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**GEOLOGY OF THE SCOTIA-QUAAL METAMORPHIC BELT
COAST PLUTONIC COMPLEX, BRITISH COLUMBIA**

by

SUSIE A. GAREAU, B.A.Sc.

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of**

Doctor of Philosophy

Department of Earth Sciences

Carleton University

Ottawa, Ontario

April 30th, 1991

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June 6th, 1991

Abstract

The Scotia-Quaal belt (SQ) comprises layered gneiss, quartzite, metasedimentary and metavolcanic units, Middle Devonian Big Falls orthogneiss, Early Jurassic metatonalite and mafic-ultramafic rocks of ≈ 115 Ma age. The assemblage correlates best with Nisling terrane and may extend north along Work Channel, south of Hawkesbury Island and west as far as the Swede Point pluton. Its eastern extent and the nature of its boundary with Stikine terrane is unknown. If it shares a common Early Jurassic history with Stikine terrane, a speculation based on the presence of Early Jurassic plutons, then no post-Early Jurassic suture exists between the SQ and the Intermontane belts.

Strong fabrics and intense folding characterize the structure. Development of strong foliation and at least three types of folds involve the Big Falls orthogneiss, but predate early Late Cretaceous Ecstall intrusion. Later deformation is restricted to the easternmost 1.5 km of the belt, increases in intensity towards the east and is associated with deformation in the Quottoon pluton, which was emplaced pre- or syn-tectonically along a plane parallel to the metamorphic fabric.

Metamorphic conditions vary between epidote-amphibolite and upper amphibolite facies (mafic), and kyanite-staurolite and high sillimanite grades (pelitic). Metamorphic temperatures increase northeasterly and pressures are around 800 MPa. The uniform pressure estimates represent peak conditions during the last regional metamorphic event which occurred approximately 110 Ma ago and indicate that no significant differential vertical movement occurred within the SQ after the end of that event. These pressures contrast sharply with pressures (≈ 500 MPa) in the Central Gneiss Complex (CGC). The SQ forms the eastern margin of a high pressure region spanning most of the western Coast

Plutonic Complex. A thermal aureole to the Ecstall pluton is noted. The thermal impact of rocks east of the SQ on the eastern margin of the belt appears intense, but short-lived.

The Work Channel structural zone does not traverse the SQ, but is located within the Quottoon pluton, near its western margin. It separates rocks with contrasting histories and is a crustal break along which Paleocene-Eocene uplift of the CGC occurred. It does not mark the boundary between Alexander and Stikine terranes.

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Introduction

The Scotia-Quaal area forms part of the Coast Plutonic Complex of British Columbia, one of five main belts composing the Canadian Cordillera (Figure 1). The Coast Plutonic Complex is a 80 to 190 km wide belt extending from southern British Columbia to southeast Alaska and the Yukon and comprising metamorphic rock and plutonic material. The crystalline belt, which roughly coincides with rugged topography of the Coast Mountains, separates the Insular from the Intermontane belt.

Monger et al. (1982) have interpreted the Coast Plutonic Complex as resulting from mid-Cretaceous collision between two composite terranes (approximately correspondent to the Insular and Intermontane belts) separated by subducting oceanic lithosphere. Brew and Ford (1983) introduced an alternative model in which the "two large composite allochthonous terranes were one and the same" and were separated through rifting during northward movement prior to Late Jurassic time, to be reunited in Late Cretaceous through early Tertiary time. A model by van der Heyden (1989) is similar to the scenario presented by Brew and Ford (1983) in that it involves the Late Jurassic break up of a single allochthonous megaterrane emplaced against the western margin of North America in Middle Jurassic time. van der Heyden (1989) interprets middle Cretaceous magmatism to have been accompanied by widespread crustal shortening across the Coast Plutonic Complex, and infers Eocene magmatism to have been accompanied by crustal extension, which may have continued into late Tertiary time. Within the framework of van der Heyden's scenario, there are no Cretaceous sutures in the Coast Plutonic Complex. If, however, a suture zone between two composite terranes or two parts of one composite terrane exists, then it is inferred to lie somewhere in the high grade core of the Coast Plutonic Complex.

Figure 1: Map showing the morphogeological belts of the Canadian Cordillera (After Gabrielse and Yorath, 1989). Black rectangle shows the location of the Scotia-Quaal metamorphic belt.

The Scotia-Quaal belt is a medium to high grade metamorphic belt of the Coast Plutonic Complex, located in the Prince Rupert and Douglas Channel map areas (Roddick, 1970 and Hutchison, 1982). The north-northwest trending, 10 to 15 km wide belt extends from Hawkesbury Island to Work Channel (approximately 53°30' to 54°30') and is bounded by the early Late Cretaceous Ecstall pluton (van der Heyden, personal communication 1991; Woodsworth et al., 1983) on the west and by the Paleocene to Eocene Quottoon pluton (Armstrong and Runkle, 1979; this study, chapter 3) on the east (Figure 2).

The Scotia-Quaal metamorphic belt is located along the southern extrapolation of a major topographical feature known as Work Channel which parallels the structural grain of the Coast Plutonic Complex at this latitude and is interpreted as the expression of a major ductile shear zone (Crawford et al. 1987; Crawford and Crawford 1990) of Late Paleocene to Early Eocene age, based on the inference that deformational features in the Quottoon pluton were formed during syn- and/or post- emplacement deformation in a Work Channel structural zone. The presence of a major structural boundary in this region is postulated because of differences in K-Ar cooling dates (for most recent summary see van der Heyden 1989) and contrasting structural styles and metamorphic histories (Crawford et al. 1987) on either side of rocks hosting the Work Channel lineament. The Work Channel structural zone is inferred to extend into southeastern Alaska along the Coast Range megalineament (Brew and Ford, 1978).

The Work Channel structural zone is believed by many to have played an important role in the overall tectonic history of the Coast Plutonic Complex. It has been alternatively interpreted as the surface expression of the contact between intrusive rocks and gneisses of the Coast Range complex and schists to the southwest (Brew and Ford 1978); as a major crustal break along which Paleocene to Eocene uplift of the Central Gneiss Complex

Figure 2: Generalized geological map of part of the Coast Plutonic Complex between latitudes 53°20' and 55°N. After Roddick (1970), Hutchison (1982) and Gareau (1991).

occurred, probably through reactivation of an older fault along which there might have been strike-slip movement (Crawford and Hollister 1982): as one of several major steep to vertical shear zones formed during Paleocene to Eocene uplift of the Central Gneiss Complex (Crawford et al. 1987); as a suture between Alexander/Wrangellia superterrane on the west and crustal blocks to the east (Crawford and Crawford 1990); and as the western boundary of an Eocene intra-arc metamorphic core complex (van der Heyden 1989; also refer to Heah 1990 and 1991 for discussion of extensional structures on the eastern side of the Central Gneiss Complex).

The objectives of the present study were to define and describe the lithological composition and age of the Scotia-Quaal belt, characterize the metamorphism of the belt, seek the southern continuation of the Work Channel structural zone and examine the regional significance of the metamorphic and young deformational history of the Scotia-Quaal belt.

Approximately five months were spent in the study area during the summers of 1987, 1988 and 1989. Mapping was done at the 1:50 000 scale and maps were released as Geological Survey of Canada Open Files (Gareau, 1991) in early 1991. The area is accessible by helicopter from Terrace or Prince Rupert and sections along the Skeena River and Douglas Channel can be reached by boat. The northernmost part of the study area is accessible via highway 16 and a logging road leading to the southern end of Work Channel.

Previous work

Previous work in and in the vicinity of the Scotia-Quaal area include reconnaissance shoreline mapping in the Central Coast Mountains between 53 and 56°N by Dolmage (1922 and 1923), mapping of the Ecstall-Quaal Rivers area by Padgham (1958) and of

Hawkesbury Island by Money (1959) and detailed studies of the Ecstall massive sulphide deposit and the surrounding area by Holyk (1952) and Douglas (1953). The Douglas Channel - Hecate Strait and the Prince Rupert-Skeena areas were mapped at 1:250 000 scale between 1962 and 1966 (Hutchison, 1967, 1970 and 1982; Roddick, 1970). Topical studies include those of Symons (1974, 1977a and b), Margaritz and Taylor (1976) and Smith et al. (1979).

More recent mapping performed within the framework of M.Sc and Ph.D. projects include mapping along Douglas, Sue and Loretta Channels (Runkle, 1979), in the Khtada Lake area (Kenah, 1979), in the Khutzeymateen area (Douglas, 1983 and 1986), in the Redcap Mountain area (Hill, 1984), on the Scotia property (Krage, 1984) and in the vicinity of the Ponder pluton (Sisson, 1985). An M.Sc project in the Shames River area is in progress (Heah, 1990).

References for previous metamorphic and geochronologic studies are given in the chapters dedicated to these topics. Recent synthesis papers were published by Crawford and Hollister (1982) and Crawford et al. (1987).

Chapter 1 - Lithological character and deformation

1.1 Description of lithologies

Eight main lithologic units define the long and narrow, 350° trending Scotia-Quaal belt. The geographical distribution of units is summarized in Figure 1-1 and shown at 1:50 000 scale in Appendix 1 which also contains station location maps and cross sectional sketches for the Scotia-Quaal area.

Although the Scotia-Quaal belt is a continuous entity from south to north, it has been subdivided into three regions (northern, central and southern; see Figure 1-1) to facilitate discussion of south to north variations in lithological characteristics, structural features and metamorphic grade.

Pre-late Early Jurassic units

Middle Devonian Big Falls orthogneiss

The Middle-Devonian (Gareau, 1989 and Chapter 3) Big Falls orthogneiss is a well-foliated tonalitic augen gneiss which extends along the western margin of the metamorphic belt in the southern and central regions. Rock composition, compositional homogeneity throughout the body and the presence of euhedral, clear and colorless zircons of typical igneous shape suggest an intrusive, rather than sedimentary origin for the Big Falls augen gneiss. Fine grained amphibolitic inclusions constitute less than 3% of the unit. The typical medium grain size of the orthogneiss decreases to the east towards the contact with adjacent metavolcanic rocks.

The orthogneiss contains varying amounts of biotite and hornblende. Andesine is generally slightly coarser grained than the other minerals and forms augen. Muscovite occurs in association with biotite and with andesine; where associated with plagioclase, muscovite occurs as porphyroblasts growing across the foliation. Garnet, epidote, chlorite and calcite are locally present in trace amounts. Accessory minerals include titanite, apatite and zircon. (See chapter 3, sample 87-172-2 for thin-section description of a typical sample).

A well-developed foliation is defined by alignment of mafic minerals and very fine (mm scale) compositional layering of felsic and mafic minerals. Mafic inclusions are oblate in shape and parallel the foliation. Concordant quartz veins (1 to 2 cm wide), and foliated and folded amphibolite dykes are locally present.

In the northern region, a weakly foliated quartz dioritic rock outcropping within the layered gneiss unit (See Appendix 1A) over an area less than 100 meters in diameter was found to be of Paleozoic age (See Chapter 3, sample 88-140-2) and could correlate with the Big Falls orthogneiss.

Paleozoic? metavolcanic unit

The Big Falls orthogneiss grades into a metavolcanic unit along a zone which is marked by gradual eastward decrease in grain size accompanied by decrease in hornblende and increase in biotite contents. In the same zone, mafic layers occur in metamorphic rock of intermediate composition and also increase in abundance towards the east. The approximately 700 m wide zone between unequivocal Big Falls orthogneiss and the metavolcanic unit could mark a transition from cogenetic high-level intrusive to extrusive rock.

The metavolcanic unit consists of mafic and intermediate metavolcanic rocks interlayered with minor metasedimentary and felsic metavolcanic rocks. The mafic

component of the unit is a fine grained amphibole $\pm$ chlorite schist which locally retains fragmental texture (Plate 1A). Mineral assemblages in mafic volcanic rocks are discussed in Chapter 2, Section 3 (See specifically Figure 2-3, Table 2-1 and Appendix 4B). Intermediate metavolcanic rocks are biotite quartzofeldspathic semi-schist of varying, but generally fine grain size. In the southern and central regions of the Scotia-Quaal belt, the intermediate component makes up less than 40% of the metavolcanic unit, but it is the dominant rock type (>60%) in the metavolcanic rocks of the northern region. Minor quartzite, semi-pelite to pelite, marble and quartz-rich semi-schist of probable volcanic origin are interlayered predominantly with the mafic volcanic rocks.

The metavolcanic unit hosts small metamorphosed volcanogenic massive sulphide bodies containing pyrite and minor sphalerite, marcasite, galena and chalcopyrite. The location of these mineral deposits is shown on the 1: 50 000 geological maps located in Appendix 1B. Away from the deposits, disseminated pyrite is commonly present in the metavolcanic unit, but does not exceeds 5%.

All metavolcanic rocks are strongly foliated; the foliation is defined by alignment of sheet silicates. Aligned mafic minerals and stretched volcanic fragments define a lineation.

In the northern region, chlorite does not occur in the metabasic component of the unit and fragments were not observed. In addition, the unit is migmatitic.

Metasedimentary unit

The metasedimentary unit bounds the east side of the metavolcanic unit and the western margin of the Big Falls orthogneiss. Along Douglas Channel, the metasedimentary unit is in gradational contact with the metavolcanic unit. It is difficult to evaluate the width of this contact zone, so subtle is the west to east change from an amphibole-chlorite schist, to a mafic semi-schist, and finally a mafic to intermediate gneiss. This is in contrast with the very sharp contact between the same two units in the central region. On the ridge north of

PLATE 1

A) Fragmental texture in mafic metavolcanic unit.

Most fragments consist of fine grained, green metavolcanic rock. A few fragments are made up of a feldspar porphyry rock. The matrix is a biotite-chlorite schist containing porphyroblasts, up to 1 cm in size, of hornblende with tremolite cores.

The outcrop is located along a logging road following Kitkiata Creek (Station # 89-16).

B) Metasedimentary clastic unit.

Epidote-rich clasts dominate, but granitoid clasts are also present. The matrix consists of fine to medium grained, epidote-rich hornblende-biotite gneiss. The prolate fragments are parallel to the regional lineation and mafic minerals define the foliation.

The outcrop is located on a ridge immediately north of Johnson Lake (Station # 88-82).

C) Intensely folded quartzite unit.

At this location, the unit consists exclusively of quartzite. Elsewhere, semi-pelitic and pelitic rocks are interlayered with the quartzite.

This outcrop is located on the ridge south of the Ecstall deposit (Station # 89-97).

D) Layered gneiss unit

The dark layers consist of medium grained (garnetiferous) amphibolite and the lighter grey layers, of epidote-rich hornblende-biotite-plagioclase gneiss.

The outcrop is located on a ridge southeast of the Ecstall River (Station # 87-231).

Johnson Lake (Appendix 1A), a sharp contact separates the metasedimentary unit and Big Falls orthogneiss.

The unit consists of fine to medium grained, epidote-rich hornblende-biotite gneiss locally containing rounded epidote-rich and granitoid clasts (Plate 1B). The proportion of mafic minerals (biotite, hornblende and epidote) is highly variable, between approximately 20 and 70%. At one location, salite was observed in hornblende cores (See Chapter 2, Section 3, sample # 88-84-3). Garnet is locally present as euhedral to anhedral porphyroblasts (See for example, sample # 89-106-3, Chapter 2, Section 4). The quartz and plagioclase (oligoclase to andesine) content varies. Accessory minerals include apatite, titanite and magnetite. Carbonate is locally present, mostly in the quartzite zone between this unit and the quartzite unit.

Prolate clasts are approximately 10 cm in length and have a length-to-width ratio anywhere between 2:1 and 10:1. Locally, they make up approximately 10% of the rock. On the ridge immediately north of Johnson Lake, where a thick section of this unit is present, bands containing fragments are approximately 300 metres in width and are interlayered with nonfragmental bands of approximately 1 km width. Alternating fragmental and nonfragmental bands are possibly the result of folding of the unit.

