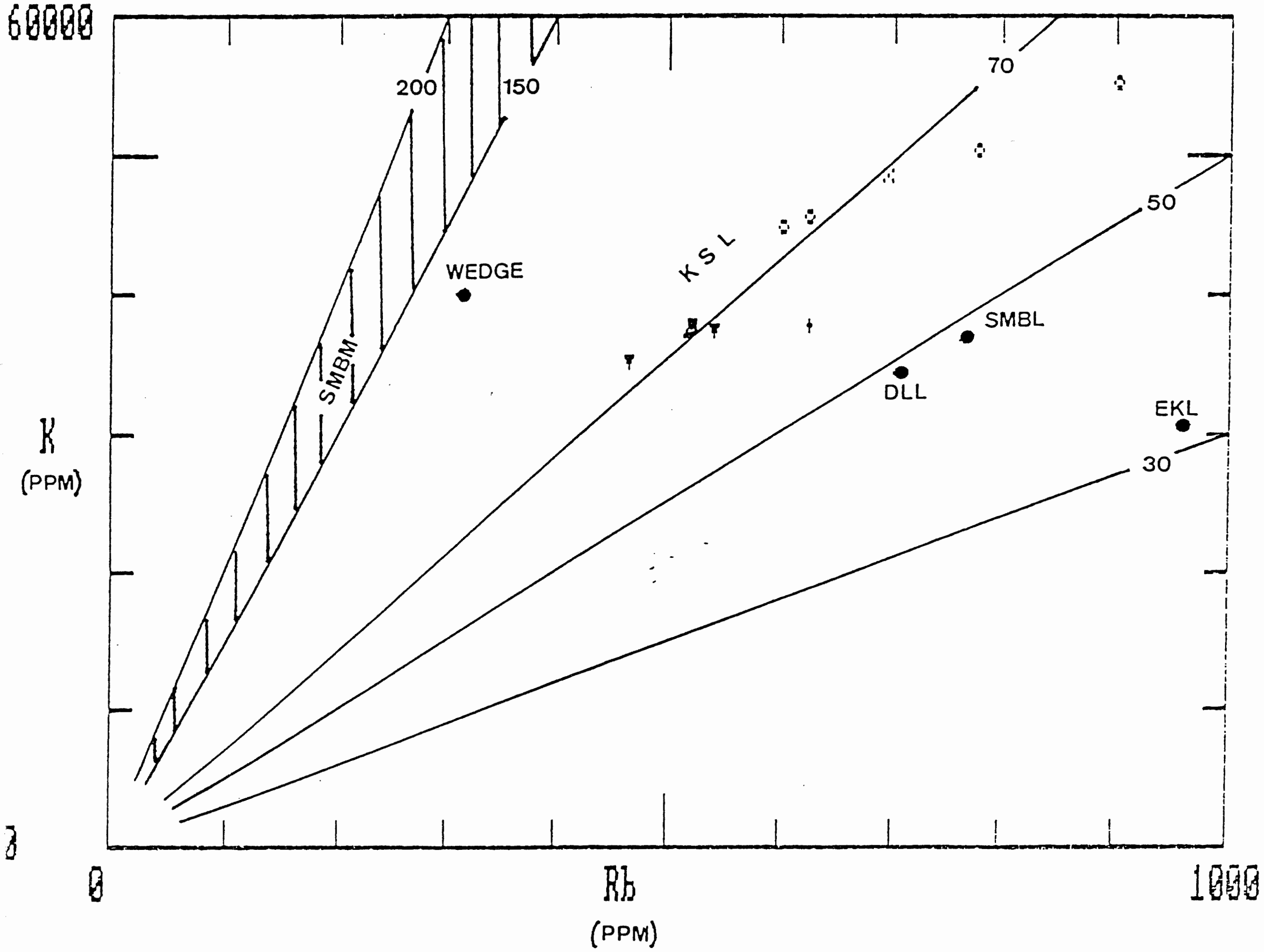


FIGURE 5.2

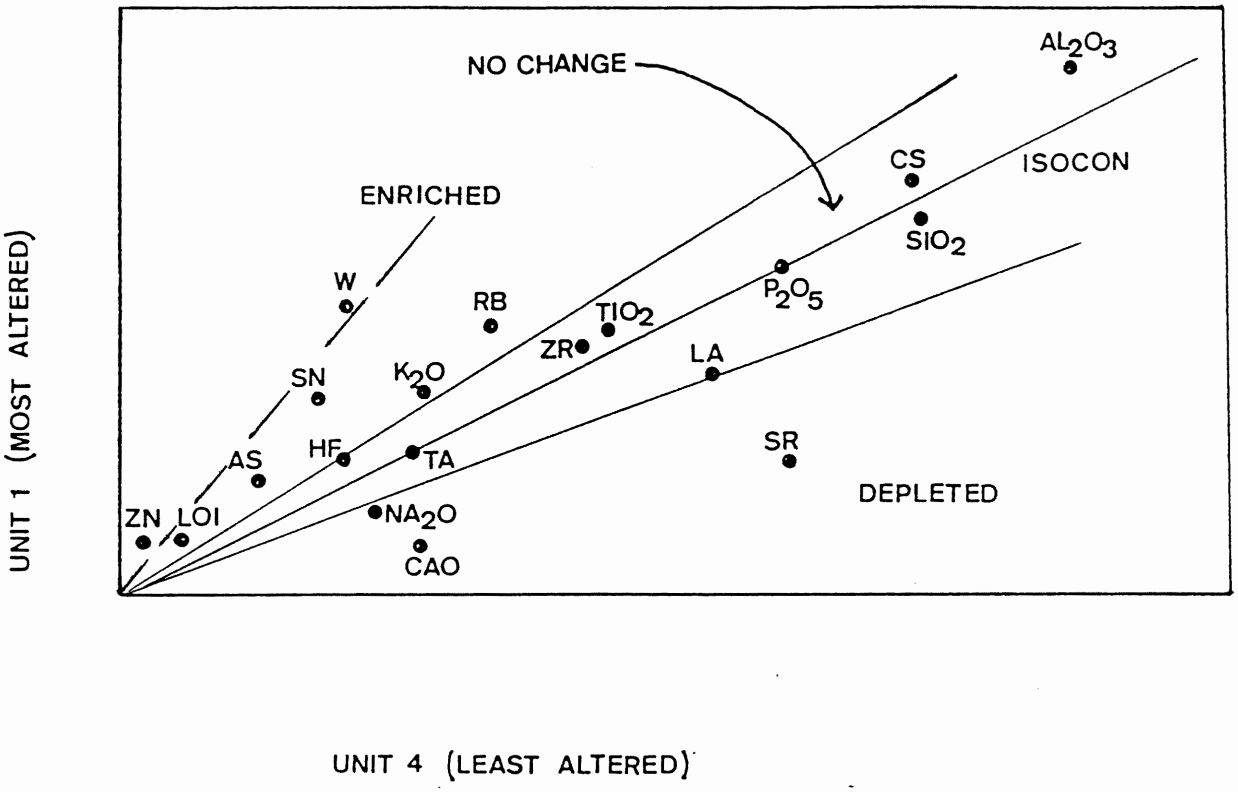

NO CHANGE
AL_2O_3
ISOCON
CS
SIO_2
ENRICHED
W
RB
TIO_2
P_2O_5
ZR
LA
SN
K_2O
HF
TA
AS
SR
DEPLETED
ZN
LOI
NA_2O
CAO
UNIT 1 (MOST ALTERED)
UNIT 4 (LEAST ALTERED)

Figure 5.3

the origin. This line represents an isocon, and indicates that these elements remained relatively immobile during alteration. The occurrence above the isocon indicates that W, Zn, As, Sn, were strongly enriched and K_2O, Rb, and As moderately enriched during fluid-rock interactions producing alteration. It also appears that Sr, CaO, and Na_2O were depleted during alteration, and that changes in Al_2O_3 and SiO_2 were not as great as indicated by the variation diagrams.

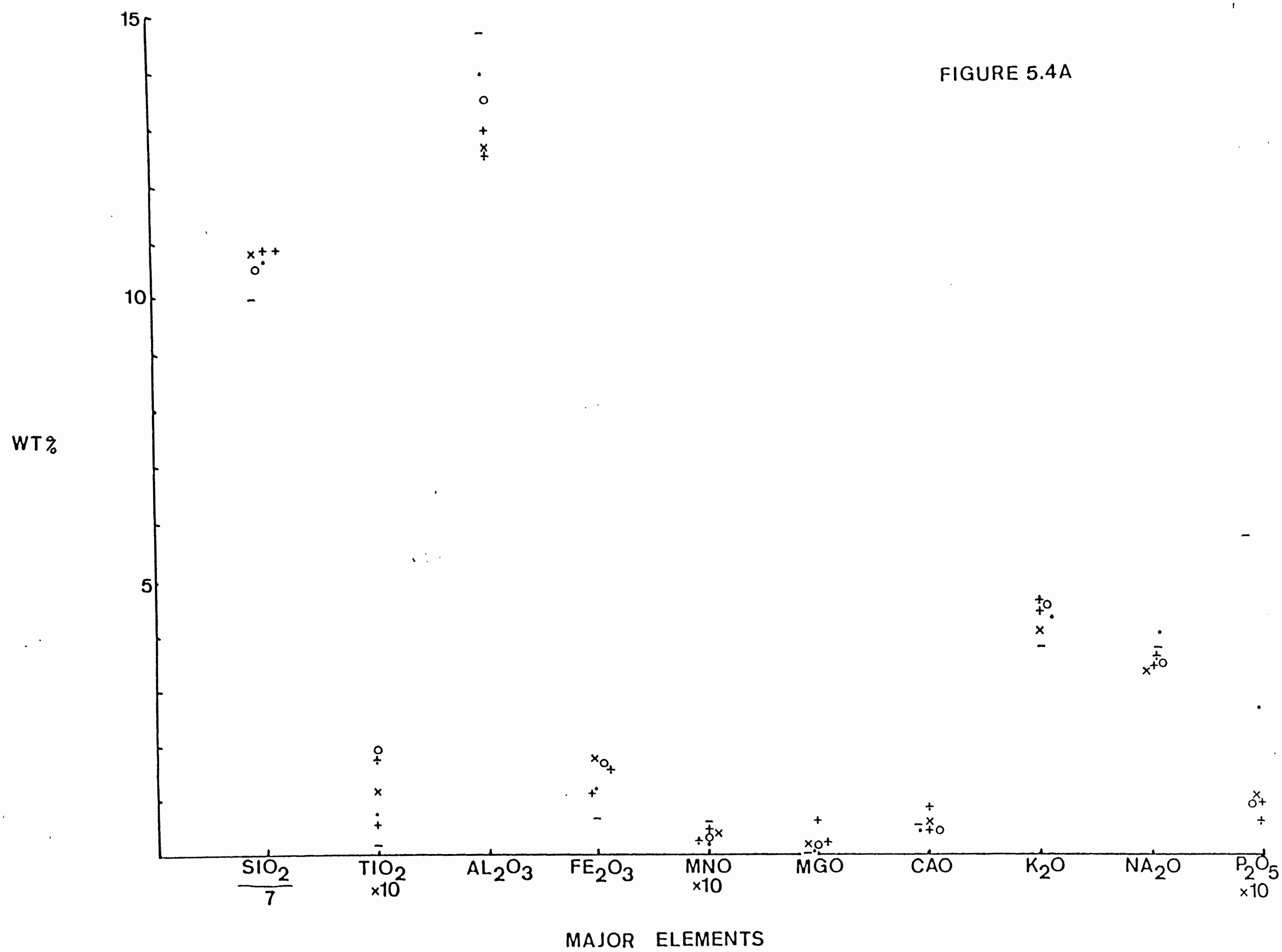
5.3 Comparison with other Southern Nova Scotian Granitoids