Prolate fragments are parallel to the regional lineation. Mafic minerals define a strong foliation.

Quartzite unit

On both sides of the belt, the metasedimentary clastic rocks are in gradational contact with a layered quartzite unit (Plate 1C). The 20 to 100 metre wide contact zone is marked by an increase in carbonate content in both units, a decrease in grain size in the clastic metasedimentary unit as well as a decrease in the proportion of quartzite layers and increase in the proportion of grey weathering biotite semi-schist (See Plate 2D) in the quartzite unit.

The quartzite unit comprises white to grey, locally pyritiferous quartzite interlayered with lesser amounts of biotite-hornblende gneiss, fissile mica schist, black phyllite to meta-argillite, semi-pelite to pelite and marble. Compositional layering is parallel to the mafic mineral foliation. Rare concordant amphibolite bands in the unit are interpreted as dykes.

The quartzitic rock is composed chiefly of granoblastic quartz (>90%) and fine grained biotite occurring predominantly in very thin (≤ 1 mm) layers parallel to the foliation. Biotite also occurs in trace amounts interstitially to quartz grains and as inclusions in quartz. Locally, quartzite contains minor plagioclase, zoisite, cummingtonite, muscovite and carbonate.

The term "quartzite" is herein used in a metamorphic sense to refer to a granoblastic rock consisting mainly of quartz (See for example Winkler, 1979 and Williams et al., 1982), rather than in the sedimentological sense of a very hard sandstone consisting chiefly of quartz grains cemented with secondary silica (Bates and Jackson, 1987). The quartzitic rock is tentatively interpreted as a metamorphosed sandstone rather than a metachert or metarhyolite, because on the one hand it locally contains potassium- and calcium-bearing minerals characteristically absent from chert, and on the other hand it is more siliceous than a typical metarhyolite.

Biotite-hornblende gneiss locally present in the quartzite unit is composed predominantly of oligoclase to andesine, quartz, hornblende and biotite. Epidote and garnet occur locally. Accessory minerals include titanite, apatite, zircon and an opaque mineral. Semi-pelitic and pelitic rocks are discussed in details in Chapter 2, Sections 3 and 4. A list of semi-pelitic and pelitic mineral assemblages is given in Appendix 4A. Coarse (≈ 5 mm), crystalline carbonate (probably calcite) composes the marble.

The quartzite unit is in sharp contact with a layered gneiss occurring along the eastern margin of the Scotia-Quaal metamorphic belt.

Layered gneiss unit

In the northern region, the contact between the quartzite and layered gneiss units is marked by a decrease in quartzite abundance and an increase in proportion of semi-pelitic to pelitic gneisses in the quartzite unit. These gneisses in turn gradationally change composition such that biotite becomes less abundant and hornblende appears in the assemblage and increases in abundance. The transition zone between the two units is approximately 500 metres wide. In the southeastern part of the belt (Figure 1-1 and Appendix 1A), the quartzite unit is missing from the sequence and the sharp contact between the metasedimentary and layered gneiss units is almost perpendicular to the foliation and to compositional layering in the rest of the belt; this suggests that the contact may represent a fault.

The well-layered gneiss (Plates 1D and 2A) consists of fine to medium grained epidote-bearing hornblende-biotite quartz dioritic to granodioritic gneiss interlayered with amphibolite and varying proportions of leucocratic rock. Rare epidote-garnet pods occur locally.

The light to dark grey quartz dioritic to granodioritic layers are composed predominantly of quartz, oligoclase to andesine, hornblende and biotite in various proportions. Zoisite and garnet occur locally, as well as retrograde chlorite and sericite. Accessory minerals include titanite, an opaque mineral and locally rutile. Finer grained layers are slightly more mafic than the other quartz dioritic to granodioritic layers. These other layers vary in grain size and composition, and generally contain more biotite than hornblende.

Medium grained garnet amphibolite bands contain more than 55% mafic minerals (hornblende, biotite and chlorite) and lesser amounts of garnet, quartz and oligoclase to andesine. Coarse hornblende bands are rare.

PLATE 2

A) Layered gneiss unit in northern region.

At this location, the unit is migmatitic with abundant leucosome and biotite-rich selvages. This outcrop is located on the ridge immediately west of Khtada Lake (Station # 89-71).

B) Contact between the mafic-ultramafic and the quartzite units.

The dark, rusty weathering hornblende gabbro and coarse hornblendite on the left-hand side intrudes and deforms the quartzite unit on the right-hand side. Folding in the quartzite is tightened near the contact between the two units. The outcrop is located on the ridge south of the Ecstall deposit. The photo was taken from station # 89-97 looking to the northeast.

C) Contact between the Ecstall pluton and the Scotia-Quaal metamorphic belt on Hawkesbury Island.

At this location, the Ecstall quartz diorite (above the dashed line) cross-cuts and overlies metamorphic rocks of the Scotia-Quaal belt (below the solid line). Dykes occur in a contact zone (between the two lines) between the Ecstall pluton and the steeply-dipping foliated metamorphic rocks.

This photo was taken from station # 89-141 looking north.

D) Refolded isoclinal folds.

Isoclinal F_i and moderately open F_m folding in carbonate-rich biotite semi-schist within the contact zone between the metasedimentary and quartzite units.

This outcrop is located on the ridge south of the Ecstall deposit (Station # 89-99).

Minor leucocratic pegmatitic layers occur in the southern and central regions (Plate 1D). In the northern region, the unit is migmatitic with abundant leucosome and biotite-rich selvages (Plate 2A). This difference in appearance is a striking example of the south-north change in appearance exhibited by all units to a greater or lesser degree.

Well-defined compositional layering (Plates 1D and 2A) is partly attributed to segregation during metamorphism, but the consistency of layering (at tens of cm scale) suggests that it may be partly depositional in nature.

Geological relationship among pre-late Early Jurassic rocks

The primary nature of contacts between the pre-late Early Jurassic units is obscured by subsequent deformation and metamorphism. Contacts are interpreted to be depositional based on their gradational character at many locations. The contact zones are not only marked by gradational changes in grain size and minor mineralogical changes, which could result from metamorphism, but also by important changes in bulk composition which could not solely have been produced by metamorphism. Examples are the decrease in quartzite abundance in the quartzite unit as the layered gneiss unit is approached and the appearance of abundant carbonate in the contact zone between the metasedimentary clastic and quartzite units.

At least four geological reconstructions of the pre-late Early Jurassic rocks are possible (Figure 1-2). The first reconstruction (Figure 1-2A) involves deposition and/or juxtaposition along depositional contacts and/or faults, of the layered gneiss, quartzite and metasedimentary units prior to emplacement of comagmatic(?) Big Falls orthogneiss and metavolcanic unit in the Middle Devonian. Such a reconstruction is supported by the gradational nature of the contact between the Big Falls orthogneiss and the metavolcanic unit, as well as by the map pattern which suggests that the stacking order of units is as shown in figure 1-2A. The current stacking order may, however, have been achieved

through deformation. Evidence against pre-Middle Devonian ages for all units is the presence of wood fossils in strata north of Johnson Lake, which suggests that at least some units are post-Late Silurian in age (See Section 1.2 for discussion).

Alternatively, the Big Falls orthogneiss and metavolcanic units may be the oldest units present in the area (Figure 1-2B). The overlying metasedimentary unit, which may have been derived from the volcanics themselves, would have been deposited nonconformably on the eroded intrusive part of the magmatic complex followed by deposition of the quartzite and layered gneiss units. This reconstruction requires emplacement of the magmatic complex into as yet unrecognised country rocks, uplift and cooling, erosion of part of the complex and deposition of the three overlying units between Middle Devonian time and Early Jurassic magmatism. The same stacking order could result from faulting between Middle Devonian and Early Jurassic time; in such a case the stacking order may not coincide with the relative age of units.

Figure 1-2: Sketches illustrating possible geological reconstructions for the pre-late Early Jurassic units in the Scotia-Quaal area. In (A) the stacking order is, from lowest to highest: layered gneiss unit; quartzite unit; metasedimentary unit; and comagmatic(?) Middle Devonian Big Falls orthogneiss and metavolcanic unit. The scenario implies a Middle Devonian or older age for all units. In (B), the order is reversed and juxtaposition of units postdates the Middle Devonian intrusion of the Big Falls body. If the metavolcanic unit and the Big Falls orthogneiss are not comagmatic, the evolution would be one of two shown in C and D. All units would have been juxtaposed prior to Middle Devonian emplacement of the Big Falls orthogneiss at the contact between the metasedimentary and the metavolcanic units. Juxtaposition of units could be the result of depositional or faulting processes. Neither the initial shape of the Big Falls body, nor facts about deformation prior to Big Falls intrusion are known.

The third and fourth (Figure 1-2C and D) hypotheses consider the cases in which the metavolcanic unit and the Big Falls orthogneiss are not comagmatic. In this case, the Big Falls orthogneiss might have intruded the original sequence along the contact between the volcanic and the clastic metasedimentary units or may have been faulted into this position.

Mesozoic units

Mesozoic rocks include the late Early Jurassic (Gareau, 1989 and Chapter 3) Johnson Lake and Foch Lake metatonalitic bodies that intrude the eastern part of the Scotia-Quaal belt and mafic and ultramafic rocks of probable Jurassic or Cretaceous age (Figure 1-1).

Johnson Lake orthogneiss

The Johnson Lake orthogneiss is a small body of medium grained, epidote-bearing biotite-hornblende metatonalite which occurs in the central region within the quartzite unit and along the contact between the quartzite and metasedimentary units. The orthogneiss is in sharp contact with surrounding units. The small metaintrusive body is elongated parallel to the regional fabric except at its northern end where it is slightly wider (750 metres versus less than 500 metres) and truncates the surrounding country rock.

The orthogneiss is composed mainly of andesine, quartz, hornblende and minor biotite. Accessory minerals include zoisite, titanite, an opaque mineral and zircon (See Chapter 3, sample 87-139-5 for petrographic description of a typical sample)

Alignment of hornblende defines a strong lineation; mafic minerals define a foliation which varies from strongly developed at the southern end of the body to weakly developed at the northern end.

Foch Lake orthogneiss

The Foch Lake orthogneiss is a medium grained, epidote-bearing biotite metatonalite. The metamorphosed pluton is an irregularly-shaped bulbous body with narrow tails

stretching to the north and south parallel to the regional structural grain. It transects the contacts between the metavolcanic, metasedimentary and layered gneiss units (Figure 1-1 and Appendix 1A). Its contact with surrounding rocks is sharp and folded by moderately open, 1 to 5 metre amplitude structures interpreted as Fm folds (See this chapter, Section 3)

The presence of large plagioclase phenocrysts (up to 5 cm in length) characterizes this unit. The orthogneiss is composed of plagioclase, quartz, epidote and biotite, as well as accessory titanite, apatite, an opaque mineral and zircon. A petrographic description is given in Chapter 3 (sample 88-108-2).

Intensity of the mafic mineral foliation varies from strong to weak. The lineation is generally weak and is marked by stretching of rare small epidote pods.

Jurassic or Cretaceous mafic and ultramafic plutonic rocks

Coarse grained, locally weakly lineated hornblende diorite, gabbro and associated rusty weathering coarse hornblende occur sporadically throughout the central region of the Scotia-Quaal belt (See Appendix 1B). This mafic-ultramafic complex occurs as bodies of various shapes; these both cross-cut and deform their host (Plate 2B). Locally, rare xenoliths of foliated gneiss occur in the mafic diorite.

In a thin-section from a gabbroic sample, plagioclase is subhedral, shows abundant twinning and varies in An content between 0.51 and 0.62. A few grains are weakly zoned. Plagioclase is sericitized and contains abundant fine grained epidote. Hornblende is euhedral, shows rare twinning and reaches 5 mm, but is generally approximately 1 mm in length. It contains fine opaque inclusions and is associated with an interstitial opaque mineral that reaches 0.4 mm in size. The opaque and epidote minerals each make up approximately 2% of the sample.

The absence of fabric in the rock suggests that the unit is unmetamorphosed because regional deformation is interpreted to have accompanied the last regional metamorphic event

(See Chapter 2, Section 6). The presence of twinning in both plagioclase and hornblende is consistent with this inference because twinning does not tend to be abundant in these minerals when formed during metamorphism (Williams et al., 1982).

The emplacement age of this unit is unknown, but it is inferred to be relatively young based on the absence of strongly developed fabrics and on its relationship with the host rocks. It may be coeval with intrusion of the Foch and Johnson Lake metatonalites or may have been emplaced subsequently, but prior to intrusion of the Ecstall pluton which, on the ridge south of the Ecstall deposit (Appendix 1A), cross-cuts rocks of this unit. This inference is in agreement with a 115 Ma hornblende K-Ar date obtained from a coarse hornblendite and interpreted as the minimum age of the unit (See Chapter 3). Small metamorphosed ultramafic bodies present in other parts of the Coast Plutonic Complex at the latitude of Terrace-Prince Rupert (Kenah 1979; Douglas 1983) are of unknown age. Ultramafic rocks in this part of the Coast Plutonic Complex may have been emplaced concurrently with late Early Cretaceous mafic and ultramafic plutons of the western metamorphic belt in southeastern Alaska (Brew et al. 1989). They could also be equivalents of mafic components of Jurassic Black Dome and Tahtsa Complexes (van der Heyden 1989) located at the eastern margin of the Coast Plutonic Complex, in the Whitesail Lake area. Another possible equivalent is the McCauley Island gabbro-diorite complex inferred to be at least as old as early Cretaceous (van der Heyden, 1989).

Bounding plutons

Early Late Cretaceous Ecstall Pluton

The early Late Cretaceous (van der Heyden, personal communication 1990; Woodsworth et al., 1983) Ecstall pluton intrudes the western margin of the Scotia-Quaal metamorphic belt (Figure 1-1). The pluton consists of a medium grained epidote-bearing

hornblende-biotite quartz diorite associated, in the southern part of the belt, with minor amounts of foliated, fine grained, epidote-free, leucocratic garnet-biotite quartz diorite.

The medium-grained epidote-bearing quartz diorite is generally composed of quartz, oligoclase to andesine plagioclase, hornblende, biotite, epidote, titanite, apatite, zircon and an iron oxide mineral. Potassium feldspar, calcite and muscovite occur locally.

Petrographic descriptions of 4 samples used for Al-in-hornblende geobarometry are presented in Chapter 2, Section 5. Epidote is euhedral to anhedral and shows textural relations between epidote and other minerals identified by Zen and Hammarstrom (1984) as characteristic of magmatic epidote. Locally, epidote is euhedral against biotite, contains hornblende inclusions and shows highly embayed, wormy, almost symplectic contacts with quartz and plagioclase.

In the Scotia-Quaal area, the Ecstall pluton is homogeneous and generally unfoliated except within 1 km (but generally less than 300 m) of its margin, where foliation defined by alignment of mafic minerals parallels the contact and increases in intensity towards it. Lineation is locally present.

The pluton's contact with the metamorphic rocks of the Scotia-Quaal belt is generally sharp and discordant. In the northern part of the belt, apophyses of generally unfoliated Ecstall igneous rock extend several kilometres into the belt and locally follow the fold pattern of the metamorphic units (Appendix 1A). The Ecstall contact becomes increasingly discordant to the south. On the west side of Hawkesbury Island, the steep contact zone appears to bend 90° towards the east and becomes horizontal so that intrusive rocks overlie, along ridge tops, the steeply foliated rocks of the Scotia-Quaal metamorphic belt (Plate 2C). There, the contact zone consists of a swarm up to 600 meter wide of dykes intruding the metamorphic rock and cutting each other (Plate 2C). At sea level, parts of the steep contact

zone are also characterized by the presence of a dyke complex up to three kilometres in width.