5.3.1 Introduction

This section compares the geochemistry of the Kempt Snare Lake leucogranite with the compositions of the South Mountain Batholith, the host leucogranite of the East Kemptville tin deposit, the Wedgeport Pluton, the Davis Lake Pluton and tin-specialized granites of southern Nova Scotia. The compositions of the Kempt Snare Lake leucogranite (KSLL) and the other southern Nova Scotian granitoids are compiled in Figure 5.4.

5.3.2 South Mountain Batholith

FIGURE 5.4A



Note: a number of elements have been proportionally changed to fit the scale, and not all elements are available for some rock types.

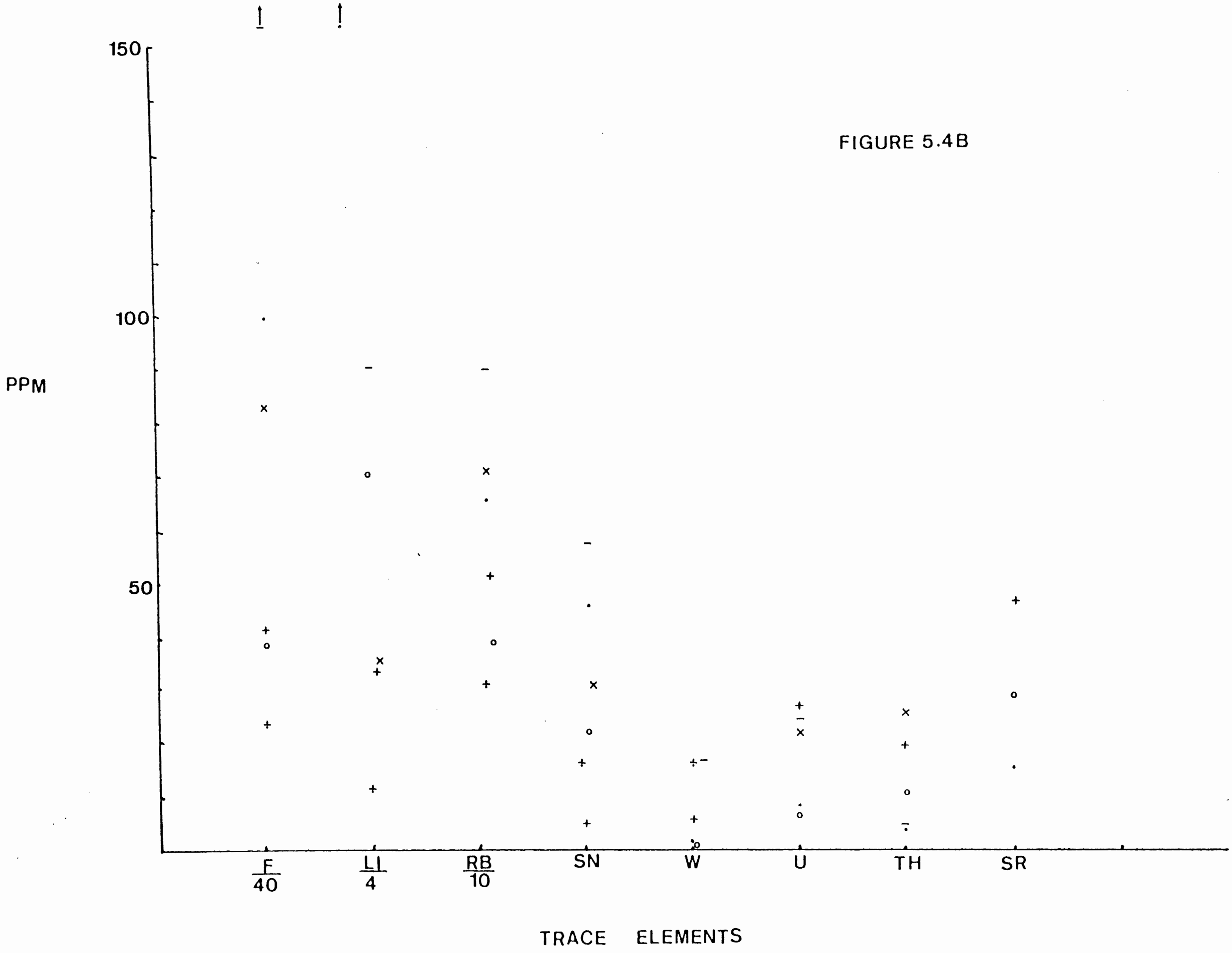


FIGURE 5.4B

Note: a number of elements have been proportionally changed to fit the scale, and not all elements are available for some rock types

Compared with the monzogranites and leucomonzogranites of the South Mountain Batholith, the levels of Al_2O_3, Li, and Sn are less in the KSLL. Conversely, the KSLL has higher levels of MgO, W, U, Th, and Sr. The KSLL has similar TiO_2 and Fe_2O_3 (total) values to the leucomonzogranite, but Na_2O, P_2O_5, and F are similar to the monzogranite.

5.3.3 East Kemptville Leucogranite

Compared with the East Kemptville leucogranite, the KSLL is depleted in Al_2O_3, P_2O_5, F, Rb, Li, Sn, and W and enriched in SiO_2, TiO_2, MgO, K_2O, and Th.

5.3.4 Wedgeport Pluton

The KSLL is geochemically more similar to the Wedgeport Pluton than the previously mentioned granitoids; however, the Kempt Snare Lake still has lower TiO_2, Fe_2O_3, CaO, and Sn; and higher MgO, F, Li, and Rb. No data for U, Th, or Sr is available.

5.3.5 Davis Lake Pluton

The KSLL and the leucogranites of the Davis Lake Pluton have similar compositions, in which lower Rb, Fe_2O_3 (total), F, and Sn, and higher MgO distinguish the KSLL. No data for W, U, or Th is available.

5.3.6 Tin-Specialized Granites of Southern Nova Scotia

According to Tischendorf (1982), increases in granophile elements (SiO_2, K_2O, F, Rb, Li, Sn, W, U, Th) and decreases in granophobe elements (TiO_2, Fe_2O_3(total), CaO, Sr, Ba), characterize granites associated with tin mineralization from barren granites. Using the data from Chatterjee et al. (1983) for tin-specialized granites in Southern Nova Scotia (Figure 5.5), the KSLL is specialized in SiO_2, K_2O, F, U, TiO_2, Fe_2O_3(total), CaO and Ba, but not in Li, Rb, Sr, W, and Sn. The black greisen, however, is specialized in all elements, with the exception of Sn, SiO_2, and Th, which remain low.

5.4 K/Rb ratios

Rubidium, because of its similar physical and chemical properties to K, concentrates in K-bearing minerals. However, the slightly higher ionic radius of rubidium results in preferential incorporation of K in early stages of

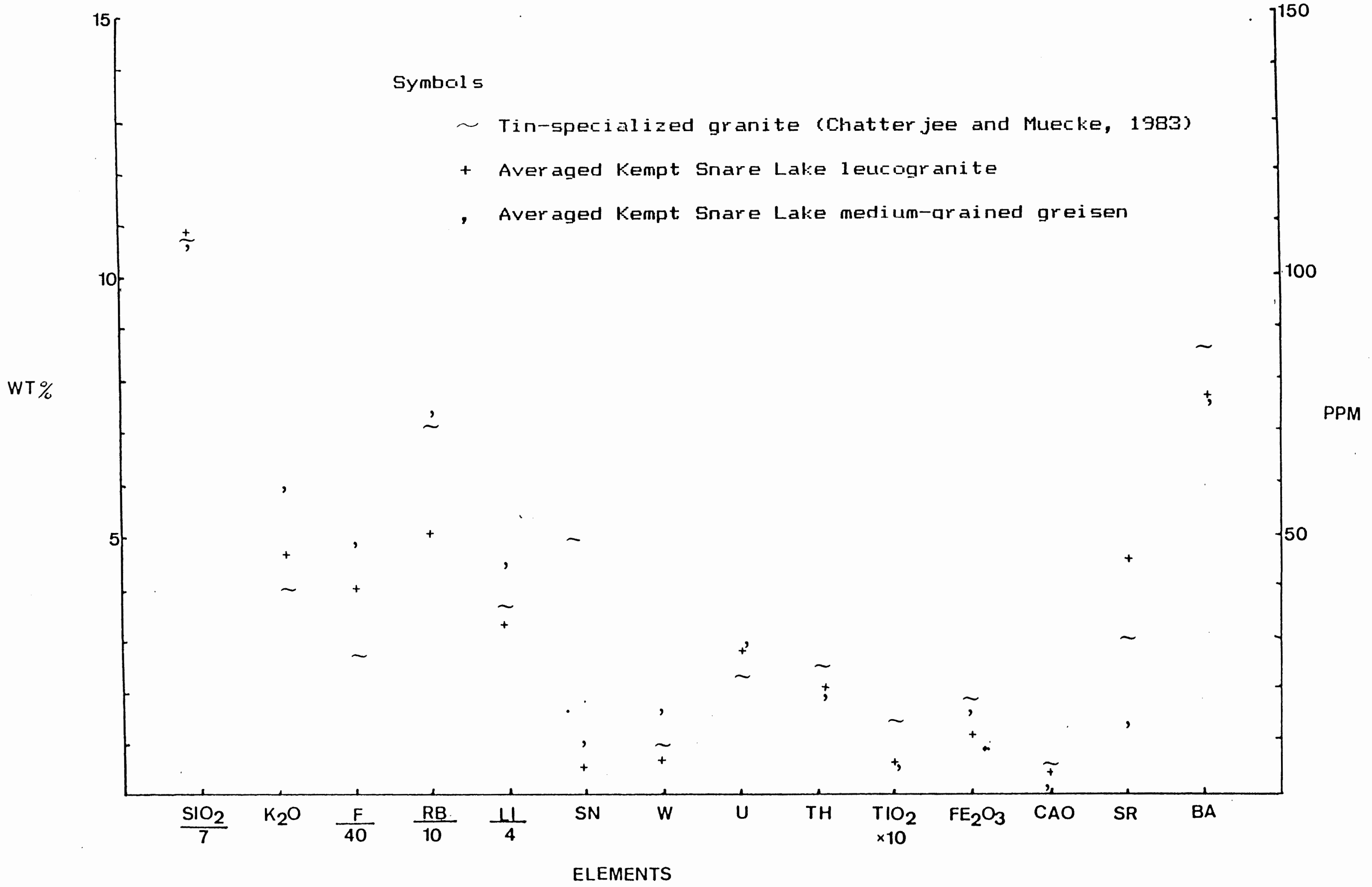

15
10
5
WT%
150
100
50
PPM
Symbols
~ Tin-specialized granite (Chatterjee and Muecke, 1983)
+ Averaged Kempt Snare Lake leucogranite
, Averaged Kempt Snare Lake medium-grained greisen
SIO2 / 7
K2O
F / 40
RB / 10
LI / 4
SN
W
U
TH
TIO2 ×10
FE2O3
CAO
SR
BA
ELEMENTS

FIGURE 5.5

crystallization, and Rb-enrichment in late magmatic stages. K/Rb ratios can therefore be used as an indicator for the degree of magmatic differentiation and fluid-rock interaction (Heier and Billings, 1970). Most igneous rocks have K/Rb ratios between 160 and 300 (Heier and Billings, 1970); however, highly differentiated granites and pegmatites may have much lower ratios (Reynolds, 1972).

The K/Rb plot in Figure 5.2 shows that the Kempt Snare Lake granites have K/Rb ratios (60-75), well below the range for the South Mountain Batholith monzogranite (150-200) and the Wedgeport Pluton (160). However, the K/Rb ratios of the Kempt Snare Lake granites are considerably higher than the East Kemptville leucogranite (36) and marginally higher than the Davis Lake Pluton (50) and South Mountain Batholith leucomonzogranite ratios (50).

5.5 Th/U

Chatterjee and Muecke (1982) established that in the South Mountain Batholith, Th/U ratios and Th decrease with increasing differentiation, while in the Davis Lake and Wedgeport Plutons U and Th increase concomitantly. Kontak (1986) found that high U and low Th distinguish the East Kemptville leucogranite from both these trends. The Th/U plot in Figure 5.6 shows that the Kempt Snare Lake granites are slightly enriched in U, but fit the Davis

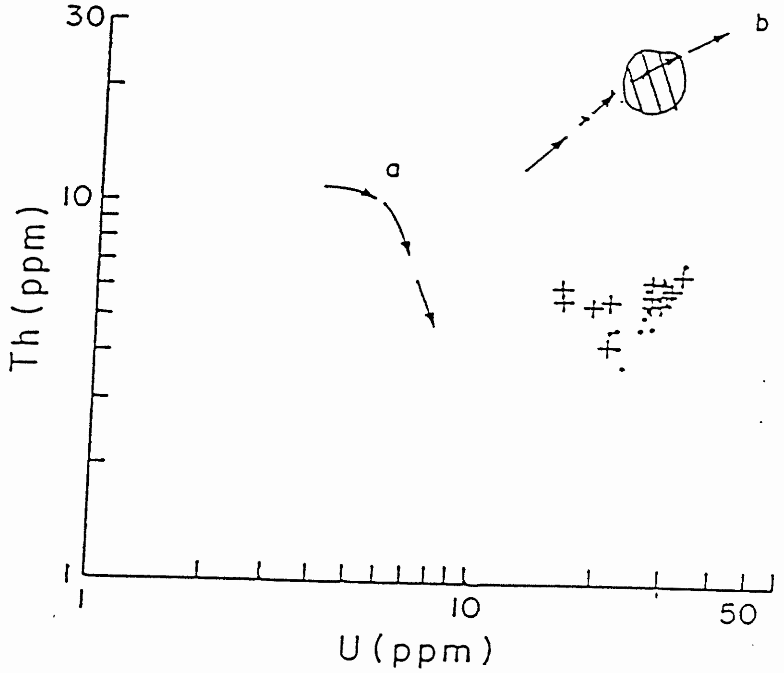


Figure 5.6

Symbols

+ East Kemptville leucogranite

. Altered East Kemptville leucogranite

▨ Kempt Snare Lake

Arrows indicate direction of increasing differentiation (Diagram modified from Kontak, 1986).

Lake trend.

Chapter 6. $^{40}Ar/^{39}Ar$ Dating

6.1 Introduction

Mineral age dating by the $^{40}Ar/^{39}Ar$ stepwise outgassing method was done on two muscovite samples and one K-feldspar sample from variously altered units.

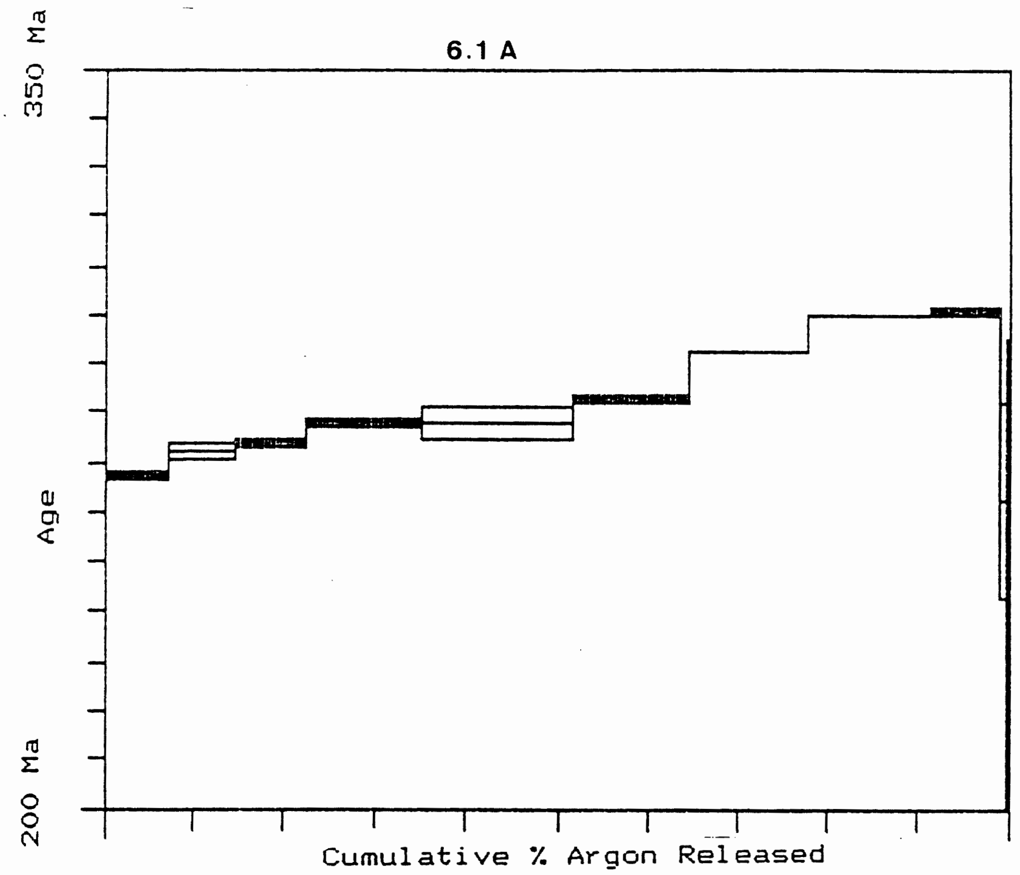
The age spectra of the muscovite samples, one relatively unaltered unit (Unit 3) and the other from a highly altered unit (Unit 1) provide constraints on the ages of intrusion and hydrothermal activity, while the K-feldspar sample from an unaltered unit (Unit 4) gives information on the low temperature history of the Kempt Snare Lake granitic stock.