Late Paleocene-Early Eocene Quottoon pluton and dykes

The Scotia-Quaal belt is bounded on the east by the Late Paleocene to Early Eocene (Armstrong and Runkle, 1979; Gareau, 1989 and Chapter 3) Quottoon pluton composed of medium to coarse grained hornblende quartz diorite to tonalite. The dominant minerals are andesine, quartz, hornblende and biotite. Apatite, an opaque mineral and zircon occur as accessory constituents (See Chapter 3, Section 3 for petrographic description of sample 87-246-1). Fine to coarse grained amphibolitic inclusions are dispersed throughout the Quottoon pluton.

The contact between plutonic and metamorphic rocks is gradational, with bands of metamorphic rocks occurring within the Quottoon pluton for several km. At a few locations a zone, up to 100 m wide, of amphibolite occurs between the metamorphic rocks and the first appearance of Quottoon tonalite. The contact zone is concordant with the regional trend; foliation and lineation in the Quottoon pluton parallel the fabrics present in the Scotia-Quaal belt. In the northern region, lineation is absent from the Quottoon and a felsic, medium grained, biotite $\pm$ garnet-bearing igneous phase is associated with the biotite-hornblende intrusive rock.

Leucocratic, coarse grained to pegmatitic, epidote-biotite quartz dioritic dykes of approximately the same age (Gareau, 1989 and Chapter 3) and apparently related to the intrusion of the Quottoon pluton occur in the easternmost 2.5 km of the Scotia-Quaal metamorphic belt. These dykes increase in abundance and degree of deformation towards the Quottoon pluton. The dyke rock contains mainly oligoclase to andesine, quartz and less than 10% biotite. Accessory minerals include zoisite, apatite, allanite, an opaque mineral

and zircon. A petrographic description of a foliated leucocratic dyke is given in Chapter 3, Section 3 (Sample 87-140-2).

On the eastern side of the northern region (See Appendix 1A), two medium grained, homogeneous garnet-biotite quartz dioritic dykes, each approximately 30 m wide, sharply cross-cut metamorphic rocks on the eastern side of the Scotia-Quaal belt. Metamorphic foliation is slightly deflected close to the dyke contacts. These dykes are at least as young as the Quottoon pluton and probably younger since they are undeformed even within 1 km of the Quottoon pluton, where other dykes in the metamorphic belts show late deformational features probably coeval with deformation in the Quottoon pluton. A few late, fine-grained hornblende porphyritic lamprophyre dykes cross-cut the metamorphic rocks throughout the area.

1.2 Terrane affiliation of the Scotia-Quaal strata

The ages and terrane affiliation of most supracrustal rocks in the Coast Mountains at the latitude of the study area are poorly known, largely because of the metamorphic overprint and lack of fossils. Roddick (1970) and Hutchison (1982) favoured a pre-Permian age for much of the Central Gneiss Complex and a Paleozoic to early Mesozoic age for metavolcanic and metasedimentary strata. Useful fossils have been found in only three localities. Woodsworth and Orchard (1985) showed that strata on islands west of Prince Rupert range in age from Mississippian to Early Jurassic and represent the extension into British Columbia of Alexander terrane strata exposed in southeastern Alaska (Figure 1-3). Poorly preserved crinoid stems in migmatites (Hill, 1985) and upper Paleozoic fossils in marble of the Central Gneiss Complex suggest that rocks are Late Paleozoic in age and may correlate with Stikine terrane (Hill et al., 1985).

Figure 1-3: Terrane map of northwestern British Columbia, southwestern Yukon Territory and southeastern Alaska. (After Gabrielse and Yorath, 1989)

Prior to this study, the only known constraints on the age of strata in the Scotia-Quaal belt were the mid Cretaceous age of the cross-cutting Ecstall pluton (van der Heyden, personal communication 1991 and Woodsworth et al., 1983) and the presence of indeterminate fossil remains in the central region of the Scotia-Quaal area (Roddick, 1970). These fossils (GSC Loc. No. 7537, located approximately 3.5 km north-northwest of the west end of Johnson Lake, UTM coordinates: 5972300N - 467150E) were examined by W.A. Bell of the Geological Survey of Canada (Report F1-6-66-WAB, dated March 14, 1966). Bell stated that the "collection comprises many samples of phyllite, largest of which has imprint of a woody stem, some 40 cm long by 4 cm wide". Bell did not give any age estimate for these fossils, but because vascular upright land plants did not arise until Late Silurian time and woody plants, until Middle Devonian time (Thomas and Spicer, 1987), their presence indicates that at least some of the Ecstall-Quaal strata are of Late Silurian (and probably even of Middle Devonian), or younger age. The terrane affiliation of the strata in which the fossils were found was unknown.

Correlation of Scotia-Quaal units with neighbouring Wrangellia, Alexander and Stikine (Figure 1-3) lithologies is poor (Table 1-1). These terranes, at the latitude of the Scotia-Quaal belt, differ in age and generally lack Middle Devonian orthogneiss and quartz-rich rock characteristic of the Scotia-Quaal belt. A Middle Devonian date (Swede Point pluton, van der Heyden, 1989) was obtained from an orthogneiss situated west of the Ecstall pluton and in contact with greenstone and minor quartzite (Roddick, 1970). This is the only documented occurrence at this latitude of rocks similar in ages and lithological character to units of the Scotia-Quaal belt. The terrane affiliation of these rocks is also uncertain. Elsewhere in the Cordillera, Wrangellia, Alexander and Stikine terranes all lack abundant quartz-rich rocks and contain an abundant carbonate component which does not occur in the Scotia-Quaal belt.

Table 1-1: Comparison between Wrangellia, Alexander, Scotia-Quaal belt and Stikine lithologies. The table presents a summary of information gathered from Anderson (1989), Gareau (this report), Gehrels and Saleeby (1987), Jones et al. (1977), Monger (1977 and 1980), Souther (1971), Wheeler and McFeely (1987), Woodsworth and Orchard (1985), Woodsworth et al. (in press).

<u>Wrangellia terrane</u>	<u>Alexander terrane</u>	<u>Scotia-Quaal metamorphic belt</u>	<u>Stikine terrane</u>
<p><i>Middle Jurassic (155-187Ma)</i> biotite-hornblende quartz diorite</p> <p><i>Early and Middle Jurassic</i> <u>Bonanza arc volcanics and near-shore clastics</u> calc-alkaline andesitic pyroclastics, lesser flows, tuffaceous sandstone and shale, marine and nonmarine <u>Westcoast intrusive suite</u> (Vancouver Island)</p> <p><i>Late Triassic</i> tholeiitic lavas, subaerial tholeiite in eastern Alaska (<u>Karnatzen Formation</u> on Vancouver on the Queen Charlotte Islands; <u>Coon Dip Greenstone</u> on Chikof Island; <u>Nikolai Greenstone</u> in Wrangell Mountains, Alaska), overlain by bioclastic and reefoid lens; marine and nonmarine (<u>Quetzalco Limestone</u> on Vancouver Island; <u>Kunga Formation</u> on the Queen Charlotte Islands; <u>Whitewine Marble</u> on Chikof Island; <u>Chitstone</u> and <u>Nizina limestones</u> in Wrangell Mountains, Alaska)</p> <p><i>Paleozoic</i> Basic to acidic volcanics overlain by sedimentary rocks (<u>Skolai Group</u> in the Wrangell Mountains, Alaska; <u>Sicker Group</u>, on Vancouver Island)</p>	<p><i>Middle Jurassic (155-187Ma)</i> foliated diorite, diorite-tonalite complex; foliated hornblende-biotite quartz diorite and granodiorite</p> <p><i>Late Triassic and Early Jurassic</i> basalt-andesite flows and breccia, rhyolite flows and tuff; massive and thin-bedded limestone, calcareous siltstone and sandstone, conglomerate and coarse breccia <u>HYD bimodal rift volcanics</u></p> <p><i>Late Triassic</i> hornblende-biotite quartz diorite</p> <p><i>Late Pennsylvanian-Permian</i> Syenite and diorite (St-Elias Mountains)</p> <p><i>Middle Devonian-Permian</i> shallow marine limestone, chert and clastic strata, volcanic rocks</p> <p><i>Early Devonian</i> clastic sedimentary rocks, minor basaltic-dacitic volcanic interlayers (<u>Karheen Formation</u>, Alaska)</p> <p><i>Silurian</i> Shallow marine limestone, thick turbidites, conglomerate leucocratic aegirine-sodic amphibole syenite, biotite hornblende syenite and trochilomite (Alaska)</p> <p><i>Ordovician - Early Mississippian</i> limestone and marine clastic strata (St Elias Mountains)</p> <p><i>Ordovician-Early Silurian</i> Basaltic to andesitic pillow lavas and breccia, rhyolitic-dacitic tuff and breccia, mudstone and greywacke turbidites, and subordinate limestone, conglomerate and shale (<u>Descon Formation</u>, Alaska) Intrusive rocks of varying composition</p> <p><i>Cambrian</i> metadiorite and megacrystic diorite</p> <p><i>Late Proterozoic(?) - Cambrian</i> metamorphosed basaltic to andesitic pillow lava, breccia and tuff; rhyolitic breccia and tuff, greywacke, mudstone and thick limestone (<u>Wales metamorphic suite</u>, Alaska)</p>	<p><i>post - Early Jurassic and pre-mid Cretaceous (?)</i> Mafic/ultramafic complex Non to weakly lineated hornblende diorite to mafic diorite and rusty weathering coarse hornblende</p> <p><i>Early Jurassic</i> <u>Johanna Lake and Fock Lake metatonalites</u> metamorphosed, lineated and weakly to strongly foliated epidote-biotite-hornblende tonalite</p> <p><i>Middle Devonian</i> <u>Big Falls orthogneiss</u> Metamorphosed and strongly foliated hornblende-biotite (muscovite-garnet) Big Falls tonalite <u>Metavolcanic unit</u> Metamorphosed volcanic equivalent(?) to Big Falls intrusion Mafic and intermediate metavolcanic, minor quartzite, semi pelite to pelite and felsic volcanic, with disseminated and massive sulphides</p> <p><i>Age unknown - definitely pre Early Jurassic, maybe pre Middle - Devonian</i> <u>Metasedimentary clastic unit</u> Lineated (garnet)-epidote-hornblende-biotite gneiss; with epidote and granitoid clasts interpreted as clastic metasedimentary rock <u>Quartzite unit</u> Quartzite with interlayers of biotite-hornblende gneiss, fissile mica schist, black phyllite to metaargillite or metapelite; minor amphibolite and marble <u>Layered gneiss unit</u> Well-layered biotite-hornblende gneiss, garnet amphibolite and biotite quartz dioritic to granodioritic gneiss; rare epidote-garnet - rich pods</p>	<p><i>Middle and Late Jurassic</i> nonmarine and marine conglomerate, sandstone, siltstone, shale and marly limestone; plant fossils, coquinas and coal <u>Bowyer Lake Group</u></p> <p><i>Early and Middle Jurassic</i> calc-alkaline subaerial basalt to rhyolite, minor sediments <u>Hamilton arc volcanics</u></p> <p><i>Early Jurassic (187-214Ma)</i> bedded granodiorite and quartz diorite in eastern Coast Plutonic Complex</p> <p><i>Late Triassic (214-235Ma)</i> subcalc-alkaline, biotite-hornblende diorite; hornblende quartz monzodiorite, granodiorite, quartz monzonite</p> <p><i>Late Triassic</i> basal conglomerate (Tulsequah area), calc-alkaline pyroxene and feldspar porphyritic mafic flows, breccia tuff, minor ignimbrite interlayered with volcanoclastics, local argillite, shale, greywacke and siltstone (IN ISKUT AREA: Limestone, chert-limestone conglomerate, claspopyroxene-phyric mafic tuff and flow; felsic tuff, shale and argillite; claspopyroxene-phyric volcanoclastics) <u>Skolai Group</u></p> <p><i>Early Permian</i> Limestone, volcanic-arc-like mafic to felsic volcanic flows, tuffs and volcanoclastics (Idkut area); limestone, calcareous mudstone and minor tuff; Permian (?) cherty volcanics, tuff, breccia and minor greywacke; metamorphosed equivalent</p> <p><i>Devonian-Permian</i> Calc-alkaline basalt to rhyolite flows and pyroclastics interbedded with limestone, shale, volcanic sandstone, minor chert; more tuffs and less rhyolite in western Stikinia; marine and nonmarine; also unnamed metasediments and greenstone <u>Asika arc volcanics and platform carbonates</u>: basement of Stikinia (IN ISKUT AREA: <u>Mississippi</u> Thick-bedded coralline limestone, chert, pillow basalt, hyaloclastite and epiclastic rocks <i>Early-Middle Devonian</i> Coralline limestone, mafic volcanoclastics, felsic crystal tuff, pebble conglomerate and siliceous shale)</p>

Correlation with Wrangellia ?

The hallmark of Wrangellia terrane is a compositionally homogeneous Late Triassic (Carnian) basalt unit, called the Karmutsen Formation on Vancouver and the Queen Charlotte Islands, overlain by thick Late Triassic platform carbonates variously labelled as Quatsino limestone, Kunga Formation, Whitestrip Marble and Chitistone and Nizina limestones (Jones et al., 1977; see Table 1-1). In the Scotia-Quaal area, carbonate rocks are rare and thick carbonate units are absent. The metavolcanic unit of the Scotia-Quaal belt comprises mafic and intermediate metavolcanic rocks interlayered with minor metasedimentary and metarhyolitic (?) rocks. It does not resemble the massive and homogeneous Triassic volcanic rocks of Wrangellia terrane

The Paleozoic sections of Wrangellia terrane vary from region to region, but generally consist of arc-derived sedimentary and volcanic rocks (Jones et al., 1977 and Monger, 1977). Pennsylvanian to Permian Skolai oceanic arc volcanics and sediments found to the north in the Wrangell mountains in eastern Alaska (MacKevett, 1978) lack quartzitic sedimentary rocks. The absence of characteristic white quartzite from Devonian to Permian Sicker platform carbonates, volcanic and clastic rocks (Brandon et al., 1986) also differentiates the Scotia-Quaal package from rocks of the Sicker Group.

Early Jurassic magmatic rocks occur locally in Wrangellia terrane. For example, the Westcoast suite and the Bonanza volcanics on Vancouver Island are of Early Jurassic age (Woodsworth et al., in press). In summary, aside from a possible shared Early Jurassic plutonic history, a correlation of Ecstall strata with Wrangellia terrane is rejected.

Correlation with Alexander terrane ?

Alexander terrane strata underlie much of southeastern Alaska (Gehrels and Saleeby, 1987) and extend into the Coast Plutonic Complex of British Columbia, possibly at least as

far south as 53°N (Woodsworth and Orchard, 1985 and Woodsworth, 1988). The lower part of the sequence consists of Late Proterozoic (?) through Early Devonian arc-type volcanic rocks (Gehrels and Saleeby, 1987). Intrusive rocks of Ordovician to Early Silurian age typically occur in Alexander terrane. The diagnostic strata of Alexander terrane are Middle Devonian through Permian carbonate and clastic rocks deposited in a shallow marine, tectonically stable environment (Gehrels and Saleeby, 1987 and Eberlein and Churkin, 1970). This thick sequence is overlain by rift-related, sedimentary and bimodal volcanic rocks of Late Triassic age (Gehrels and Saleeby, 1987 and Woodsworth and Orchard, 1985).

It could be argued that the Paleozoic (?) metavolcanic and layered gneiss units in the Scotia-Quaal area represent the pre-Middle Devonian arc sequence found in Alexander terrane. However, the Scotia-Quaal sequence lacks Ordovician to Silurian plutonic rocks characteristic of Alexander terrane. Moreover, stable-shelf carbonate rocks characteristic of the middle part of Alexander terrane are absent in the Scotia-Quaal area and Middle Devonian plutons, present in the Scotia-Quaal area, have not been documented in Alexander terrane. Finally, the bimodal volcanic suite characteristic of the upper part of Alexander terrane has no counterpart in the Scotia-Quaal area. Collectively, these points strongly suggest that the Scotia-Quaal belt is not part of Alexander terrane.

Correlation with Stikine terrane ?

Stikine terrane appears on tectonic maps as the largest coherent terrane in the Canadian Cordillera (Wheeler et al., 1989; Monger and Berg, 1984). Hill et al. (1985) suggested that rocks of Stikine terrane are the protolith of a large part of the Central Gneiss Complex at the latitude of Terrace-Prince Rupert.

A characteristic unit of Stikine terrane is a regionally extensive Early Permian coralline reef carbonate that, near Terrace, is about 500 metres thick (Woodsworth et al., 1985);

locally this unit contains intercalated felsic and mafic tuff. These rocks are unconformably overlain by Middle Triassic sedimentary rocks (Woodsworth et al., 1985 and personal communication 1991) and Late Triassic and Early to Middle Jurassic arc-derived volcanic rocks of the Stuhini and Haselton groups (Tipper and Richards, 1977; Anderson, 1989). The pre-Permian stratigraphy of Stikine terrane is not everywhere preserved and is generally poorly understood. The best-studied area, the Iskut area, contains Lower to Middle Devonian carbonate units interlayered with mafic and felsic volcanoclastic rocks, pebble conglomerate, and siliceous shale (Anderson, 1989). Mississippian rocks are thick-bedded coralline limestone interlayered with chert, pillow basalt, hyaloclastite and related sedimentary rocks (Anderson, 1989).

Correlation of the Scotia-Quaal units with Stikine terrane cannot be completely ruled out. Middle Devonian orthogneiss in the Scotia-Quaal area may be correlative with felsic volcanic rocks of Stikine terrane, and the Paleozoic (?) metavolcanic and layered gneiss units of the Scotia-Quaal area may be equivalent to Devonian to Permian arc-related rocks of Stikine terrane (Table 1-1). However, stratigraphic differences between the Scotia-Quaal belt and Stikine terrane outweigh the similarities between the two packages. Examples of differences are the lack of abundant carbonate in the Scotia-Quaal belt and its abundance throughout Paleozoic strata of Stikine terrane, and the scarcity in quartz-rich sedimentary rocks in Stikine terrane compared to their abundance in the Scotia-Quaal belt. Based on these differences, the correlation between the Scotia-Quaal belt and Stikine terrane is rejected.

It should be noted that igneous rocks of Early Jurassic age are relatively abundant in the eastern Coast Plutonic Complex and western Stikine terrane. Plutonic bodies such as the Texas Creek granodiorite (Alldrick et al., 1986; Anderson and Bevier, 1990; Bevier and Anderson, 1990) near Stewart, the Topley suite (Woodsworth et al., in press) east of

Kitimat and parts of the Black Dome complex (van der Heyden, 1989) in the Whitesail Lake area as well as a myriad of unnamed, small, partly foliated and altered bodies (Wheeler and McFeely, 1987) are Early Jurassic in age. In addition, volcanic rocks of the Telkwa Formation (Tipper and Richards, 1976) and correlative metavolcanic rocks in the Gamsby Complex (van der Heyden, 1989) are Early to Middle Jurassic in age. An orthogneiss in the Shames River area, on the eastern side of the Central Gneiss Complex, was recently found to be late Early Jurassic in age (Heah, personal communication 1991). The Early Jurassic plutonism in the Scotia-Quaal belt could suggest that the belt has shared a common history, at least from Early Jurassic time on, with rocks to the east, in the eastern Central Gneiss Complex and in Stikine terrane. Although this possibility is intriguing, without supporting evidence it must be considered speculative.

Correlation with Taku terrane ?

The Taku terrane separates Alexander terrane and the Coast Mountains batholith (Coast Plutonic Complex) in southeastern Alaska (Figure 1-3). It was originally defined by Berg and others (1972) to refer to upper Paleozoic and Triassic volcanic and sedimentary rocks. Subsequently, a more detailed description of this terrane was made by Monger and Berg (1987). They divided the terrane into the following units: upper Paleozoic basaltic metatuff and agglomerate; Permian crinoidal marble intercalated with pelitic phyllite and felsic metatuff; Middle and Upper Triassic carbonaceous limestone, shale, phyllite and basaltic breccia; flysch and metatuff that may be correlative with strata of the Gravina belt; undated quartzite and felsic metatuff; and a southern central subterrane of primarily pelitic and volcanoclastic rocks. Recently, Gehrels and other (1991) have suggested that Taku terrane is composed of two distinct, apparently unrelated, lithic assemblages, some strata belonging to the Yukon Crystalline terrane and other strata for which the designation Taku terrane is retained.

Taku terrane appears to have been and still be used to refer to poorly known strata for which a terrane affinity has not yet been defined. As additional data is gathered, many strata originally classified as part of Taku terrane have been found to be correlative with a better defined terrane of the western Cordillera. For this reason, it is judged inappropriate to attempt to correlate the units of the Scotia-Quaal belt with Taku terrane. However, some strata of Taku terrane similar to units of the Scotia-Quaal belt have been tentatively correlated with Nisling and/or the Yukon Crystalline terranes (Gehrels et al., 1989 and Gehrels et al., 1991).

Correlation with Nisling terrane ?

In recent years, rocks of cratonic affinities have begun to be recognized in the western Canadian Cordillera. Although their nomenclature and cratonic affiliation is controversial (for example Currie, 1990a & b and 1991; Erdmer, 1989 and 1990; Gehrels et al., 1989 and 1990; Jackson, 1990; Mortensen in press) the general term "Nisling terrane" was coined by Wheeler and McFeely (1987) for the assemblage composed of quartz-rich metasedimentary rocks, semi-pelite to pelite, marble and mafic volcanic rocks. Very little is known about the origin and age of Nisling rocks and the relationship between these rocks and adjacent terranes. Detailed studies of the geological history of Nisling rocks in northern British Columbia are in progress (Currie, 1990a, 1990b and 1991; Jackson et al., 1990). Mortensen (in press) correlates Nisling assemblages of the Yukon with Yukon-Tanana terrane. Gehrels et al. (1989) have correlated quartz-rich metasediments and subordinate metapelite, marble and metabasalt from the northern Coast Mountains Batholith to Nisling terrane. Table 1-2 presents a comparative compilation of stratigraphy of the Scotia-Quaal belt, Nisling terrane in the Florence Range of northern British Columbia described by Currie (1990a, 1990b and 1991) and Nisling/Yukon-Tanana in the Yukon (Mortensen, in press). Although Nisling and Yukon-Tanana lithologies from the Yukon

Table 1-2: Comparison between strata in the Scotia-Quaal belt (this report) and Nisling strata in the Florence Range of northern British Columbia (Currie, 1990a, 1990b, 1991 and personal communication 1991) and in the Yukon territory (Mortensen, in press and Wheeler and McFeely, 1987).

<u>Scotia-Oual metamorphic belt</u>	<u>Nisling terrane in the Florence Range, B.C.</u>	<u>Nisling and Yukon-Tanana terranes in Yukon</u>
<p><i>post-Early Jurassic and pre-mid Cretaceous (?)</i> Mafic/ultramafic complex Non to weakly lineated hornblende diorite to mafic diorite and rusty weathering coarse hornblende</p>	<p><i>Mesozoic</i> diorite to tonalite, granite, syenite to quartz monzonite, hornblende</p>	
<p><i>Early Jurassic</i> <u>Johnson Lake and Fock Lake metatonalites</u> metamorphosed, lineated and weakly to strongly foliated epidote-biotite-hornblende tonalite</p>	<p><i>Early Jurassic</i> <u>Hale Mountain Granodiorite</u> biotite-hornblende (-chlorite-epidote) granodiorite</p>	<p><i>Late Triassic to Middle Jurassic (212-185Ma)</i> Quartz diorite and granodiorite to quartz monzonite and syenite, hornblende, pyroxenite and rare dunite</p>
		<p><i>Late Permian to Mid-Triassic</i> D1 deformation</p>
<p><u>Layered gneiss unit</u> Well-layered biotite-hornblende gneiss, garnet amphibolite and biotite quartz dioritic to granodioritic gneiss; rare epidote+garnet- rich pods</p>	<p><i>Permian</i> <u>Wann River Gneiss</u> Dioritic to gabbroic epidote-biotite-hornblende gneiss interpreted as volcanic in origin</p>	<p><i>Mid-Permian</i> Felsic metavolcanic and metaplutonic rocks</p> <p><i>Carboniferous to Early Permian</i> massive marble (in Nisling subterrane)</p> <p><i>Devono-Mississippian (?)</i> carbonaceous quartz, silts and pelite, quartz-muscovite schist, minor mafic metavolcanic rocks, metagabbro, marble and stretched pebble conglomerate (Nasina assemblage in Nisling Terrane)</p>
<p><i>Middle Devonian</i> <u>Big Falls orthogneiss</u> Metamorphosed and strongly foliated hornblende-biotite-(muscovite-garnet) Big Falls tonalite Metavolcanic unit <i>Middle Devonian?</i> Metamorphosed volcanic equivalent(?) to Big Falls intrusion Mafic and intermediate metavolcanic, minor quartzite, semi pelite to pelite and felsic volcanic, with disseminated and massive sulphides</p>	<p><i>Late Devonian to Early Mississippian</i> <u>Bighorn Creek orthogneiss</u></p> <p><i>Proterozoic to Paleozoic (?)</i> <u>Boundary Range Metamorphic Suite</u> chlorite-(actinolite) schist, minor chlorite-pyroxene schist, discontinuous carbonate layers granitic to dioritic orthogneissic dykes</p>	<p><i>Late Devonian - mid Mississippian</i> Peraluminous granitic orthogneiss and metamorphosed hbd-bearing quartz diorite, granodiorite and quartz monzonite with minor gabbro and quartz gabbro</p> <p>Cogenetic with the hbd-bearing plutonic suite. Dominantly submarine mafic and felsic metavolcanic rocks; minor metasedimentary interlayers, widespread small volcanogenic sulphide deposits.</p>
<p><i>Age unknown: definitely pre-Early Jurassic, maybe pre-Middle Devonian</i> <u>Metasedimentary clastic unit</u> Lineated (garnet)-epidote- hornblende-biotite gneiss; with epidote and granitoid clasts interpreted as clastic metasedimentary rock <u>Quartzite unit</u> Quartzite with interlayers of biotite-hornblende gneiss, fissile mica schist, black phyllite to metaargillite or metapelite, minor amphibolite and marble</p>	<p><i>Florence Range Metamorphic Suite</i> Semipelitic to pelitic rocks, carbonate, amphibolite and calc-silicate, minor quartzite</p>	<p><i>Pre-Late Devonian</i> Quartz-rich metasediments, locally abundant abundant metapelite and marble, minor chlorite schist, amphibolite and metagabbro (Nisling assemblage in Nisling Terrane)</p>
<p><u>Layered gneiss unit</u> Well-layered biotite- hornblende gneiss, garnet amphibolite and biotite quartz dioritic to granodioritic gneiss; rare epidote+garnet - rich pods</p>		

are grouped in the table, it is beyond the scope of this study to discuss a possible correlation between Nisling and Yukon-Tanana terranes.

Examination of Table 1-2 reveals that similarities exist between the Scotia-Quaal belt and Nisling/Yukon-Tanana rocks in the Yukon. Both packages contain quartz-rich metasedimentary rocks of pre-Middle Devonian age in the Yukon and of uncertain, but possibly pre-Middle Devonian age in the Scotia-Quaal area. In the Yukon, these quartzitic rocks are overlain by an intrusive/extrusive complex of Devonian age; metaintrusive rocks of Middle Devonian age occur in the Scotia-Quaal area and could be cogenetic with the metavolcanic unit. A correlation between Devonian to Permian strata mapped in the Yukon and units of the Scotia-Quaal package cannot be ascertained. These strata may have never been deposited in "British Columbian Nisling", they may have been eroded, or they may be identified in the future based on additional dates from units of the Scotia-Quaal belt, or based on mapping and dating of units in adjacent areas, west of the Ecstall pluton and east of the Quottoon tonalite. No equivalents for the Scotia-Quaal metasedimentary (clastic) unit occur in the Yukon. Massive marble in Nisutlin subterrane has no equivalent in the Scotia-Quaal area, but the relationship between Nisutlin subterrane and Nisling terrane in the Yukon is still uncertain.

Ages and contact relationships between lithologies of the Florence Range are still under study (Currie, 1990a, 1990b and 1991). A remarkable coincidence exists between lithologies of the Scotia-Quaal belt and of the Florence Range. Correlations could be made between the Middle Devonian Big Falls orthogneiss and the metavolcanic unit in the Scotia-Quaal belt, and granodioritic to dioritic orthogneissic dykes and mafic schist of the Boundary Range Metamorphic Suite. The quartzite unit could be correlative with metasedimentary rocks of the Florence Range Metamorphic Suite. A facies change could explain the different proportion of semipelitic to pelitic and quartz-rich rocks at the two

locations. The Scotia-Quaal layered gneiss unit may be equivalent to the Wann River gneiss. Early Jurassic intrusive rocks occur in both areas (Table 1-2).

In summary, lithologies mapped in the Scotia-Quaal area have more affinities with rocks of northern British Columbia and, to a certain extent, western Yukon Nisling terrane than with Wrangellia, Alexander and Stikine terranes. The correlation, if real, would be difficult to establish with certainty because rocks of the Scotia-Quaal belt have been metamorphosed and intensely deformed. Fossils, sedimentary features and paleomagnetic signatures that may have facilitated correlation have all been destroyed. One characteristic of Nisling terrane which may allow correlation is its older detrital source. A 900Ma Rb/Sr isochron for Nisling lithologies was reported by Werner (*in* Monger and Berg, 1987). Nd analyses of Nisling rocks gave an early Proterozoic neodymium mantle separation age (Samson et al.; 1989a). Nd and Sr data obtained from four samples of the Scotia-Quaal metamorphic belt are discussed in Chapter 4. The results of this analytical work are in agreement with the tentative lithological correlation made in this section.

1.3 Deformation

The most striking structural features in the Scotia-Quaal metamorphic belt are the well-developed steeply dipping planar and steeply plunging linear fabrics, particularly in the central region of the belt. These steep fabrics also occur in the metamorphic rock along trend with the Scotia-Quaal belt, north of the Skeena River (Hutchison, 1982; Crawford and Hollister, 1982 and Crawford et al., 1987). Northwestern strike of planar fabrics and trend of linear elements parallel the regional grain of the Coast Plutonic Complex. North of the Skeena River, Work Channel follows the zone of strong fabric (Figure 1-4). Steeply

Figure 1-4: Geological map of part of the Coast Plutonic Complex between latitude 53°20' and 55° (After Roddick, 1970; Hutchison, 1982 and Gareau, 1991) showing the location of the Khtada Lake and Prince Rupert areas where metamorphic and structural work was conducted by Crawford and Hollister (1982) and a cross-section of the Foch Antiform as inferred by Roddick (1970).

oriented fabrics do not occur to the same extent west and east of the narrow Scotia-Quaal metamorphic belt (Roddick, 1970 and Hutchison, 1982).

Roddick (1970) interpreted the steep easterly dipping fabrics in the Scotia-Quaal belt, coupled with the gently easterly dipping fabrics in the Central Gneiss Complex as a large scale, overturned to the southwest, antiformal structure that he called the Foch Antiform (Figure 1-4). Crawford and Hollister (1982), based on differences in K-Ar ages in rocks on either side of Work Channel as first documented by Hutchison (1970), and on observed differences in structural styles and metamorphic histories between rocks of the Khtada Lake area (Figure 1-4) and rocks close to Prince Rupert (Figure 1-4), interpreted the steep fabrics along Work Channel as representing a shear zone along which the Central Gneiss Complex was uplifted in Eocene time. One objective of mapping in the Scotia-Quaal area was to follow, south of the Skeena River, the zone of steep fabrics in metamorphic rocks bounded by the Ecstall and Quottoon plutons, and to evaluate its role with respect to Eocene uplift of the Central Gneiss Complex.