6.2 Results

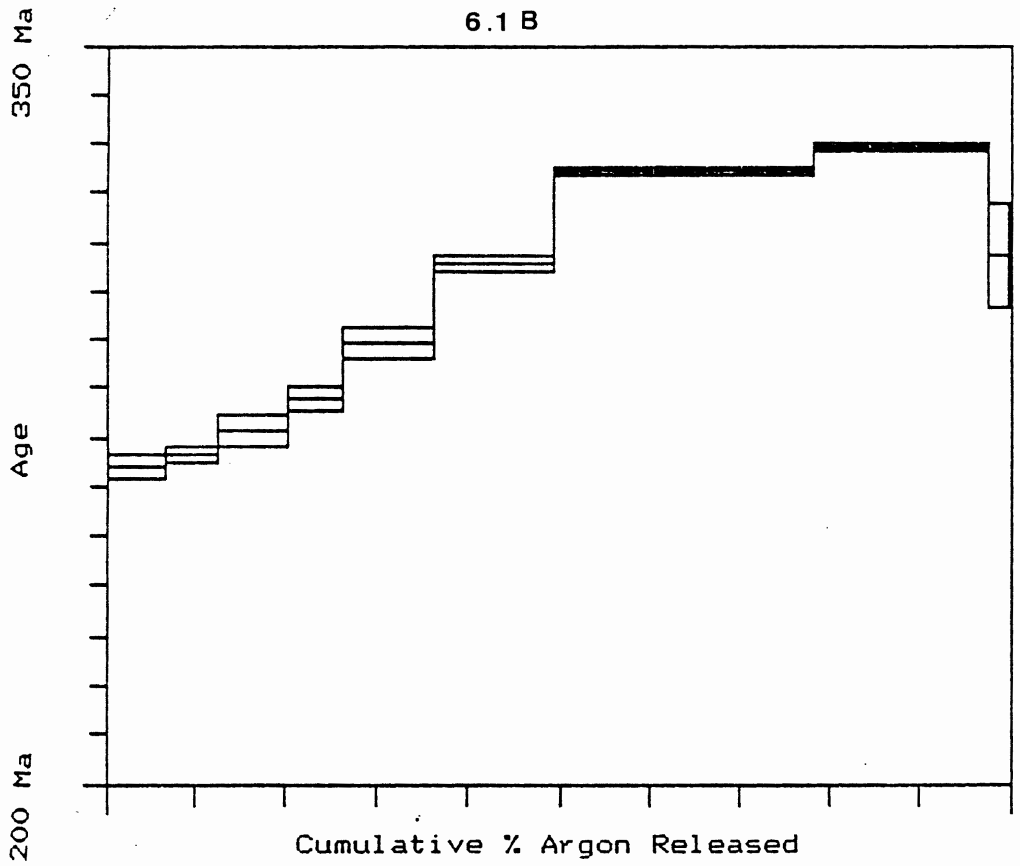
6.2.1 Muscovite

The spectrum plots of both muscovite samples (Figure 6.1) represent age gradient spectra in which successive temperature steps yield higher ages resulting in staircase patterns. A comparison of the two spectra shows that the sample from the highly altered rocks has a lower age gradient. Initial argon

6.1 A


350 Ma
Age
200 Ma
Cumulative % Argon Released

6.1 B


350 Ma
Age
200 Ma
Cumulative % Argon Released

release in both samples corresponds to an age between 265 and 270 Ma, while maximum ages are 332 ± 5 Ma for the unaltered unit and 303 ± 4 Ma for the altered unit.

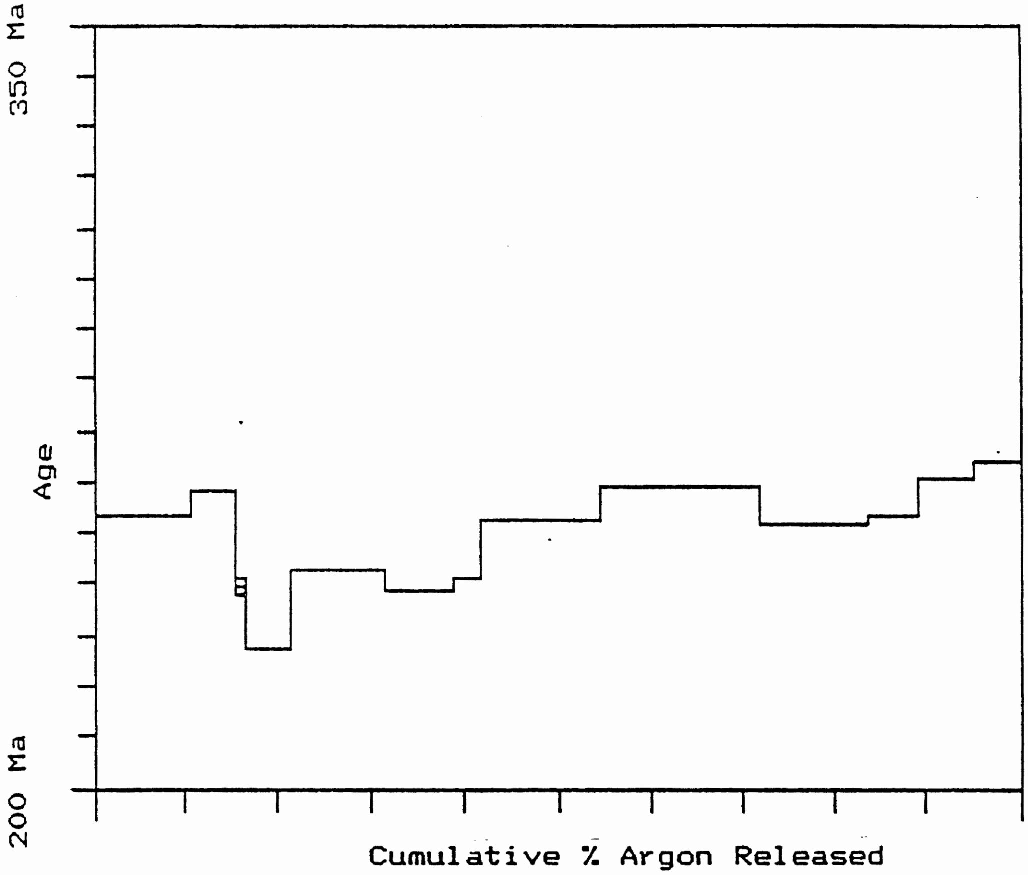
6.2.2 K-feldspar

The spectrum plot of the K-feldspar sample (Figure 6.2) represents a disturbed age gradient spectrum in which some anomalous ages disrupt the staircase pattern. Ignoring the anomalously high ages between 250 and 260 Ma for the first low temperature steps, a best-fit curve for the plot indicates a minimum age of approximately 220 Ma and a maximum age of 264 ± 3 Ma.

6.3 Interpretation of Age Spectra

6.3.1 Introduction

Two models, slow cooling or episodic loss, in theory can give rise to age gradients (Turner, 1968; Harrison and MacDougall, 1982). In the episodic loss model, an overprinting event has partially reset the argon clock. Ideally, thermally undisturbed rocks yield perfect plateau ages, but during an



6.2

overprinting event, argon loss progresses from the rims of the crystals to the cores. If the event did not completely outgas the argon, spectra with increasing ages for successive temperature steps result. In these spectra, the minimum ages should reflect the ages of the overprints, and the maximum ages should reflect the ages of the original cooling (Turner, 1968). Because rims may have retained, and the cores may have lost some of the original argon, only maximum ages of the overprinting events and minimum ages for the times of original cooling can be determined.

A slow-cooling model has been suggested for age gradients spectra of K-feldspar (Harrison and MacDougall, 1982); however, abundant quartz veins and faults in the Kempt Snare Lake stock give strong evidence for post-intrusion thermal activity. Therefore, the slow cooling is not considered in the interpretation of these spectra.

6.3.2 Muscovite

The age gradient spectra of the muscovite samples indicate that an overprinting event occurred at a minimum age of 265 Ma. The maximum age of the the sample from the unaltered unit indicates that the stock is no younger than 332 ± 5 Ma. The lower apparent age of the sample from the altered unit and the lower age gradient indicate that this sample has been affected more severely by an overprinting event at ca. 300 Ma. This younger age probably reflects more abundant secondary muscovite, formed during the overprinting event, in the altered unit.

6.3.3 K-feldspar

The age gradient spectrum of the K-feldspar sample indicates that an overprinting event occurred approximately 220 Ma ago. Because K-feldspar retains Ar less effectively than muscovite (Dalrymple and Lanphere, 1969), the event, which at least partially reset the muscovites, probably completely reset the K-feldspar; and is responsible for the lower apparent age (ca. 265 Ma) of the K-feldspar.

The anomalously high ages (250-260 Ma) of the first two steps are similar to the corresponding ages in the muscovite spectra, and probably represent minor sericite in the K-feldspar. Petrography confirmed the presence of sericite. The minor disturbances at higher temperature steps in the age spectrum may represent heterogeneously distributed Ar, possibly produced by K-redistribution during deformation.

Chapter 7. Fluid Inclusions

7.1 Introduction

Fluid inclusions from eight doubly-polished quartz chips were analyzed using the Fluid Inc. heating-freezing stage at Dalhousie University. The quartz chips came from a variety of veins including mineralized, barren, carbonate-bearing, pre-fault, and post-fault veins. This chapter describes the types of fluid inclusions occurring in quartz, and presents and discusses heating and freezing data in order to make estimates of T-P conditions and fluid compositions during vein formation.

7.2 Fluid Inclusion Types

Fluid inclusions are abundant in all veins. Three types of fluid inclusions occur:

Type 1: 2-phase inclusions containing a liquid and a gas bubble.

Type 2: 3-phase CO_2-bearing inclusions containing gaseous and liquid CO_2 and aqueous solution.

Type 3: 3-phase inclusions containing a liquid, a gas bubble, and a solid.

Type 1 inclusions (Plate 7.1) constitute approximately 90% of all fluid inclusions. Most have well-developed negative crystal shapes, but rounded inclusions and irregularly-shaped inclusions are common as well. Most of these inclusions range in size from <5 to 25 um, and occur in planes associated with healed microfractures, and as isolated inclusions. Common isolated, large (25-125 um), irregularly shaped, dendritic inclusions are probably primary.

Type 2 inclusions (Plate 7.2) have the same forms as Type 1; however, isolated, large (25-125 um), irregularly shaped, dendritic inclusions are more common (Plate 7.2).