Conclusions with respect to deformational features in the Scotia-Quaal metamorphic belt, that are discussed in this section are the following. (1) Based on the cross-cutting relationship between the 94 Ma old (van der Heyden, personal communication and Woodsworth et al., 1983) Ecstall pluton and the steep fabric in the metamorphic belt, deformation resulting in these steep fabrics was found to be older than mid-Cretaceous. (2) Late Paleocene-Early Eocene fabrics were found to be restricted to an approximately 1.5 km wide band close to the Quottoon pluton, where deformed Late Paleocene (-Early Eocene?) dykes occur. (3) Kinematic indicators were found in the field to be virtually nonexistent, probably due to the fact that metamorphism outlasted deformation. (4) The dominant pre-mid Cretaceous structures in the area were found to be abundant folds that have been separated into three categories based on overprinting relationships observed on

two ridges and on fold geometry, but that could usually not be differentiated elsewhere in the Scotia-Quaal area. (4) It is likely that the final orientation of planar and linear fabrics be mainly dictated by latest regional deformation since, at least in the central region, all structures are similarly oriented. Consequently, fabric elements generally could not be separated according to the episode of deformation during which they were formed. For this reason, the discussion of structural elements in the metamorphic belt is descriptive in nature. The main objective of this section is to address the postulate that a young structural zone may cross the Scotia-Quaal metamorphic belt. A discussion of the timing relationship between deformation and metamorphism is presented in Chapter 3, Section 6.

Structural elements in the metamorphic rocks

All metamorphic rocks, except parts of the late Early Jurassic orthogneisses, are strongly foliated. In the central region, the foliation generally strikes approximately 350° and dips steeply ($>60^\circ$) east (Figure 1-5). To the north and south, orientations are more variable. In the northern region, the foliation strikes generally to the northwest and dips moderately to steeply ($>40^\circ$) dominantly to the southwest. There is a large spread in orientation of foliation in the southern region. Strikes are dominantly northwest and dips vary from vertical to less than 10° both to the southwest and the northeast.

Mineral and stretching lineations are ubiquitous throughout the metamorphic belt. In the central region, lineation fairly consistently plunges steeply ($>50^\circ$) towards north-northwest or south-southeast (Figure 1-5). Orientation of lineation is more variable in the northern region; it is generally steep to the northwest, but is locally as shallow as 13° . Shallow to steep lineations occur in the southern region. Axial surfaces of folds in the central region dominantly strike north-northwest and dip steeply ($>65^\circ$) to the east (Figure 1-5). The average strike of axial surfaces in the northern region is slightly more westerly than in the central region and dips are steep ($>60^\circ$) to the southwest or northeast. A similar

Figure 1-5: Equal area plots of structural elements in the Scotia-Quaal metamorphic belt.

Figure 1-5 (end): Equal area plots of structural elements in the Scotia-Quaal metamorphic belt.

trend occurs in the southern region except that dips are dominantly to the northeast and that there is greater dispersion in data. Dips vary between 15 and 90°.

Hinge lines (Figure 1-5) plunge gently to steeply (22-90°) to the north-northwest in the central region and to the west in the northern region. They are more randomly oriented in the southern region.

In summary, a very strong north to north-northwest trend of planar and linear fabrics is noted in the central region of the Scotia-Quaal belt. This trend shifts slightly towards the west in the northern region. The northern region exhibits more dispersion in trends, and mostly in plunges, of both linear and planar fabrics. Fabric orientation is most variable in the southern region.

Structural history and kinematic indicators

The pre-early Late Cretaceous sequence of deformation in the Scotia-Quaal belt includes the early development of a strong planar fabric followed by isoclinal folding (Fi), formation of outcrop-scale, moderately open folds (Fm) and large-scale, tight to isoclinal folding (FI) of all preceding deformational features (Plates 2D and 3A). Limbs of Fi isoclinal folds parallel the strong foliation; such folds are recognized when a layer is seen to terminate along strike and to be folded upon itself such that the width of the recognizable band is doubled, and when the hinge zone is not completely attenuated (Plate 2D). They occur in all pre-Early Jurassic units. Fm folds were only recognized with certainty in the central region, on the ridge immediately south of the Ecstall deposit (Appendix 1). There, moderately open folds of 1 to 5 metre amplitude refold isoclinal Fi structures (Plate 2D) and are rotated around a large-scale (hundreds of metres) FI fold. Isolated structures geometrically similar to Fm folds were recognized throughout the belt. In some locations, Fm folds could not be differentiated from minor FI structures. Variation in the orientation of foliation, minor z, m and s folds and the pattern defined by rare easily recognizable

bands of rock helped identifying F1 folds. At one location in the northern region, on the ridge north of Big Falls Creek and east of the Scotia River (Appendix 1), large-scale folding resulted in formation of an axial planar foliation overprinting the preexisting planar fabric (Plate 3A).

Development of the early foliation postdates the emplacement of the Middle Devonian Big Falls orthogneiss and of the pre-late Early Jurassic units which are all strongly foliated and contain F1 folds. Large F1 folds, hundreds of metres in scale, predate the cross-cutting early Late Cretaceous Ecstall pluton.

The timing of intrusion of the Early Jurassic orthogneissic bodies with respect to deformation is only partially resolved. The contact between the Foch Lake orthogneiss and its host is locally deformed by folds assumed to belong to the Fm generation, which thus would have formed after Early Jurassic magmatism. Absence of isoclinal F1 folds in the Johnson Lake and Foch Lake plutons and a foliation generally much less strongly developed in the late Early Jurassic plutons in comparison to the foliation in older units suggest that early deformation is older than late Early Jurassic time. The difference in intensity of fabric could, however, be explained by difference in competency between the Early Jurassic intrusive rocks and their host during deformation.

The repetition of units on either side of the possibly comagmatic Big Falls orthogneiss and metavolcanic rocks, the occurrence along the southern shore of Hawkesbury Island of rocks of the layered gneiss unit (Appendix 1A), and the abundance of z-folds along the eastern margin of the Scotia-Quaal metamorphic belt suggest that the dominant regional structure of the long and narrow belt is a steeply plunging nearly isoclinal synform of either the F1 generation or postdating F1. Steepening of fabrics in the Scotia-Quaal belt is assumed to have occurred late in the deformational history of the area, because structural elements all appear to have a similar orientation, particularly in the central region. This

PLATE 3

A) Folding in felsic biotite gneiss of the metavolcanic unit.

Two foliation are seen at this outcrop; the younger foliation (from top to bottom of the picture) is related to large-scale F1 folding. Minor folds deform an earlier foliation.

The outcrop is situated on a ridge north of Big Falls Creek and west of the Scotia River (Station # 88-125).

B) Deformation in the Quottoon pluton.

The foliation in the Quottoon pluton is defined by alignment of mafic minerals, stretched amphibolitic inclusions and schlieren.

This outcrop is located on a ridge east of Scotia-River and immediately north of Big Falls Creek (Station # 89-166).

C) Late Paleocene (-Early Eocene?) dykes cross-cutting steeply dipping metamorphic rocks of the Scotia-Quaal belt.

These dykes belong to a suite of coarse grained to pegmatitic, leucocratic dykes that intrude the metamorphic rock in a 2.5 km wide zone adjacent to the Quottoon pluton contact. The westernmost dykes, such as the ones in the foreground of this picture, (between approximately 2.5 and 1.5 km from the Quottoon pluton contact) are undeformed and cross-cut the metamorphic rock.

This outcrop is located on the ridge immediately north of Johnson Lake. The photo was taken from station #87-132, looking east.

D) Strongly deformed Late Paleocene (-Early Eocene?) leucocratic pegmatite dyke located close to the Quottoon pluton contact.

This dyke belongs to the same suite of young dykes as the ones in plate 3C. As the Quottoon pluton contact is approached, the dykes become more abundant, increasingly mylonitized and reoriented into parallelism with the Quottoon pluton contact.

This outcrop is located on the ridge north of Johnson Lake (Station # 88-90).

steepening could have occurred during or after the last folding event, but happened prior to emplacement of the early Late Cretaceous Ecstall pluton which overlies the steeply dipping belt on Hawkesbury Island.

In contrast with folds which are ubiquitous throughout the metamorphic belt, kinematic indicators are extremely rare. The majority of asymmetric fabrics (mainly quartz boudins, rare equivocal shear bands and rotated? porphyroblasts) occur on a plane at a large angle to the orientation of lineation and do not provide consistent shear directions. Evidence that would allow unravelling of the detailed deformational history in the Scotia-Quaal belt has apparently been removed through overprinting of multiple generations of deformational features and annealing. It is clear, however, that in the Scotia-Quaal area the deformational features described above are cut by and predate the intrusion of the Ecstall pluton. Post-early Late Cretaceous fabric development is restricted to the margins of the Scotia-Quaal belt.

Structural elements in the bounding plutons and post-early Late Cretaceous deformation in the belt

In the Scotia-Quaal area, the Ecstall pluton is undeformed except along its margin and generally cross-cuts the fabric in the metamorphic belt. This indicates, as previously mentioned by van der Heyden (1989), that emplacement of the early Late Cretaceous pluton postdates deformation in the metamorphic belt. Intrusion of the Ecstall quartz diorite does not appear to have generated a deformation aureole around the pluton, although it may be unrecognizable in the strongly deformed rocks of the Scotia-Quaal area.

Late Paleocene-Early Eocene deformation associated with the Quottoon pluton (Plate 3B) is restricted to the easternmost 1.5 km of the Scotia-Quaal belt as evidenced by non to strongly deformed Late Paleocene dykes emplaced into the metamorphic belt (Plate 3C and D). These dykes are increasingly mylonitized (Plate 3D) and reoriented into parallelism

with the Quottoon pluton contact and its fabric as the contact is approached. Deformation of the dykes becomes evident in outcrop approximately 1.2 km west of the Quottoon pluton contact. Stronger foliation in the Johnson Lake orthogneiss where it is closer to the Quottoon pluton may also result from Late Paleocene-Early Eocene deformation localized around the western margin of the Quottoon pluton.

The western part of the Quottoon pluton is foliated and locally lineated. The foliation is defined by alignment of mafic minerals, oblate mafic inclusions and mafic schlieren (Plate 3B). Alignment of hornblende defines the lineation. Along Douglas Channel, the orientation and intensity of structural elements in the Quottoon pluton are highly variable. Dips and plunges are generally relatively shallow ($<45^\circ$) and are steepest close to the Scotia-Quaal metamorphic belt. In the central region strong foliation and lineation parallel fabrics in the metamorphic rocks; foliation strikes north-northwest to north and dips steeply ($>60^\circ$) to the east and lineation plunges steeply ($>60^\circ$) to the north-northwest to north. Lineation is conspicuously absent from the Quottoon tonalite in the northern region. Steeply ($>70^\circ$) east-dipping foliation strikes consistently to the north-northwest.

Fabric in the western part of the Quottoon pluton parallels the Quottoon pluton contact with the Scotia-Quaal metamorphic belt as well as the pre-early Late Cretaceous fabric in the metamorphic belt. The concordance between the Quottoon pluton contact and the older regional fabric in the Scotia-Quaal belt suggests that emplacement of the Quottoon pluton was achieved by ascent of Quottoon magma along a plane parallel to the strong steep fabric already present in the metamorphic rock. Fabrics in the Quottoon pluton such as planar and linear alignment of mafic minerals, subgrain structures in quartz, bending of plagioclase crystals, reduced grain size in areas of higher strain and asymmetric fabrics suggest that the pluton was emplaced prior to or synchronously with deformation. Detailed outcrop and microstructural analysis would be necessary to document with more precision the timing of

emplacement with respect to deformation. The elongate shape of the pluton is suggestive of emplacement in an active fault zone, but the pluton shape is not sufficient evidence of syntectonic emplacement; the presence of both magmatic and high-temperature solid-state foliations roughly parallel to one another, for example, is another condition which should be fulfilled (Paterson et al., 1989).

Late Paleocene-Early Eocene structural elements are localized within the Quottoon pluton and at the eastern margin of the Scotia-Quaal metamorphic belt. If a major Late Paleocene-Early Eocene shear zone is postulated to explain the disparity in cooling dates, metamorphic histories and structural styles between the western and central Coast Plutonic Complex, then it does not traverse the Scotia-Quaal metamorphic belt, but must be located within or near the western edge of the Quottoon pluton.

Chapter 2 - Metamorphism and thermobarometry

2.1 Objectives of metamorphic study

The objectives of a metamorphic study in the Scotia-Quaal area are to define the metamorphic grade on a regional scale, to characterize metamorphic gradients across the area and to assess the possibility of there being an important metamorphic and structural break in or on either side of the area. In Chapter 1, it was established, based on structural and lithological observations, that no major structural break of young age such as the Work Channel lineament (Crawford and Hollister, 1982; Crawford et al, 1987) cuts across the Scotia-Quaal belt, and that the most probable locus for a major Paleocene/Eocene tectonic boundary is within and/or at the western margin of the Quottoon pluton. Comparison of the metamorphic history of the Scotia-Quaal belt with metamorphic histories in the rest of the East Plutonic Complex at this latitude is an important tool to evaluate this postulate.

A major problem inherent to the study is the fact that the Scotia-Quaal area is a long and narrow belt bounded on either side by young plutons, the thermal effects of which are unknown and difficult to separate from the effects of regional metamorphism. This is particularly true for the Quottoon pluton because deformation affecting the western part of the pluton and a zone of metamorphic rocks approximately 1 km wide at the eastern margin of the Scotia-Quaal belt parallels the older structural grain in the metamorphic belt. The correspondence in orientation of new and old fabrics makes it difficult to use textural relationships to separate regional metamorphic mineral growth from that which has occurred during later contact metamorphism. Additional difficulties are related to the possibility that the Scotia-Quaal belt underwent multiple metamorphic episodes, regional in nature and/or related to Early Jurassic and/or Middle Devonian magmatism. It would be

extremely difficult to differentiate and isolate the effect of one metamorphic event in such a complex polymetamorphic setting. Because of these problems and considering the purpose of the study, the latest regional metamorphic event has been assumed to be responsible for the mineral assemblage present in the rocks, except on either margin of the Scotia-Quaal belt, where the possibility of Late Cretaceous-Early Tertiary contact metamorphism exists.

Other problems arise from the large uncertainties related to the use of geothermobarometers and our poor knowledge of closure temperatures of various elements in a particular system. A detailed discussion of problems related to geothermobarometry is presented in a later section.

This chapter includes a review of metamorphic data already available for the Coast Plutonic Complex at the latitude of Terrace-Prince Rupert, a discussion of the information that can be readily extracted from pelitic and mafic assemblages throughout the Scotia-Quaal belt, a detailed study of metamorphism of mafic volcanic samples across the central region of the Scotia-Quaal belt, comparative geothermobarometry on samples collected throughout the area and in the Ecstall pluton, discussion of the relationship between deformation and metamorphism, and evaluation of the regional significance of the metamorphic data, particularly with respect to the postulate of the presence of a major structural boundary immediately east of the Scotia-Quaal area and in light of the geochronologic and structural data.