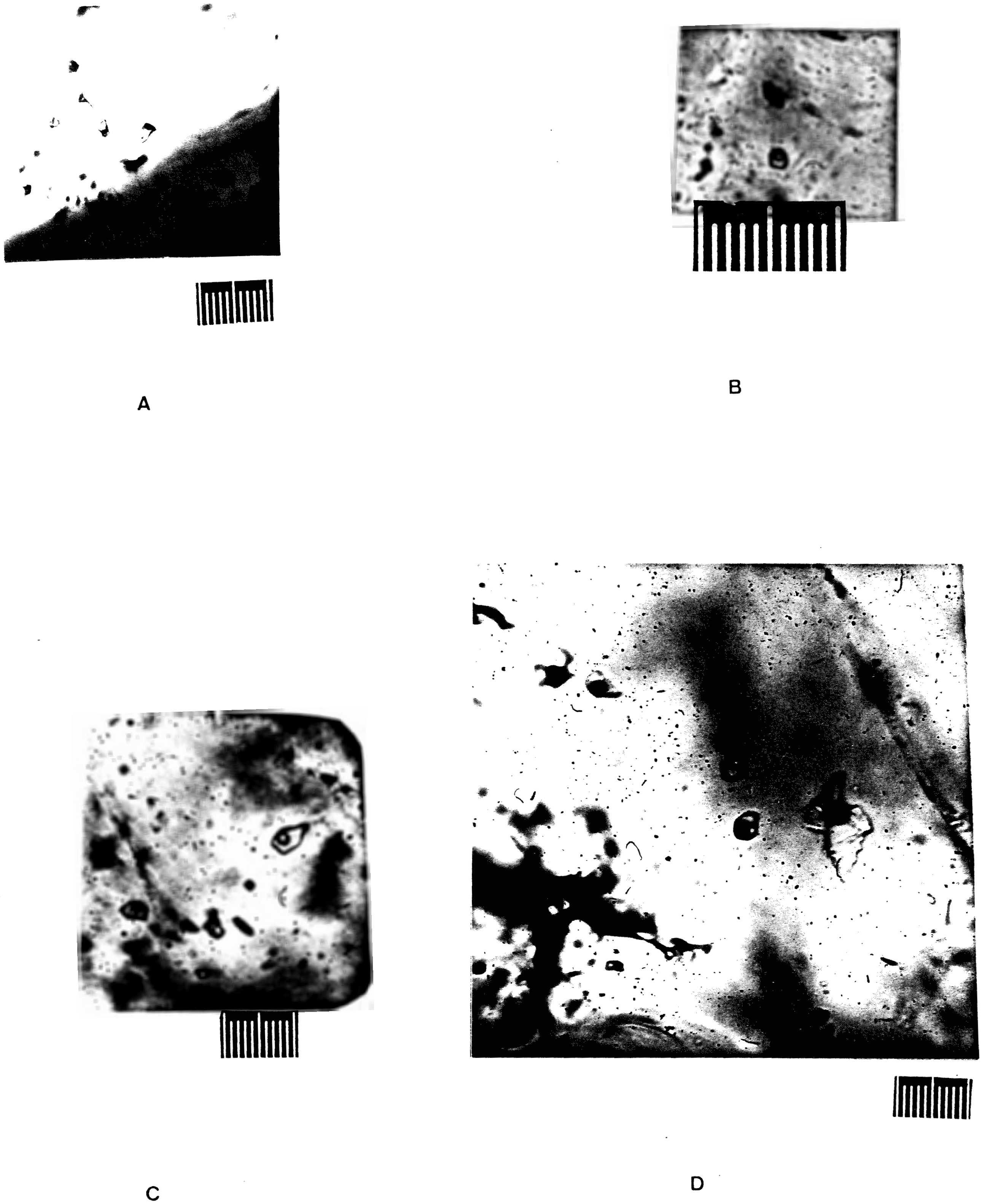
Type 3 inclusions (Plate 7.3) are uncommon. They have irregular and negative crystal shapes, and contain unidentified solid phases which occur as white, small anisotropic anhedral crystals.

Liquid to vapour ratios, with the exception of inclusions in which necking down has occurred and liquid-rich inclusions in some microfractures, are relatively constant. Limited petrographical work made it impossible to distinguish between fluid inclusion populations in different vein types.

7.3 Heating

Homogenization temperatures for 70 fluid inclusions were

PLATE 7.1



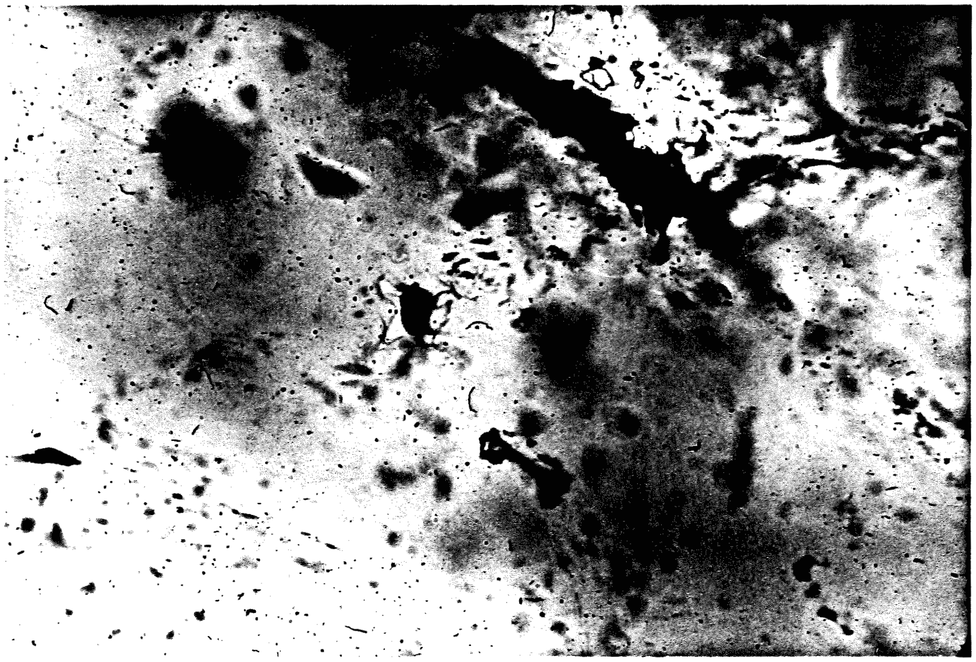
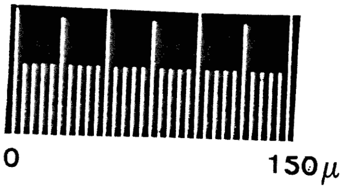


PLATE 7.2



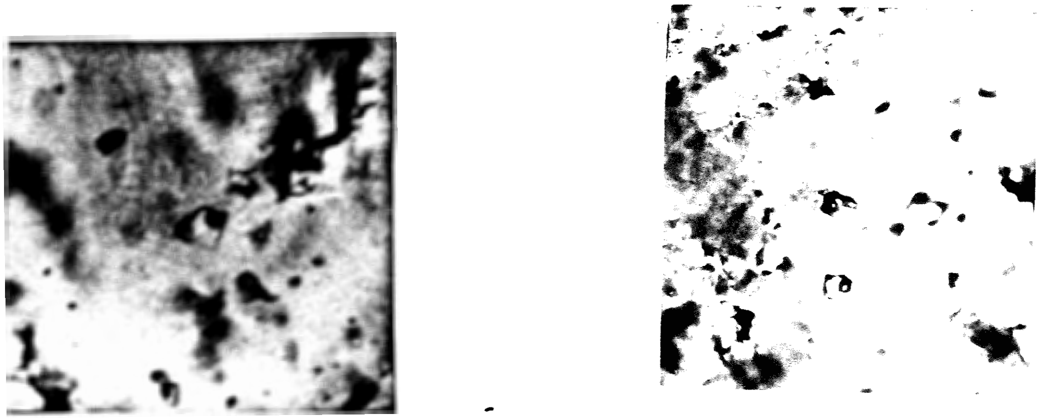


PLATE 7.3

determined by heating the inclusions, with the heating-freezing stage, according to the procedure in Roedder (1984).

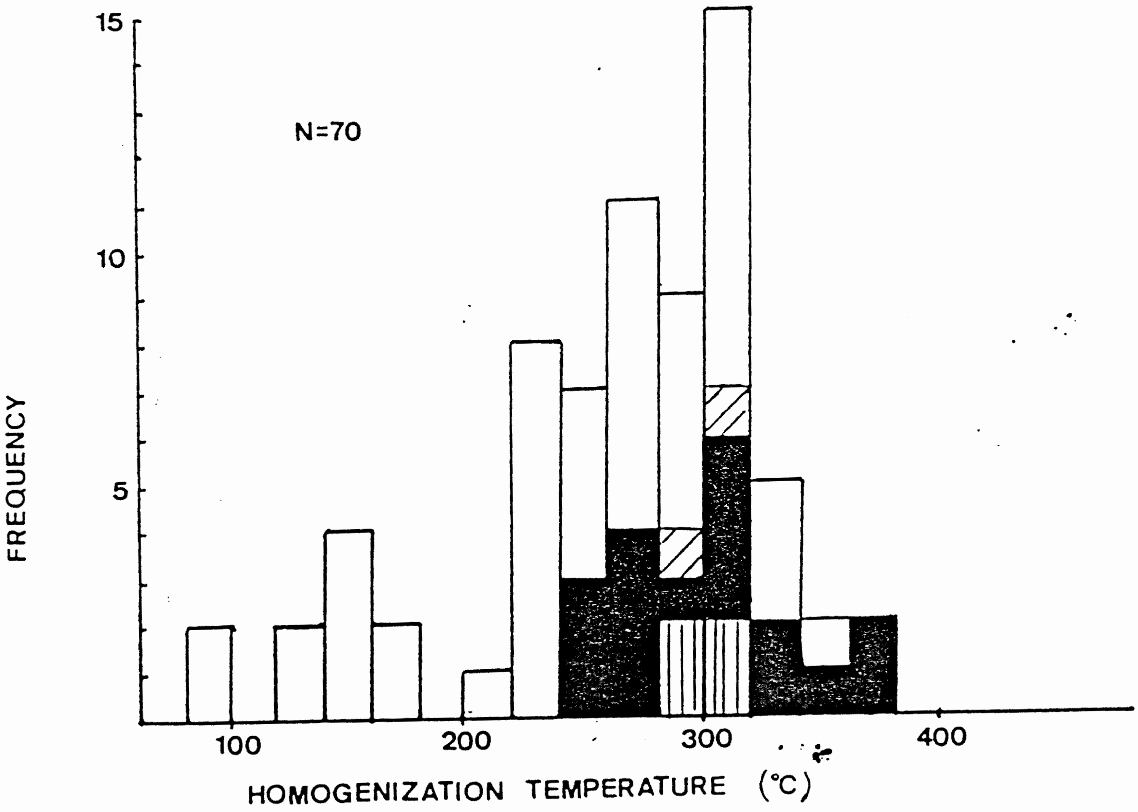
7.3.1 Type 1 Inclusions

Homogenization to a liquid phase occurred between 220 and 340°C for most Type 1 inclusions (Figure 7.1). Nevertheless, some fluid inclusions from microfractures homogenized below 200°C. In a number of inclusions, the bubble increased in size and partially or totally filled the inclusion, indicating homogenization to the vapour phase. Homogenization measurements of inclusions, partially filled by the expanding bubble, were not reproducible, but during reheating, the bubble expanded and filled the inclusion at a higher temperature. Once vapour filled the inclusion, liquid did not reappear during cooling. Large irregular inclusions usually exhibited this type of homogenization behaviour.