2.2 Previous work

Previous work in the Coast Plutonic Complex at the latitude of Terrace-Prince Rupert

The Coast Plutonic Complex at the latitude of Terrace-Prince Rupert has been divided into three main belts (Figure 2-1) of apparently different metamorphic histories (Crawford

Figure 2-1: Map of the Coast Plutonic Complex at the latitude of Terrace-Prince Rupert showing location of previous metamorphic studies. P-T estimates and references are:

- 1) $560 \pm 20^{\circ}\text{C}$, $560 \pm 50 \text{ MPa}$; Crawford et al. (1987)
- 2) 625°C , $800 \pm 100 \text{ MPa}$; Crawford et al. (1979)
- 3) $675\text{--}750^{\circ}\text{C}$, $600\text{--}800 \text{ MPa}$; Lappin (1976), Lappin and Hollister (1980)
- 4) $750 \pm 50^{\circ}\text{C}$, $460 \pm 50 \text{ MPa}$; Kenah (1979)
- 5) $725\text{--}775^{\circ}\text{C}$, $420\text{--}550 \text{ MPa}$; Selverstone (1978), Selverstone and Hollister (1980)
- 6) $650 \pm 50^{\circ}\text{C}$, $450 \pm 50 \text{ MPa}$; Douglas (1986)
- 7) $600\text{--}700^{\circ}\text{C}$, $760 \text{ MPa}\text{--}510 \text{ MPa}$; Hill (1984)
- 8) $550\text{--}660^{\circ}\text{C}$, $700 \pm 100 \text{ MPa}$; Runkle (1979)
- 9) $565\text{--}600^{\circ}\text{C}$, 480 MPa and 723°C , 710 MPa ; Krage (1984).

et. al., 1987). The western belt consists of low- to high-grade metamorphic rocks. Metamorphic grade increases to the east from chlorite, through garnet, chloritoid, staurolite, and kyanite±migmatite zones (Crawford et al., 1987). West of the Prince Rupert shear zone (locality 1, Figure 2-1), a moderately easterly dipping zone of intense deformation, metamorphic conditions have been estimated at $560\pm 20^{\circ}\text{C}$ and $560\pm 50\text{MPa}$ (Crawford et al., 1987). East of the shear zone (locality 2, Figure 2-1), Crawford et al. (1979) have documented high-pressure and high-temperature mineral assemblages and estimated metamorphic conditions at 625°C and $800\pm 100\text{MPa}$. Based on zoning patterns in garnet and plagioclase, mineral growth was interpreted to have continued during uplift of these rocks to pressures of approximately 400MPa.

Conditions of $675\text{--}750^{\circ}\text{C}$ and 600-800MPa in migmatitic gneiss north of the Skeena River and west of the Quottoon pluton (locality 3, Figure 2-1) have been documented by Lappin (1976) and Lappin and Hollister (1980). North of the Skeena river, metamorphic grade (temperature) is highest close to the Work Channel lineament which has been concluded to form the eastern limit of the western belt (Crawford et al., 1987).

Crawford et al. (1987) noted that within the western belt, highest pressure rocks have been superimposed over lower pressure rocks along easterly-dipping shear zones. This resulted in emplacement of highest pressure rocks at the highest structural level. Crawford et al. concluded that westward and northwestward tectonic transport and stacking of at least three separate rock packages occurred during crustal thickening. Movement on the Prince Rupert shear zone was interpreted to be simultaneous with ongoing metamorphism and intrusion of the Ecstall pluton approximately 94 Ma ago (van der Heyden, personal communication 1991 and Woodsworth et al., 1983). Westward and northwestward thrusting of high-temperature and high-pressure rocks along the Prince Rupert shear zone

caused biotite through kyanite metamorphism in the underlying rocks around 90 ± 1 Ma ago (K-Ar date on hornblende; Sutter and Crawford, 1985).

High-grade gneisses and plutonic bodies including and east of the Quottoon pluton form the central belt, also called Central Gneiss Complex. Regional metamorphism has locally reached granulite facies (Hollister, 1975) and is interpreted to have occurred prior to the intrusion of the Quottoon pluton which is itself unmetamorphosed. In the Khtada Lake area (locality 4, Figure 2-1), immediately east of the Quottoon pluton, Kenah (1979) estimated equilibration pressure and temperature around $750 \pm 50^\circ\text{C}$ and $460 \pm 50\text{MPa}$. Selverstone (1978) and Selverstone and Hollister (1980) have recorded similar metamorphic conditions ($725\text{--}775^\circ\text{C}$ and $420\text{--}550\text{MPa}$) in the Shewolf area (locality 5, Figure 2-1). Evidence of an early kyanite/staurolite metamorphism (Hollister, 1977, 1982), inferred to have occurred prior to 85 Ma ago is preserved in the Khtada Lake area. According to Crawford et al. (1987), this metamorphism was synchronous with the development of the highest pressure assemblages in the western belt, but occurred at somewhat shallower levels. In the Khutzeymateen Inlet area (locality 6, Figure 2-1), metamorphic rocks record conditions of $650 \pm 50^\circ\text{C}$ and $450 \pm 50\text{MPa}$ (Douglas, 1986). Mineral reaction textures in gneisses of the central belt show that metamorphic conditions evolved from relatively high pressure moderate temperature to relatively low pressure high temperature prior to cooling to surface conditions (Crawford et al., 1987). In the Redcap Mountain area (locality 7, Figure 2-1), Hill (1984) documented temperature conditions around 600 and 700°C and pressures of 760 MPa decreasing to 510 MPa.

Metamorphism of the eastern belt is at or below greenschist facies. Late Cretaceous and early Tertiary plutons obscure the boundary between the central and eastern belt. The Ponder pluton has imparted a narrow, low-pressure (approximately 250 MPa) contact metamorphic aureole to the subgreenschist sediments of the eastern belt (Sisson, 1985).

Previous work in the Scotia-Quaal area

Five studies provide preliminary information on the metamorphic conditions in the Scotia-Quaal belt. Padgham (1958) recognized that much of the belt had been metamorphosed to staurolite-kyanite grade. Money (1959) estimated metamorphic temperatures on Hawkesbury Island between 400 and 600°C. Runkle (1979) estimated metamorphic conditions on Hawkesbury Island (locality 8, Figure 2-1) at 550 to 660°C and 700 ± 100 MPa. The presence of fibrolite and diopside in the proximity of plutonic rocks on Hawkesbury Island was interpreted by Runkle as possibly resulting from contact metamorphism. Easterly increase in metamorphic grade in the central region was postulated by Roddick (1970) based on increase in abundance of biotite-garnet schist and sillimanite schist towards the east. Geothermobarometry on the West Scotia property (locality 9, Figure 2-1) gave temperatures of 565-600°C and pressures around 480 MPa based on mineral rim composition and 723°C-710 MPa based on garnet core composition (Krage, 1984). The low pressure estimates obtained from mineral rim compositions fall well below pressures predicted by the mineral assemblages and have been interpreted as a lower pressure limit, probably resulting from mineral reequilibration during uplift.

2.3 Metamorphism of pelitic and mafic rocks

Metapelitic assemblages

Pelitic assemblages are relatively rare and unevenly distributed in the Scotia-Quaal belt. Pelitic rocks occur predominantly as fine layers in the quartzite or, in one case, as a pelitic band of almost 1 km in thickness. Rare pelitic layers occur within the metavolcanic unit. Pelitic and semi-pelitic assemblages in 39 thin-sections from the study area are listed in Appendix 4A. The distribution of pelitic assemblages is summarized on Figure 2-2.

Figure 2-2: Geological map of the Scotia-Quaal metamorphic belt summarizing the distribution of metapelitic assemblages. MM = metamorphic.

Kyanite+staurolite+muscovite is the stable pelitic assemblage in the southern region of the Scotia-Quaal belt. Fibrolite occurs on Hawkesbury Island, but has been interpreted to result from contact effect of the Ecstall pluton.

Kyanite+staurolite+muscovite is stable on the western side of the central region. The assemblage staurolite+muscovite+kyanite+fibrolite+biotite+garnet occurs east of the Ecstall river. In this assemblage garnet might be stabilized as an extra phase by the presence of extra components such as Ca and Mn or relic staurolite may remain in disequilibrium with other minerals. The staurolite-bearing assemblage does not persist over a great distance to the east where pelitic samples contain the muscovite+almandine+ kyanite+fibrolite+biotite assemblage. It is likely that staurolite + muscovite reacted to produce almandine + kyanite + biotite. Further east, sillimanite appears and kyanite becomes unstable. At the contact with the Quottoon pluton, kyanite is no longer present.

Although fibrolite is widely distributed, it increases in abundance towards the east and sillimanite occurs only on the eastern side of the metamorphic belt. One sample at the Quottoon pluton contact is free of muscovite and contains sillimanite+potassic-feldspar indicating that metamorphic conditions in the area reached the second sillimanite isograd. Other samples in the area show no sign of potassic-feldspar and generally contain muscovite. The coexistence of samples at close proximity to each other with assemblages on either side of the reaction $\text{muscovite} + \text{quartz} = \text{Al}_2\text{SiO}_5 + \text{potassic-feldspar} + \text{H}_2\text{O}$ probably does not reflect a variation in grade, but more likely results from differences in the reaction threshold due to the presence of additional components such as Na substituting for K in muscovite or volatile species other than H_2O in the fluid phase, or to kinetic factors responsible for the persistence of the reaction over a finite temperature range. The presence of muscovite in many samples and absence of potassic-feldspar in all but one of the

samples examined suggests that metamorphic conditions are on the low-temperature end of the zone within which the reaction occurs.

In the northern region kyanite+fibrolite occurs on the western side of the metamorphic belt. Fibrolite was interpreted by Krage (1984) to have grown during rapid decompression of the belt, but could also at least partly result from an increase in temperature at the time of intrusion of the Ecstall pluton. Sillimanite is the stable aluminosilicate mineral on the eastern side of the northern region. The occurrence of muscovite and the absence of potassic-feldspar and cordierite indicate that metamorphism stayed below the upper sillimanite and the cordierite-garnet-potassic-feldspar zones.

Gedrite occurs in K-poor pelitic rocks on the western side of the belt both in the central and in the northern regions. In the central region, it is associated with biotite, staurolite and almandine, whereas in the northern region it is associated with biotite±kyanite (and trace of fibrolite). This difference in mineral assemblage could result from differing bulk rock composition or indicate slightly different metamorphic conditions.

Metamorphism of mafic rocks

Mafic assemblages

In the Scotia-Quaal area the relative abundance of mafic volcanic rocks allows to acquire more widespread information about metamorphic conditions than is obtained from the pelitic assemblages. Metabasites occur throughout the metamorphic belt, but mostly within the metavolcanic unit situated more or less in the center of the area, within the layered gneiss unit and as dykes in other units.

The minerals present in mafic rocks of the Scotia-Quaal area are quartz+plagioclase+amphibole±epidote±chlorite±carbonate+titanite, ilmenite and/or rutile±K-mica±garnet±apatite±pyrite and/or chalcopyrite (Table 2-1 and Appendix 4B). In the

chlorite-bearing rocks, at least some chlorite texturally appears to have formed by later retrogressive replacement of hornblende and biotite; prograde chlorite is differentiated with difficulty from retrograde chlorite.

The mineral assemblage in mafic rocks indicates that they were metamorphosed at epidote-amphibolite to upper amphibolite grade. The distribution of mafic assemblages (Figure 2-3) indicates a south to north and west to east increase in metamorphic grade. Metabasic rocks in the southern region away from the Ecstall and Quottoon pluton typically contain chlorite and chlorite+tremolite+hornblende where hornblende is replacing tremolite. In the central region, metabasites contain hornblende and chlorite in various proportions with increasing hornblende abundance towards the east. Eventually chlorite disappears from the stable assemblage. At the easternmost margin of the belt clinopyroxene appears in the mafic assemblage. Chlorite is absent from the mafic assemblage in the northern region. Hornblende+clinopyroxene is the stable assemblage.

On either margin of the southern region of the belt and on Hawkesbury Island, metamorphic grade appears to be slightly higher than that recognized in the central part of the southern region (Figure 2-3). At these locations, chlorite and tremolite are absent and hornblende±garnet is stable. This observation may be explained in two ways: first, metamorphic grade may be truly higher in these regions due to contact metamorphism caused by the late intrusions of the Ecstall and Quottoon plutons; secondly, the bulk rock composition may differ enough from that of mafic rocks in the central part of the belt to produce a different assemblage. The absence of chlorite from mafic rocks at the western margin of the belt in the central region may also have the same cause(s).

Figure 2-3: Geological map of the Scotia-Quaal metamorphic belt summarizing the distribution of mafic assemblages. MM = metamorphic.

Variation in mafic mineral composition across the central region

Introduction

The metamorphism of mafic igneous rocks is characterized by continuous variations in mineral chemistry and modal proportions rather than phase changes. For this reason, although mafic assemblages are poorly calibrated and do not provide pressure and temperature values, the study of mafic rocks allows observation of gradational changes in metamorphic conditions.

Evidence for an easterly gradient in regional metamorphism is drawn from a detailed study of 9 mafic samples across the central region of the Scotia-Quaal belt. The study is based on the premise of dependence of mineral composition on metamorphic grade for rocks of identical bulk composition. This approach has been used successfully by many petrologists including for example Harte and Graham (1975), Laird (1980), Laird and Albee (1981a and 1981b), Leake (1965), Liou et al. (1974) and Raase (1974).

Sample locations are shown on Figure 2-4 and in Appendix 1B. UTM coordinates are given in Appendix 2. The mineral assemblage of each specimen is presented in Table 2-1. Samples belonging to the metavolcanic belt (11A-7 excepted) are assumed to have identical bulk composition such that changes in mineral composition can be attributed to variations in metamorphic grade. This assumption cannot be applied to samples collected from rocks with different protoliths (88-84-3 & 87-145-2). Minerals analysed are assumed to have equilibrated at peak regional metamorphic conditions.

Electron microprobe analyses of minerals from samples of the study area were obtained at Carleton University and are presented in Appendix 6. Electron microprobe techniques (described in Appendix 5) do not allow differentiation between Fe^{2+} and Fe^{3+} ; the following three approaches can be taken to this problem: (1) assume all Fe is ferrous, (2)

Figure 2-4: Sample location map for study of metabasic rocks in the central region of the Scotia-Quaal metamorphic belt. MM = metamorphic.

**Table 2-1: Mineral assemblages in metabasic rocks from the central region of the Scotia-Quaal belt (in order of geographical west to east location).
Equivalence between abbreviations and mineral names are given in Appendix 3. MS stands for Metasedimentary.**

Sample #	Rock Type	Unit	Qtz	Plag	Chl Act	Hb	Px	Epi	Cc	Bt	WM	Tit	Ilm	Rut	Ap	Sx	Gn	Other
87-203-3	Mafic schist	Metavolcanic	3		3	90				3	Tr							l-opaque (spinel?)
87-84-2	Chl. schist	Metavolcanic	40	3-Olig	15	37		Tr(relict)		<5		<1						
87-175-1	Chl. schist	Metavolcanic	10	3-Olig	39	5		25		25			1			1-Py		
88-73-3	Chl. schist	Metavolcanic	40	1-And.	40	10		4		1 to 2			1		Tr		<5	
86-11A-7	Qtz-mn schist	Metavolcanic	60(Qtz+ Celsian)			15		5			10				Tr	5-Py/Cpy		
86-5B-2	Chl. schist	Metavolcanic	25	7-Olig	25	20		10	20						Tr	2-Py/Cpy		
87-182-1	Chl-hio schist	Metavolcanic	30	Tr-Ab to And	25	10		5	8	20			1	1	Tr			
88-84-3	Bio-hbd gneiss	Clastic MS	Tr	30-And		50	10-Salite			10					Tr			Tr-opaque
87-145-2	Amph. dyke	Quartzite	5	30-And		50				10		2	1		1		1	

use a constant $\text{Fe}^{3+}/\text{Fe}_T$ ratio based on measured (by wet chemical analysis) $\text{Fe}_2\text{O}_3/\text{FeO}$ values for each mineral in similar rocks, and (3) attempt to calculate Fe^{2+} and Fe^{3+} by determining the structural formula of the mineral based on cation (rather than anion) distribution (See Laird and Albee, 1981a for examples of calculation techniques; Appendix 5). Assuming iron to consist totally of Fe^{2+} is simplest, although it introduces errors in the structural formula. Using a constant $\text{Fe}^{3+}/\text{Fe}_T$ ratio is also easy and has the advantage of recognizing that at least some of the iron is Fe^{3+} . The advantage of calculating the structural formula of minerals based on cation distribution is that it takes into account the behaviour of each cation; the most obvious problem with the calculation is that it gives variable $\text{Fe}^{3+}/\text{Fe}_T$ ratios in a particular mineral, whereas wet chemical analysis often produces relatively constant ratios for a particular mineral, at least in rocks of similar composition regionally metamorphosed together. Laird and Albee (1981a) fully recognized that such estimates of Fe^{2+} and Fe^{3+} can be subject to major errors, but based on observations of complex Fe^{2+} and Fe^{3+} zoning in minerals, they considered the method superior to arbitrary assignment of Fe^{2+} and Fe^{3+} to a fixed value. In this study, structural formulae have been calculated both according to anion distribution, with total iron as FeO , using the appropriate normalization factor (See Appendix 6) for each particular mineral and by using the cation distribution procedure presented by Laird and Albee (1981a), which separates Fe^{2+} and Fe^{3+} . Data obtained by these two methods are compared in order to evaluate the effect of the structural formula calculation technique on results and interpretations.