7.3.2 Type 2 Inclusions

In Type 2 inclusions, homogenization of the inner vapour phase occurred between 23 and 29°C, and homogenization of liquid CO_2 and H_2O phases occurred between 290 and 310°C (Figure 7.1). A number of inclusions appeared to homogenize to a vapour phase

FIG. 7.1



Symbols

Type 1 inclusions ☐

Type 2 inclusions ▥

Type 3 inclusions ▨

Inclusions which "homogenized to a vapour phase" ■

as described for Type 1.

The disappearance of the vapour phase below 30 °C makes these inclusions indistinguishable from Type 1 at high temperatures; therefore, some of the homogenization temperatures reported for Type 1 may actually represent Type 2 inclusions.

7.3.3 Type 3 Inclusions

Limited data for Type 3 inclusions show homogenization to the gas phase at temperatures similar to Types 2 and 3 (Figure 7.1). No change in the solid phase occurred within the range of temperatures attained during homogenization runs (0-400°C).

7.4 Freezing

Using the heating-freezing stage, the freezing temperatures of the fluids in 32 inclusions were determined by reheating frozen inclusions until all ice melted according to the procedure outlined by Roedder (1984). Accuracy and precision of melting temperatures is better than ± 2°C.

7.4.1 Type 1 Inclusions

Type 1 inclusions, froze, between -30 and -50°C upon supercooling. During reheating, melting occurred between -19.4 and +3.0°C; however, as the histogram of melting temperatures (Figure 7.2) shows that most inclusions melted between -10 and -2°C.

7.4.2 Type 2 Inclusions

The outer liquid in Type 2 inclusions froze between -30 and -50°C; however, complete freezing did not occur until temperatures dropped below -80°C. During reheating, melting of the inner liquid occurred between -56.8 and -56.3°C. Final melting did not occur until temperatures reached +0.8 - +5.4°C (Figure 7.2).

7.4.3 Type 3 Inclusions

Freezing data for only one of these inclusions was obtained. Upon supercooling, freezing occurred between -30 and -50°C, and during reheating, final melting occurred at 0.0°C.

7.5 Interpretation of Results

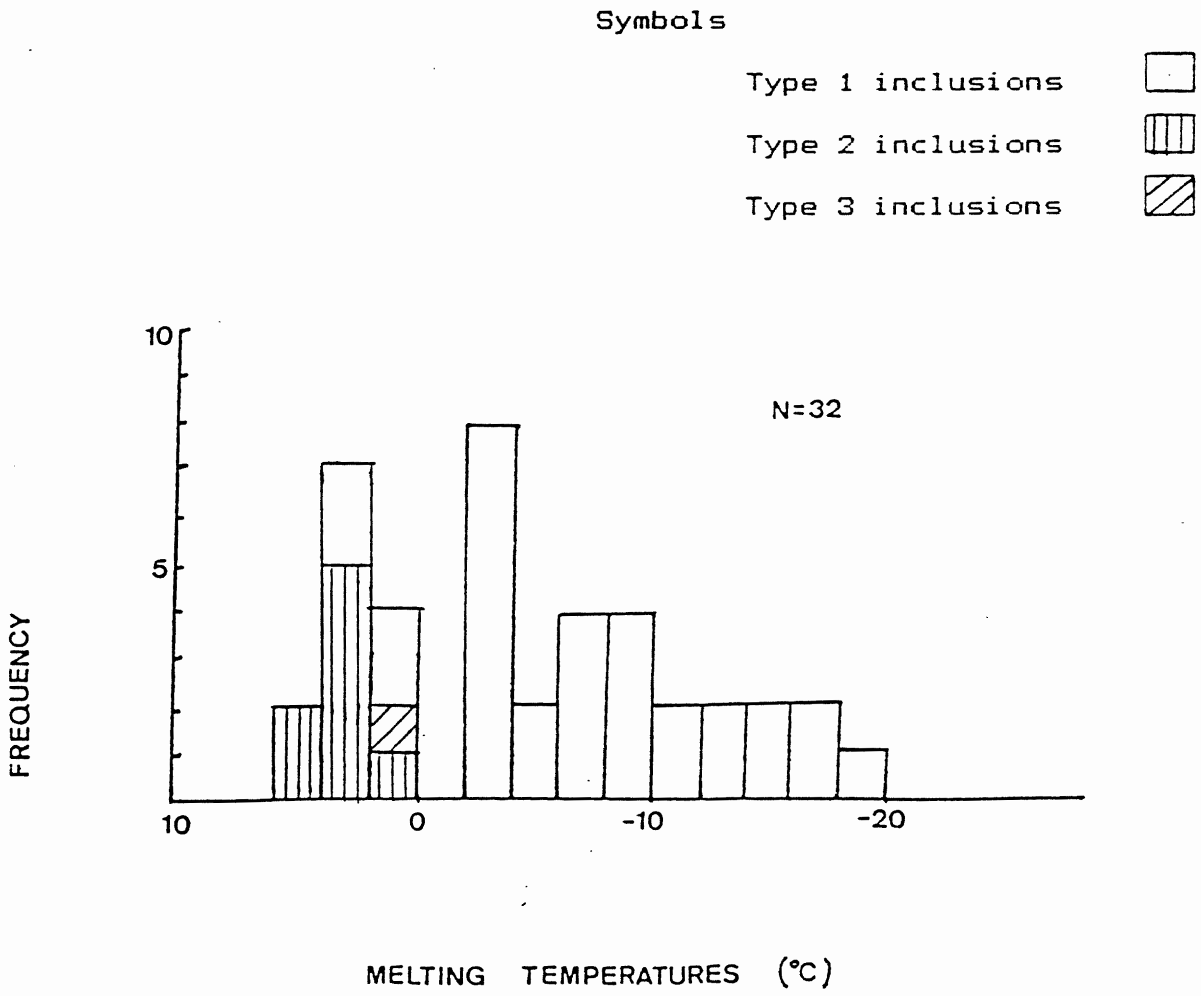

Symbols
Type 1 inclusions
Type 2 inclusions
Type 3 inclusions
10
5
FREQUENCY
N=32
10
0
-10
-20
MELTING TEMPERATURES (°C)

Figure 7.2

7.5.1 Freezing

Type 1 Inclusions

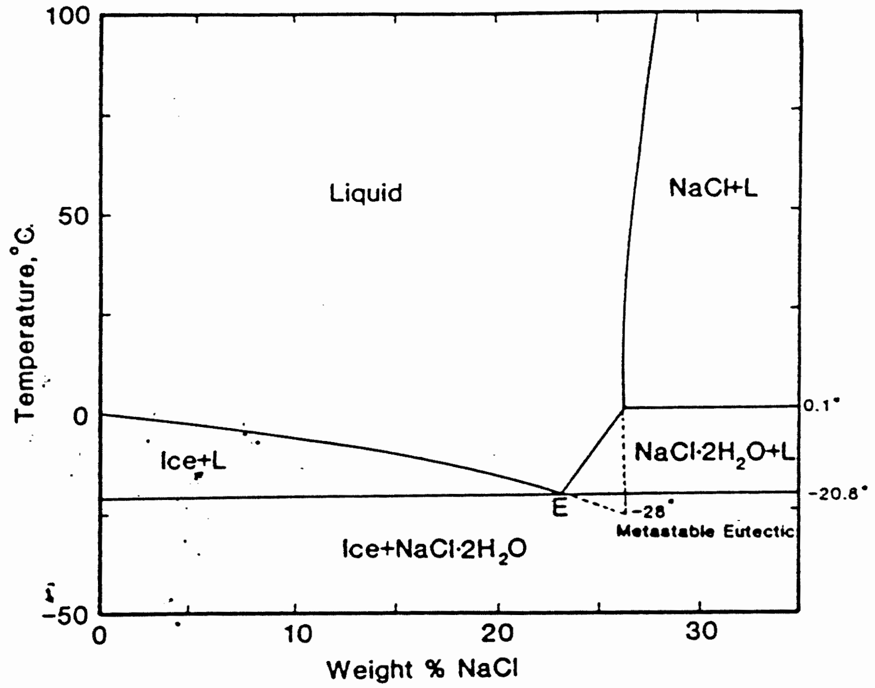
Using the depression of the melting temperature of ice method (Roedder, 1984), salinities of Type 1 inclusions, which melted below 0°C, vary from 3 to 22 wt.% NaCl; however, most inclusions have salinities between 3 and 14 wt.% NaCl corresponding to the -2 to -10 °C temperature range.