Results

Changes in metamorphic conditions are most readily observed through amphibole and chlorite compositional variations. Relevant analytical data for amphibole and chlorite from the Scotia-Quaal metamorphic belt are given in Tables 2-2 and 2-3.

Table 2-2: Analytical data for amphiboles from metabasic rocks collected in the central region of the Scotia-Quaal belt. The data are used in Figures 2-5 to 2-8.
Complete electron microprobe data are given in Appendix 6.

Thin Sec.	87-203-3	87-84-2	87-84-2	87-175-1	87-175-1	87-73-3	86-11A-7	86-5B-2	86-5B-2	86-5B-2	87-182-1	87-182-1	88-84-3	87-145-2
# of analyses	N-8	N-4	N-2	N-1	N-1	N-12	N-4	N-1	N-1	N-1	N-1	N-1	N-4	N-5
100Na/Ca+Na	9.642	21.086	15.723	17.707	18.294	19.774	6.264	17.791	16.394	20.274	9.880	14.684	10.154	17.794
100Al/Si+Al	16.768	28.293	19.046	26.850	31.642	34.191	14.072	25.834	20.336	23.178	9.627	23.063	20.031	26.846
NaMg	0.136	0.245	0.213	0.188	0.151	0.221	0.047	0.126	0.142	0.112	0.191	0.238	0.080	0.144
NaAl	0.063	0.224	0.120	0.202	0.263	0.217	0.084	0.280	0.223	0.368	0.007	0.066	0.137	0.258
NaA+K	0.115	0.270	0.154	0.250	0.325	0.298	0.106	0.307	0.243	0.401	0.026	0.106	0.280	0.408
AlVI+Fe3+Ti+Cr	1.080	1.581	1.192	1.554	1.667	1.849	0.652	1.397	1.158	1.062	0.901	1.608	1.014	1.242
AlVI+Fe3+Ti	0.996	1.570	1.176	1.539	1.664	1.840	0.630	1.397	1.137	1.031	0.883	1.586	0.971	1.231
AlVI	0.296	0.838	0.430	0.681	0.908	1.168	0.422	0.615	0.416	0.633	0.080	0.426	0.415	0.536
Ti	0.037	0.057	0.043	0.034	0.069	0.040	0.053	0.032	0.036	0.017	0.043	0.041	0.057	0.159
K	0.052	0.046	0.034	0.048	0.062	0.081	0.022	0.027	0.020	0.033	0.019	0.040	0.143	0.240
AlIV	1.095	1.663	1.175	1.650	1.911	1.966	0.763	1.611	1.295	1.368	0.779	1.518	1.271	1.755

Thin Sec.	87-203-3	87-84-2	87-84-2	87-175-1	87-175-1	87-73-3	86-11A-7	86-5B-2	86-5B-2	86-5B-2	87-182-1	87-182-1	88-84-3	87-145-2
# of analyses	N-8	N-4	N-2	N-1	N-1	N-12	N-4	N-1	N-1	N-1	N-1	N-1	N-4	N-5
AlVI	0.296	0.838	0.430	0.681	0.908	1.168	0.422	0.615	0.416	0.633	0.080	0.426	0.415	0.536
Si	6.905	6.337	6.825	6.35	6.089	6.034	7.237	6.389	6.705	6.632	7.221	6.482	6.729	6.245
Ti	0.037	0.057	0.043	0.034	0.069	0.040	0.053	0.032	0.036	0.017	0.043	0.041	0.057	0.159
Rel. location	1	2	2	3	3	4	5	6	6	6	7	7	8	9

Normalization to 13 total cation less (Ca + Na + K)

Thin Sec.	87-203-3	87-84-2	87-84-2	87-175-1	87-175-1	87-73-3	86-11A-7	86-5B-2	86-5B-2	86-5B-2	87-182-1	87-182-1	88-84-3	87-145-2
# of analyses	N-8	N-4	N-2	N-1	N-1	N-12	N-4	N-1	N-1	N-1	N-1	N-1	N-4	N-5
AlVI	0.417	0.970	0.562	0.840	1.043	1.296	0.450	0.543	0.759	0.215	0.637	0.508	0.639	
Si	7.006	6.432	6.931	6.466	6.181	6.117	7.261	6.806	6.496	7.342	6.644	6.804	6.32	
Ti	0.038	0.057	0.044	0.035	0.071	0.041	0.033	0.053	0.016	0.044	0.042	0.048	0.07	0.161
Rel. location	1	2	2	3	3	4	5	6	6	7	7	8	8	9

Normalization to 23 oxygen anions

A first estimate of regional metamorphic pressures is obtained by comparing the $\text{Al}^{\text{VI}}/\text{Si}$ ratios in amphiboles of the area with ratios in amphiboles of world-wide occurrences plotted by Raase (1974). Figure 2-5 illustrates the $\text{Al}^{\text{VI}}/\text{Si}$ relationship in amphiboles of the area for formulae obtained with Fe^{3+} calculated according to 13 Total less ($\text{Na}+\text{Ca}+\text{K}$) cations (Appendix 5 and Laird and Albee, 1981a) and with Fe assumed all ferrous. The diagonal solid line on these plots indicate the maximum possible Al^{VI} as determined by Leake (1965). The dashed line was obtained by analysis of amphiboles from petrographically well-known regional metamorphic terranes (Raase, 1974); it separates high-P data points from low-P points. All samples of the study area except 88-73-3 plot along a relatively narrow band; this indicates that pressure was relatively constant in the metamorphic belt, or at least in the metavolcanic unit where bulk rock composition is assumed uniform. Sample 88-73-3 appears to have been metamorphosed under slightly higher pressure conditions. In the first plot in which a Fe^{3+} value is calculated, regional pressure conditions appear to be slightly below 500MPa except for sample 88-73-3 which plots in the high-pressure field. In the second plot, for Fe assumed all ferrous, slightly higher pressures around and above 500MPa are indicated. Amphiboles from the samples collected in the central region of the Scotia-Quaal metamorphic belt have Al-contents consistent with medium pressure conditions of metamorphism. This is in agreement with the pressure range indicated by the occurrence of kyanite and sillimanite but not andalusite in pelitic rocks and by the absence of high-pressure minerals such as jadeite, lawsonite and glaucophane.

An estimate of regional metamorphic grade is given by comparison of titanium content in amphiboles of the study area with that in amphiboles from petrographically well known regions (From Raase, 1974). In Figure 2-6, the Ti content indicates epidote-amphibolite to lowest amphibolite facies of metamorphism except in sample 11A-7 where the unusual Ti

87-203-3	87-84-2	87-175-1	88-73-3	86-11A-7	86-5B-2	87-182-1	88-84-3	87-145-2
W								E
Massive sulphide								

Figure 2-5: Relation between Al^{VI} and Si in amphiboles of the Scotia-Quaal area. Location of 500MPa line from Raase (1974). (A) Mineral formula calculated based on 13 - (Ca+Na+K) cations, $\text{Fe}_T = \text{Fe}^{2+} + \text{Fe}^{3+}$, (B) 23-oxygen mineral formula, Fe assumed all ferrous.

Figure 2-6: Plot of Ti in amphibole versus location across the central region of the Scotia-Quaal area. Facies boundaries from Raase (1974). (A) Mineral formula calculated based on 13 - (Ca+Na+K) cations, $Fe_T = Fe^{2+} + Fe^{3+}$, (B) 23-oxygen mineral formula, Fe assumed all ferrous.

content of some of the amphiboles are attributed to unusual rock composition and in sample 87-145-2 where the very high Ti content reflects upper amphibolite facies conditions.

Various compositional relationships between amphiboles from the 9 samples of the study area are shown in Figure 2-7. The structural formulae for data plotted in this figure have been calculated on the basis of Total-(Na+Ca+K) cations=13 in order to facilitate comparison with data from amphiboles in metavolcanic rocks from Vermont treated in that fashion by Laird and Albee (1981b). The envelopes on each plot delimit the amphibole compositions at biotite-, garnet-, and staurolite/kyanite-grade in the samples from Vermont. Grade increases along a more or less constant positive slope line towards the upper right corner of each plot. The composition of amphiboles from the central region of the Scotia-Quaal area do not fit within the envelopes defined by the rocks from Vermont. The Scotia-Quaal points fall within or in the proximity of compositional fields defined by the Vermont samples which are characteristic of lower grade than that defined in the Scotia-Quaal area based on pelitic assemblages. Most samples plot in the vicinity of the biotite and garnet grade fields obtained from samples from Vermont when they should plot in the staurolite-kyanite grade field or at higher grade. This is probably, at least partially, due to differences in bulk rock composition and pressure conditions between the two areas. The effect of differences in bulk rock compositions is best exemplified by the two easternmost samples (88-84-3 and 87-145-2) which have a different protolith than the other samples; these two amphibolites differ quite substantially from the other samples in their Al^{VI} , Ti and K contents. The influence of pressure on metamorphic amphibole composition is poorly understood. Yet another explanation for the discrepancy between the metamorphic grade indicated by the pelitic assemblage and that inferred from amphibole composition by comparison with the Vermont compositional fields is that mafic rocks in the Scotia-Quaal area were affected by late retrogressive metamorphism.

Figure 2-7: Comparative relationships in amphiboles from the central region of the Scotia-Quaal metamorphic belt. Envelopes are for comparison with samples from Underhill, Pinney Hollow, Ottauquechee, and Missiquoi Formations in Vermont (From Laird and Albee, 1981b, Fig. 2) and delimit greenschists intercalated with biotite grade pelitic schists (-----), epidote-amphibolites and low-grade amphibolites with garnet grade pelitic schists (——) and amphibolites with staurolite-kyanite grade pelitic schists (.....) in samples from Vermont. Mineral formula based on 13 - (Ca+Na+K) cations. Reference to samples 11A-7, 182A and 182B is made in the text.

Nonetheless, Scotia-Quaal amphibole points do move up slope from west to east until the massive sulphide deposit is reached. They show an increase in Al^{VI} , Ti and Al^{IV} which indicates an increase in tschermak substitution. Na^{M4} and $Al^{VI}+Fe^{3+}+Ti+Cr$ also increase suggesting glaucophane substitution. Rising Na^A and K contents are indicative of edenite substitution. This systematic and gradual increase in tschermak, glaucophane and edenite substitutions west of the Ecstall deposit is not consistent with compositional changes caused by variations in bulk rock composition which would likely produce more scattered data. The variation in amphibole composition suggests a gradual increase in temperature from west to east until the massive sulphide deposit is reached.

Amphiboles from the massive sulphide host rock have comparatively low $Na/Ca+Na$, $Al/Si+Al$, Na^{M4} , Na^A , $Al^{VI}+Fe^{3+}+Ti+Cr$, Al^{VI} , Al^{IV} and K values, but the data points do fall along the slope lines defined by the other samples. This sample is interpreted to have, at some point during its history, been affected by fluids concentrated in the sulphide deposit zone.

Amphiboles from sample 87-182-1 appear to have a bimodal distribution in composition (Figure 2-7); some amphiboles from this specimen have compositions similar to amphiboles of sample 11A-7 (182A; Figure 2-7), while compositions of others are indicative of growth at higher metamorphic grade (182B; Figure 2-7). This may be the result of partial retrogression in this sample which was collected from a zone of the metavolcanic unit relatively rich in calcite and disseminated pyrite. These minerals could have formed during a retrogressive metamorphic event involving movement of fluids in preferential zones. Interestingly this sample also contains three plagioclase compositional ranges: albite (An 2.6 to 3.6), oligoclase (An 17 to 24) and andesine (An 32 to 38); these are indistinguishable in thin-section. Albite and low Fe and Al amphibole could have formed early in the metamorphic history of the rock or during late retrogressive

metamorphism close to the massive sulphide zone acting as a channel for fluids. Andesine and high Fe and Al amphibole could approach plagioclase and amphibole compositions produced by the last prograde metamorphic event. Additional analytical work for a statistically meaningful distribution in amphibole and plagioclase compositions is needed to confirm this hypothesis.

Samples 88-84-3 and 87-145-2 have protoliths different from samples collected in the metavolcanic unit and their composition cannot be meaningfully compared with that of the metavolcanic samples. A striking reminder of this is the position on the plots of the data points for sample 88-84-3. Based on direct comparison with the other samples, this rock would be interpreted to have been metamorphosed at relatively low grade, but the mineral assemblage in the specimen (no chlorite, salite replacing hornblende & andesine) indicates that the sample reached high amphibolite grade. High Na, Al (Al^{VI} and Al^{IV}), Ti and K content in amphiboles from sample 87-145 are consistent with the high metamorphic grade expected close to the Quottoon pluton contact. Comparatively low Na^{M4} content is probably related to bulk rock composition.

Analyses of chlorites (Figure 2-8) from mafic schists of the Scotia-Quaal area are more difficult to interpret. Al^{VI} and Al^{IV} increase irregularly from west to east until the deposit is reached. Ti contents are more or less constant. The sulphide deposit host (11A-7) does not contain any chlorite. The large differences in Al^{VI} , Al^{IV} and Ti contents in sample 5B-2 and the low Al^{IV} content in sample 87-182-1 are attributed to alteration in the proximity of the massive sulphide deposit.

An AFM projection of the main metamorphic minerals in mafic samples of the central region of the Scotia-Quaal belt is shown in Figure 2-9. Projection from epidote onto the AFM plane displays mineral paragenesis in the $CaO-Al_2O_3-FeO-MgO$ subsystem and allows observation of Fe/Mg and Al substitution in silicates during metamorphism. Such a

Figure 2-8: Compositional relationships in chlorite from mafic schist in the central region of the Scotia-Quaal belt. Envelopes are for comparison with samples from Vermont (From Laird and Albee, 1981b, Fig. 4) and delimit chlorite composition for greenschists intercalated with biotite grade pelitic schists (-----), epidote-amphibolites and low-grade amphibolites with garnet grade pelitic schists (——) and amphibolites with staurolite-kyanite grade pelitic schists (-----) in samples from Vermont. $Fe = Fe^{2+} + Fe^{3+}$; Fe^{3+} calculated on the basis of 13 cations - (Ca+Na+K). Analytical data presented in Table 4-3.

Table 2-3: Analytical data for chlorite from metabasic rocks collected in the central region of the Scotia-Quaal belt. The data are plotted in Figure 2-9. Normalization to 28 oxygen anions

Thin Sec.	87-203-3	87-84-2	87-175-1	87-73-3	86-5B-2	86-5B-2	86-5B-2	87-182-1
# of analyses	N=2	N=9	N=8	N=6	N=1	N=1	N=1	N=6
Al^{VI}	1.157	1.253	1.214	1.333	1.266	1.200	1.614	1.120
Ti	0.010	0.011	0.010	0.012	0.002	0.000	0.009	0.012
Al^{IV}	1.306	1.300	1.433	1.411	1.296	1.340	1.069	1.337

2

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

Figure 2-9: Mol % $\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 - \text{Na}_2\text{O}$ (A) versus $\text{FeO} + \text{MnO}$ (F) versus MgO (M) diagrams for compositions of coexisting minerals in medium-P facies series mafic rocks of the Ecstall-Quaal rivers area, projected from epidote. Quartz, plagioclase and epidote present in the assemblage. Fe assumed all ferrous in (A) and Fe^{3+} calculated according to 13 Total less (Ca+Na+K) cations method in (B). Vertical scales on the left-hand side of the page measure:

$$\frac{[(\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3) - (0.75\text{CaO} + \text{Na}_2\text{O})] * 100}{(\text{FeO} + \text{MgO} + \text{MnO}) + [(\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3) - (0.75\text{CaO} + \text{Na}_2\text{O})]}$$

projection is valid in metabasites with ubiquitous quartz and low-Ca plagioclase and with fluids composed entirely of H_2O and CO_2 (at fixed X_{CO_2}).