Positive melting temperatures of ice in several inclusions may reflect salinities between 23.3 and 26.3 wt.% NaCl at which levels, the solid phase hydrohalite forms upon freezing (see H_2O-NaCl phase diagram, Figure 7.3). Hydrohalite equilibrates slowly, and may persist at temperatures as high as 4°C for several hours without melting (Hollister and Crawford, 1981).

Type 2 Inclusions

The melting of the solid phase near -56.6°C indicates that these inclusions contain CO_2 (Roedder, 1984). The final melting temperatures between 0.8 and 5.4°C probably reflect the melting of clathrate (see phase diagram for the system CO_2-H_2O, Figure). Clathrate usually melts at 10.0°C, but the presence of NaCl depresses the melting point (Hollister and Crawford, 1981), indicating that dissolved NaCl is present in these inclusions as well.

Figure 7.3



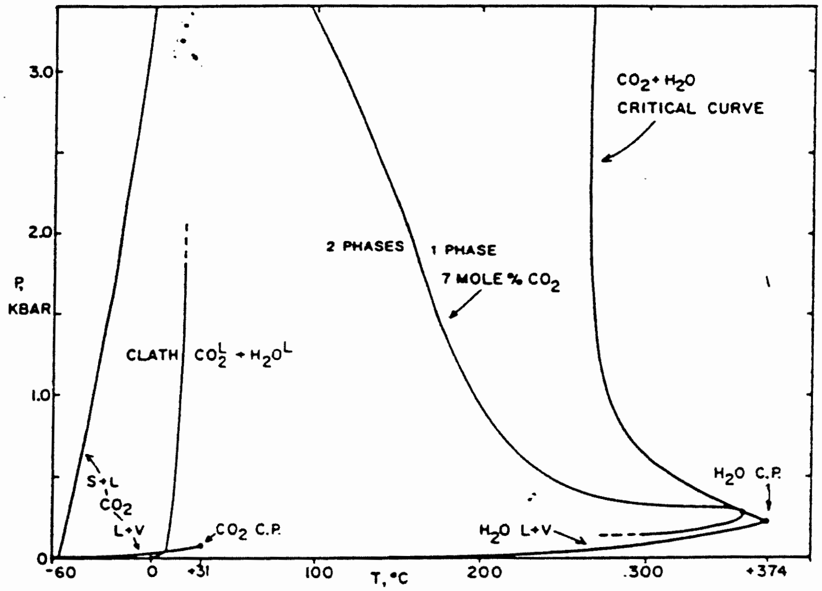


Figure 7.4

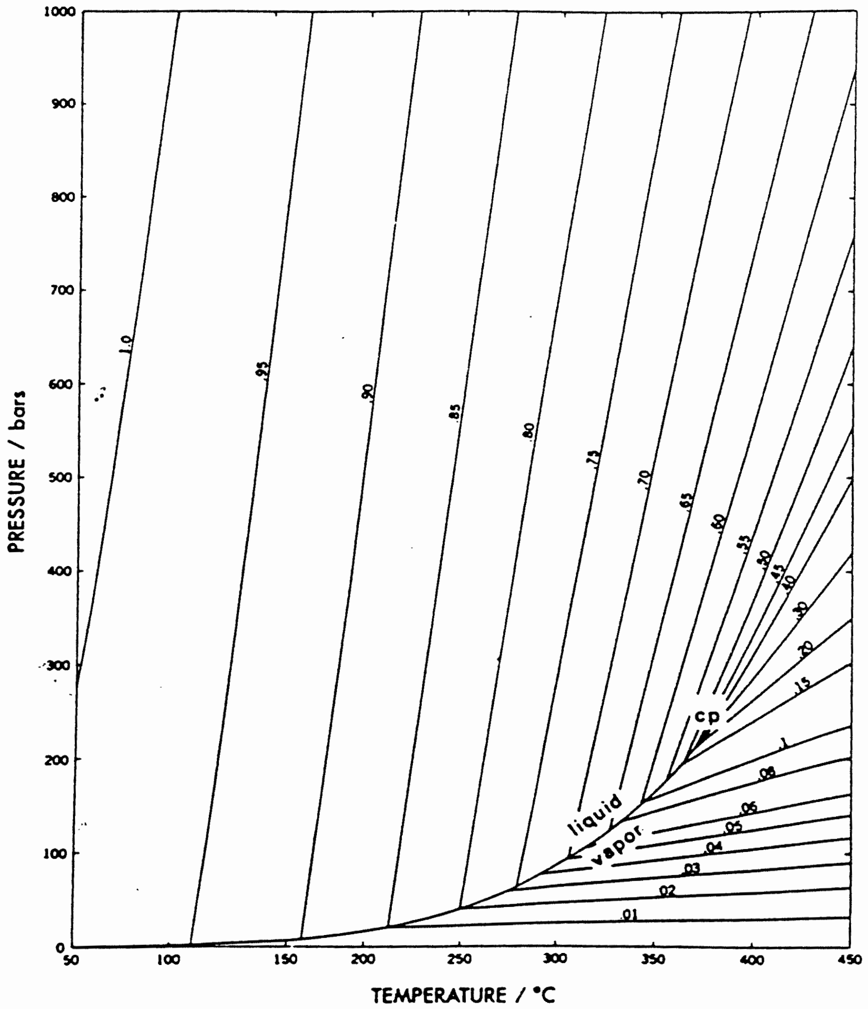
7.5.2 Heating

Because fluid inclusions generally trap a homogenous fluid, which has shrunk to form a bubble, the temperature at which homogenization to one phase occurs, represents the minimum temperature of trapping (Roedder, 1984). The histogram of homgenization temperatures (Figure 7.1), which includes decrepitation temperatures as minimum homogenization temperatures, shows a population of fluid inclusion that homogenized between 220 and 340°C. The peak from 300 - 320°C reflects the minimum temperature of formation of these veins.

The H_2O phase diagram (Figure 7.5) shows that inclusions which homogenized at 320°C, formed at minimum pressures of 100 bars, corresponding to a minimum depth of 300 m. Complex phase relations in the system H_2O-CO_2-NaCl and lack of detailed compositional data make make pressure estimates using Type 2 inclusions impossible.

The wide range of observed homogenization temperatures may be the result of a number of post-trapping processes such as necking down and microfracturing, or may be the result of several generations of veins. Low temperature inclusions with low salinities in healed microfractures indicate that microfracturing in the presence of meteoric water occurred at shallow depths.

Figure 7.5


PRESSURE / bars
1000
900
800
700
600
500
400
300
200
100
0
50
100
150
200
250
300
350
400
450
TEMPERATURE / °C
1.0
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50
.45
.40
.30
.20
.15
.1
.08
.06
.05
.04
.03
.02
.01
cp
liquid
vapor

Chapter 8. Discussion

8.1 Introduction

This chapter uses the information from the previous chapters to discuss the petrogenesis of the Kempt Snare Lake prospect. The intrusive history of the host granites, the post-intrusive history including deformation, alteration, mineralization, and finally, the nature and origin of the ore-bearing fluids are considered.

8.2 Granitic Rocks

Units 1, 3, and 4 comprise >70 % of the Kempt Snare Lake cupola, and similar grain sizes, textures, and gradational contacts between units indicate that they belong to the same intrusion. Different degrees of alteration have produced variations in the original granite (Unit 4, the medium-grained leucogranite).

Except for lower F, Rb, Fe_2O_3 (total), and Sn, and higher MgO, the leucogranite is geochemically similar to the Davis Lake leucogranite. The similar geochemistry and the proximity of the Davis Lake Pluton (Figure 1.2) indicate that the Kempt Snare Lake cupola and the Davis Lake Pluton may be comagmatic. Low K/Rb ratios (< 200) indicate that the leucogranite had significant interaction with hydrothermal fluids; however, low Rb, Li, Sn, W, Th, and high Sr concentrations suggest that it is not a tin-specialized granite.

A coarse-grained leucomonzogranite (Unit 5) occurs at the bottom of hole KS-86-2. The coarser grain-size and higher concentrations of TiO_2, Zr, Ce, and La than the leucogranite indicate that Unit 5 represents a less evolved intrusion. This unit also has a considerably higher F concentration, indicating perhaps that it formed from a F-rich melt; but because only one analysis is available, the high value can not be validated.

8.3 Intrusive History

Radiometric $^{40}Ar/^{39}Ar$ dating shows that the Kempt Snare Lake cupola intruded at least 330 Ma ago. This determination agrees with the ages, younger than the South Mountain Batholith, obtained for other southern plutons, including the 350 Ma age for the Davis Lake Pluton (Reynolds et al. 1987, 1980; Zentilli and Reynolds, 1984). The age spectra for muscovite samples from Kempt Snare Lake and the Davis Lake Pluton have similar age gradients (Zentilli and Reynolds, 1984), and appear to represent varying degrees of resetting. This interpretation supports a South Mountain Batholith age of intrusion, as suggested by

Reynolds **et al.** (1987) for most southern plutons.

8.4 Post-Intrusive History

After intrusion, many faults and some shear zones have cut the cupola. Complex age relations, suggesting a simultaneous origin of veins and faults, indicate that faulting was accompanied by the introduction of fluids.

It is probable that the faulting and veining partially reset the muscovite argon clocks. The relatively low age gradient of the muscovite sample from the highly altered rocks implies that nearly complete resetting has occurred; therefore, faulting, veining, and mineralization probably occurred ca. 300 Ma ago. This age agrees with the 300-320 Ma Hercynian Orogeny which has been well documented in the granitic rocks of the Meguma terrane (Reynolds **et al.** 1987; O'Reilly **et al.** 1985).

If resetting occurred during the Hercynian Orogeny, the ages of the inital steps in the muscovites suggest that a weaker thermal event, with a maximum age of 260 Ma, partially outgassed the rocks. The K-feldspar spectrum suggests that this event occurred ca. 220 Ma ago. This age is consistent with other dating studies in southern Nova Scotia, and has been attributed to upper Triassic dyke injection associated with the initial rifting phase of the Canadian Atlantic margin (Reynolds **et al.** 1987). A number of other interpretations have been suggested

(Reynolds et al.,1987; Kontak, 1986), but it is beyond the scope of this thesis to discuss these.

8.5 Alteration

The occurrence of the least altered units (4 and 5) in areas with few veins indicates that the fluids in the veins altered the granite. The alteration assemblages include sericitized K-feldspar and plagioclase, albitized K-feldspar and plagioclase, and complete replacement of biotite by chlorite, muscovite, and Fe-Ti oxides. Sericitization dominated and produced increases in Al_2O_3, K_2O, and Rb; and decreases in SiO_2, Na_2O, CaO, and Sr in the altered rocks. Fluid-rock interaction also produced increases in ore-forming elements (W, Zn, Sn, As) and volatiles in the altered units resulting in compositions similar to tin-specialized granites in southern Nova Scotia. Tin concentrations are lower than the tin-specialized granites; however, the isocon diagram shows that Sn appears to have been enriched by the same degree as the other ore-forming elements.

8.6 Mineralization

In addition to altering the granites, the fluids deposited scheelite, sulphides, fluorite, and carbonate in the veins and wallrock (see Figure 3.1 for paragenesis). Microprobe analyses confirmed the presence of argentiferous galena. This finding and the coincidence of high Ag and Pb values in the drill core (Falconbridge Limited, unpublished geochemical data, 1987) accounts for anomalously high silver values found by Falconbridge Limited.

8.7 Nature of Fluids

Fluid inclusions, compositions of altered units, and mineralization associated with veins indicate that the ore-forming fluids were enriched in granophile elements, sulfur, base metals, NaCl, CO_2 and other volatiles. Enrichments of granophile and depletion of granophobe elements indicate a magmatic origin for the fluids. Homogenization of fluid inclusions shows that veining occurred at temperatures $\geq$ 320 °C. High fluid temperatures and evidence for sericitization and albitization indicate that the prospect represents a greisen deposit, and that the term greisen (rock in which high-temperature (500 - 300 °C), post-magmatic fluids, high in silica and volatiles, produced alteration and deposited ores (Shcherba, 1970) for the highly altered rocks is justified.

The origin of the fluids is unknown, but it is suggested that they represent one of the following:

1. Late magmatic fluids from the Kempt Snare Lake cupola
2. Fluids associated with a southwest-trending shear or fault zone.

The composition of the fluids suggest that they are of late magmatic origin associated with the Kempt Snare Lake cupola. However, the apparent age of the mineralization is at least 30 Ma younger than the minimum age of intrusion of the cupola, meaning that the cupola had almost certainly cooled by the time mineralization had occurred. The evidence for fault-related veining, and the occurrence of numerous mineral deposits along a linear zone in the Kempt Snare Lake area (Figure 1.2) suggests that fluids, not associated with the Kempt Snare Lake cupola, exploited a major southwest-trending fault or shear zone. Highly variable fluid compositions, shown by fluid inclusion freezing data, are consistent with fluids generated by different episodes of movement along this structural zone. No evidence was found to indicate that this zone existed before the Kempt Snare Lake cupola, and acted as a structural control for emplacement, as suggested by Kontak (1986) for the East Kemptville Leucogranite.

Chapter 9. Conclusions

At Kempt Snare Lake, a leucogranite and leuconmonzogranite stock has intruded the metawackes of the Goldenville Group. ^{40}Ar/^{39}Ar dating has constrained the age of intrusion to a minimum age of ca. 330 Ma. This age agrees with the results from age dating studies of other southern plutons; however, the significance of these ages, younger than the South Mountain Batholith, is controversial (Reynold **et al.** 1987; Kontak, 1986).

Shear zones, and abundant faults and veins have cut the stock during a complex deformation event probably associated with the well-documented Hercynian orogeny 300-320 Ma ago (Reynolds et al. 1987; Dallmeyer and Keppie, 1986). Hot fluids (> 320 C) high in granophile elements, base metals, sulfur, volatiles, and containing variable salinities metasomatized the wallrocks resulting in major sericitization, albitization, biotite replacement, and increases in granophile elements and base metals. The metasomatism produced greisens with tin-specialized compositions, but tin values remained low. The reason for the tin depletion is not known.

The fluids also deposited sulphides, scheelite, fluorite, carbonate, and rare tourmaline mostly in veins but also in the wallrock. Argentiferous galena accounts for high silver values found by Falconbridge Ltd.

No incontrovertible evidence for the origin of the mineralizing fluids was found; however, veining associated with faulting at least 30 Ma after intrusion, highly variable fluid compositions, and the linear trend of mineral deposits in the Kempt Snare Lake area suggest mineralization is related to fluids from a major southwest-trending shear zone.

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Appendix A -- Unit Descriptions

Unit 1 - Black, Medium-grained, Porphyritic Greisen

Mineralogy	Quartz	K-feldspar	Plagioclase	Biotite	Muscovite
Phenocrysts % mm	2 - 5 4 - 10	1 - 2 10 - 20	< 1 5 - 10		
Groundmass (mm)	0.5 - 3.0	2.0 - 5.0	0.25 - 2.0	1.0 - 2.0	1.0
Alteration Extent (%)		sericite black sericite albite 20% (5 - 100%)	sericite black sericite 20% (5 - 100%)	muscovite chlorite Fe - Ti oxides 100%	
Textures	phenocrysts: anhedral angular equant	anhedral contains: exsolution strings icipient chessboard replacement patch subhedral plag. inclusions	subhedral blocks and laths	anhedral contain trace zircon	-interstitial subhedral -alteration product
	Cataclastic - angular, irregular grian boundaries, high alteration, deformation Igneous - interlocking plagioclase, relic biotite, K-feldspar phenocrysts				
Deformation	Sub-grain development and recrystallization in quartz Kinked muscovite (interstitial type) Microfractures, some with < 1cm displacement				
Other	Disseminated arsenopyrite common; disseminated scheelite rare Quartz "eyes" stand out because of extensive replacement of Feldspar by black sericite Unit is very heterogeneous with variations in grainsize and color				

Unit 2 - Grey - Black Fine-grained Greisen

Mineralogy	Quartz	K - Feldspar	Plagioclase	Biotite	Muscovite
% Phenocrysts mm	< 1 4 - 10	< 1 3 - 10			
Groundmass (mm)	0.5 - 1.5	1.0 - 2.0	.75 - 2.0	1.0 - 2.0	.25 - .5
Alteration Extent (%)		sericite "black sericite" albite 20% (5 - 10%)	sericite black sericite 20% (5 - 100%)	muscovite chlorite Fe - Ti oxides 100%	
Textures	subequant, anhedral,	anhedral with: exsolution strings replacement patch subhedral plag. inclusions	subhedral blocks and laths	anhedral contain trace zircon	-interstitial subhedral -alteration products
	highly cataclastic - highly altered, abundant recrystallization				
Deformation	kinked muscovite microfactures with chlorite, some with < 1cm displacement weak subgrain development extensive recrystallization				
Other	Disseminated arsenopyrite common in black unit; rare scheelite locally highly albitized				

Unit 3 - Grey, Medium-grained Greisenized Granite

Mineralogy	Quartz	K - Feldspar	Plagioclase	Biotite	Muscovite
%	2 - 5	1 - 2	< 1		
Phenocrysts mm	4 - 10	10 - 15	5 - 10		
Groundmass (mm)	2 - 3	5 - 6	.15 - 2	1.5 - 2	< 1.0
Alteration	sericite "black sericite" plagioclase	sericite "black sericite"	muscovite chlorite Fe-Ti oxides		
Extent (%)	10%	10%	100%		
Texture	anhedral, angular, equant	anhedral contains: exsolution strings incipient chessboard replacement patch subhedral plag. inclusions	subhedral	anhedral with trace zircon	-interstitial subhedral -alteration products
	Cataclastic texture, but igneous textures dominate				
Deformation	recrystallized quartz sub-grain development in quartz micro factures with < 1cm displacement bent twin planes of plagioclase				
Other	This unit is very heterogeneous and grades into units1 and 4. No disseminated arsenopyrite present				

Unit 4 - Medium-grained Leucogranite

Mineralogy	Quartz	K-feldspar	Plagioclase	Biotite	Muscovite
Phenocrysts % mm	< 1 5 - 10	< 1 10 - 15	< 1 5		
Groundmass mm	1 - 2	2 - 5	1 - 2	2 - 3 (2%)	.5 - 1.0
Alteration		sericite albite	sericite	muscovite chlorite Fe-Ti oxides	
Extent (%)		< 5%	< 5%	50%	
Textures		anhedral with abundant exsolution: strings, replacement patch, subhedral plag inclusions	subhedral blocks and laths. small plag overgrows muscovite and large plag (:, 20)	red anhedral biotite; contains some zircon	subhedral interstitial alteration grains and alteration products
	Good igneous textures however; however cataclastic textures still prevelent				
Deformation	recrystallized quartz kinked muscovite undulose extinction in quartz				
Other	This unit is less altered than units 1 - 4. Sulfides are absent. Contacts are gradutional.				

Unit 5 - coarse-grained Leucomonzogranite

Mineralogy	Quartz	K-Feldspar	Plagioclase	Biotite	Muscovite
% Phenocrysts mm					
Groundness mm	-10	10 - 20	1 - 5	3 - 5 (2 - 5%)	1 - 2
Alteration		sericite "black sericite"	sericite "black sericite"	muscovite Fe-Ti oxides	
Extent		< 10%	< 10%	50%	
Texture	anhedral; good interlocking textures	anhedral, perthite: strings replacement patch subhedral inclusions	subhedral	green-brown subhedral contains trace zircon	subhedral interstitial grains and alteration products
Deformation	sub-grain development in quartz stringers of recrystallized quartz bent twin planes in plagioclase				
Other	This unit becomes progressively more altered upwards, as veins increase. At the top, the rock is black, and biotite, completely replaced. The only observed contact was a fault				

Drill Section: Kempt Snare Lake

(Modified from Falconbridge Limited, 1987)

Symbols

∿∿∿	major faulting
∿∿∿	minor faulting
▬	quartz vein
as	arsenopyrite
fl	fluorite
cp	chalcopyrite
sp	sphalerite
ga	galena
py	pyrite
calc	calcite
sch	scheelite
sid	siderite
	overburden

NOTE: Overburden is not to scale.