Quartz is ubiquitous in samples from the central region of the Scotia-Quaal metamorphic belt. Additional constituents (such as K_2O and TiO_2) are present only in minor amounts in the dominant minerals of the assemblage and their presence is balanced by addition of components such that the variance of the assemblage in the $CaO-Al_2O_3-FeO-MgO$ subsystem is not significantly affected. Plagioclase of some of the samples is quite anorthitic; this forbids more than a semi-quantitative use of the projection which is based on the presence of albitic plagioclase. Restricted variation in f_{O_2} is assumed because of the lack of hematite and magnetite in the rock. Fe_2O_3 is ignored in Figure 2-9A and calculated according to 13 total less (Na+Ca+K) cations (Laird and Albee, 1981) in Figure 2-9B.

Both plots show increasing Fe^{2+} content in amphibole and chlorite as well as a change in Fe^{2+}/Mg distribution between amphibole and chlorite in favor of the amphibole in samples from west to east until the massive deposit is reached. Garnet is present in the easternmost sample before the deposit ; this is consistent with extension at higher metamorphic grade of the garnet stability field to higher Mg/Fe rock compositions.

Chlorite and amphibole from metavolcanic samples east of the deposit have low Fe^{2+} content that can be related to decrease in metamorphic grade or change in rock composition. Tie-lines from these samples cross-cut the tie-lines from the samples west of the deposit and cross-cut each other. This suggests changes in bulk rock composition. Fe^{2+}/Mg distribution between amphibole and chlorite suggests that metamorphic grade east of the deposit is lower than the grade immediately west of the deposit. Sampling density does not allow to determine if the metamorphic grade of volcanic rocks east of the massive sulphide deposit increases or decreases with distance from the deposit or if the rock composition changes in an orderly manner away from the deposit.

Summary and discussion of information given by mafic and metapelitic rocks

Metamorphic conditions vary from kyanite-staurolite grade in the southern region and on the western side of the central region, to kyanite grade on the western side of the northern region and sillimanite grade on the eastern side of the central and northern regions. Mafic rocks have assemblages indicative of epidote-amphibolite to upper amphibolite facies of metamorphism with a metamorphic gradient coinciding with the gradient shown by the pelitic assemblages. The northeasterly metamorphic gradient could be regional in nature, caused by heat input from younger plutonic bodies such as the Quottoon pluton or the result of both effects.

In the central region, the metamorphic facies indicated by the pelitic assemblages differ from the metamorphic facies inferred from the mafic mineral assemblages. Epidote-amphibolite facies mafic rocks are stable in the same region as the pelitic assemblage kyanite+staurolite which usually correspond to amphibolite facies in mafic rocks. The same observation was made when Scotia-Quaal amphibole compositions were plotted in metamorphic fields defined by samples from Vermont. The apparent misfit in Scotia-Quaal amphibole compositions with respect to the metamorphic grade defined by pelitic assemblages is probably due to differences in bulk rock composition and/or in pressure conditions between the Scotia-Quaal belt and the rocks from Vermont. It is possible that in the Scotia-Quaal area the chlorite field extends to higher metamorphic grades than generally observed.

Subtle changes in regional grade across the central region of the metamorphic belt are suggested by variations in mineral compositions in metabasic rocks. Metamorphic grade appears to increase gradually from west to east until the massive sulphide deposit is reached. This gradient is attributed to regional metamorphism rather than contact

metamorphism caused by the Quottoon pluton for three reasons. First, even though the Quottoon pluton might have a contact aureole it is unlikely for such an aureole to be so large as to affect samples between 6 and 12 kilometers away from the Quottoon pluton; if it were so then the Ecstall pluton immediately west would likely be affected too. Second, K-Ar dates on hornblende in the middle of the central region (See Chapter 3) are inconsistent with heat input from the east around the time of intrusion of the Quottoon pluton (refer to Figure 3-11). Finally, the easterly increase in metamorphic grade is consistent with the regional metamorphic gradient documented by Crawford et al. (1987) in the whole of the western belt.

Increased sampling density close to the deposit on both sides could help us unravel the history of the massive sulphide deposit and understand its role with respect to metamorphism in its vicinity. An unusual mineral assemblage (quartz-celsian-actinolite-epidote-white mica-rutile-pyrite-chalcopyrite) is present in the massive sulphide host. Mineral compositions in metabasites located east of the deposit do not follow the compositional trend exhibited west of the deposit; they are consistent with metamorphic grades lower than those indicated on the west side. This is particularly noticeable in a plot of Fe/Mg distribution between chlorite and amphibole (Figure 2-9). Lower metamorphic grade could be the result of late retrogressive metamorphism in the proximity of the massive sulphide deposit along which fluids could have been transported. Cross-cutting tie-lines suggest that bulk rock composition also differs on either side of the deposit. It is possible for the compositional changes close to the deposit to be related to formation of the deposit or to later alteration in the vicinity of the deposit.

Variations in chlorite composition correlate with variations in composition of other minerals of the assemblage. This concurrence indicates that chlorite belongs to the

assemblage and is not totally a product of late retrograde metamorphism. No evidence for polymetamorphism is preserved in the metabasites.

My final comment addresses the effect of the structural formula calculation technique on results and interpretation. Unexpectedly high and variable $\text{Fe}^{3+}/\text{Fe}^{2+}$ ratios are obtained when the structural formulae of minerals are calculated according to cation distribution as proposed by Laird and Albee (1981a). For example, such calculations for amphiboles of the Ecstall-Quaal area give ferric iron contents anywhere between 19% and 65% when Fe^{3+} typically makes up only 20 to 30% of the total iron in Ca-amphiboles. On an AFM diagram projected from epidote (Figure 2-9), the Fe^{3+} calculation emphasizes the difference in Mg/Fe distribution between chlorite and amphibole. Low grade amphiboles are closer to the M apex of the triangle and the Fe/Mg ratio increases more rapidly with increasing temperature than for the same minerals in which Fe has been assumed to consist exclusively of Fe^{2+} . In spite of these differences, compositional plots are strikingly similar. The same trends in mineral compositions are observed and the same conclusions are reached with respect to gradients in metamorphic conditions.

2.4 Geothermobarometry in the metamorphic belt

So far in this chapter the stable mineral assemblages throughout the Scotia-Quaal belt have been described, the general metamorphic conditions consistent with these assemblages have been established and a northeasterly metamorphic gradient at least partly due to regional metamorphic conditions has been documented. Additional work presented in this section is aimed at confirming metamorphic conditions and quantifying the nature of the metamorphic gradient with respect to pressure and temperature via geothermobarometry. Many problems, some discussed in the following pages, stand in the way of putting accurate numbers on metamorphic conditions recorded in rocks found at the earth's

surface. The need for careful petrographic examination, detailed analytical work, and time-consuming calculations and tests for chemical equilibrium often preclude applying the method to large areas. Many studies apply as many geothermobarometers as possible to small areas and regional conditions are established by comparing P-T conditions in areas a certain distance apart and extrapolating the results. This was the approach for previous work in the Coast Plutonic Complex at the latitude of the study area. Studies were conducted in various small areas dispersed across the Coast Plutonic Complex and numbers were compared to infer a regional metamorphic history. The emphasis of the present study is on the metamorphic gradient across the whole of the Scotia-Quaal belt, a region approaching 2000 square kilometers in size. The study is not aimed at finding the number reflecting with the most accuracy the exact conditions at which a particular rock was equilibrated, an impossible task! The emphasis is put on obtaining reasonably accurate data throughout the belt, the data being obtained in a consistent fashion so as to allow comparison of results throughout the belt. This section comprises a discussion of the thermobarometric technique, presentation of data from 12 garnet-bearing metamorphic rocks and a discussion of results.

Geothermobarometry - Background information

Definition

Geothermobarometry is a technique that uses the composition, structure and inclusions of a mineral or mineral assemblage to determine the temperature and/or pressure of equilibration of a rock, mineral or fluid. Three main categories of geothermobarometry exist: exchange thermometry, phase equilibria and other methods such as the study of fluid inclusions.

Problems related to the application of geothermobarometers

Most geothermobarometers are based on the pressure and temperature dependence of the equilibrium constant. The equilibrium constant is determined by measuring mineral compositions and converting them into activities through the application of the activity coefficient, which varies in complex fashion with temperature, pressure and composition. Problems are encountered when deciding on an activity model that best represents mixing of the phases involved in the geothermobarometer.

Another fundamental problem is related to the basic assumption that the mineral compositions used for geothermobarometry represent equilibrium coexistence. Careful petrographic observation can help to evaluate the degree of chemical equilibrium in a sample. Spear and Peacock (1989) suggests the following tests for chemical equilibrium.

- 1) Analyze minerals for zoning which is a reflection of disequilibrium. If zoning is revealed, one must decide which part of the zoned mineral is in equilibrium with other minerals.
- 2) Check for crossing tie-line relations and overlapping volumes in compositional plots. These indicate disequilibrium conditions.
- 3) Check for consistency in element partitioning within a thin-section and among a suite of samples.
- 4) Check for consistency of temperatures and pressures obtained over a small area.
- 5) Apply many thermobarometric calculations to a suite of rocks.
- 6) Evaluate the P-T conditions obtained with respect to the regional context.

Reequilibration of minerals during uplift and cooling of the rock has an important effect on thermobarometers based on continuous reactions. Mineral compositions may change as the rock evolves along a retrograde portion of its P-T path until the rock has cooled to the closure temperature of the system under study. Different equilibria have different closure temperatures depending on the reaction kinetics and the relative diffusion rates within various minerals (Spear and Peacock, 1989). These differences in closure temperature

between various systems on which different thermobarometers are based may have important effects, as yet poorly understood, on the application of many thermobarometers for obtaining a P-T point.

In attempting to calculate peak conditions in a sample, one would likely encounter problems in finding mineral compositions reflecting peak prograde conditions. Core compositions of zoned minerals are usually chosen to represent peak metamorphic conditions although it may not always be the case. Unzoned minerals such as biotite, which has a large Fe-Mg diffusion coefficient allowing it to rapidly change composition compared to garnet, are usually assumed to approach peak compositions if the mineral is present in large proportion and if the mineral's composition is consistent throughout the thin section. At best, calculations based on these assumptions will provide a minimum value.

Similarly, geothermobarometry based on mineral rim compositions may actually reflect the closure temperature of the system under study. At best, this approach gives a minimum estimate of peak metamorphic conditions for an exchange mechanism and an estimate below or above the peak metamorphic conditions, depending on the reactions involved in a net transfer mechanism (Spear and Peacock, 1989).

The approach taken in the present study is to calculate minimum metamorphic conditions based on garnet rim composition except when there are strong textural or analytical arguments for disequilibrium of garnet rims with the sample's matrix. Garnet rim compositions are assumed to be closest to equilibrium with matrix minerals at the scale of the thin-section or less. The consistency of matrix mineral composition is verified as well as that of garnet rim composition. At the scale of the thin-section, the minerals under study must occur in contact with each other in order to ascertain that they form the equilibrium assemblage. However, contiguous mineral pairs are not used for

geothermobarometry because they probably reequilibrated through an exchange mechanism after peak metamorphism.

Although it is not possible to ascertain without doubt that chemical equilibrium between phases involved was attained, careful petrographic observation was done to evaluate the degree of equilibrium in each sample and identify areas of disequilibrium. Analytical traverses were done in many minerals to check for zoning and when zoning was identified a decision was taken as to which mineral composition was closest to equilibrium with other minerals in the sample. Reasons for selecting a particular mineral composition are given. Consistency in element partitioning was examined within each thin-section, but not among a suite of samples. Because of the scale of the study, consistency of temperatures and pressures over a small area was not verified. All pressure and temperature estimates are evaluated in the regional context.

Error analysis - Precision and accuracy

Precision is defined as the degree of agreement of repeated measurements of a quantity. In geothermobarometry, precision depends on the quality of the electron microprobe analyses. Analytical errors will produce scatter in P-T estimates. Papers describing new calibrations for geothermobarometry usually give an estimate of precision calculated from error propagation based on assumed analytical error of $\pm 3-5\%$ or from repeated measurements of one quantity.

The accuracy of a measurement is the extent to which the measurement approaches the real value. This translates into the question of how close are P-T estimates based on geothermobarometry to real P-T conditions to which the rocks were subjected. Accuracy in geothermobarometry is a function of the accuracy of the electron microprobe analyses, the degree to which an activity model represents with accuracy the activity-composition relationship and the accuracy of the thermodynamic data used. All these factors are poorly

known. Attempts at calculating accuracy have led to discouraging results. For example Hodges and McKenna (1987) have calculated an accuracy of ± 500 MPa for garnet-plagioclase geobarometry. Attempts at estimating accuracy by comparing results obtained from various independent techniques may do nothing more than demonstrate the internal consistency of the different methods (Spear and Peacock, 1989).

The root of the problem encountered in attempting to estimate accuracy in geothermobarometry lies in the fact that the system is studied from within, and therefore a reference point is defined from inside the system. For this reason, geothermobarometric studies cannot aim at measuring absolute values, but should compare data based on the same reference point. Approached in this manner, the attainment of accuracy in geothermobarometry is secondary to attainment of precision and internal consistency.

Review of thermobarometers applied to garnet-bearing samples of the Scotia-Quaal belt.

Fe-Mg exchange thermometry

Garnet-biotite

This thermometer is based on intercrystalline Fe-Mg exchange between coexisting garnet and biotite through the reaction:

Numerous calibrations of this thermometer have been proposed: Thompson (1976), Goldman and Albee (1977), Ferry and Spear (1978), Perchuk and Lavrent'eva (1983), Hodges and Spear (1982), Ganguly and Saxena (1984) and Indares and Martignole

(1985). Both Thompson's (1976) and Goldman and Albee's (1977) calibrations were derived empirically. Thompson (1976) calibrated the thermometer by correlating K_D values of natural biotite-garnet assemblages against estimated temperatures based on experimental phase equilibria. Goldman and Albee (1977) correlated K_D values with temperatures derived from quartz-magnetite oxygen isotope geothermometry. These two calibrations are said to give lower temperatures than the Ferry and Spear (1978) calibration which is based on experiments conducted in a purely binary system in which the Fe/Fe+Mg was held constant at approximately 0.9. The cause of this discrepancy may be that both empirical thermometers represent cooling temperatures for Fe-Mg exchange between garnet and biotite or oxygen isotope exchange (Spear and Peacock, 1989). Perchuk and Lavrent'eva also calibrated the thermometer experimentally, this time in systems held around 0.6 Fe/Fe+Mg. Hodges and Spear (1982) applied the Ferry and Spear (1978) calibration using a non-ideal mixing term for Ca in garnet. This procedure results in a temperature increase for garnets rich in Ca. Ganguly and Saxena's (1984) method, also based on the Ferry and Spear (1978) calibration, attempts to take into consideration the non-ideal behaviour of not only Ca, but also Mn and Fe-Mg solid solution in garnet. This calibration will give results similar to those of Ferry and Spear (1978) for samples containing Mn-poor garnet, but significant differences will appear with increasing Mn-content in garnet. Indares and Martignole's calibration (1985) combines the experimental data of Ferry and Spear (1978) with data from natural garnet-biotite occurrences in order to take into account the effect of Ti and Al^{VI} in the biotite solution model. It results in temperatures lower than without this correction. The effect of the correction is small in low-grade rocks with little Al^{VI} and Ti in biotite, but may be as large as 100°C in high-grade rocks.

Chipera and Perkins (1988) conducted a comparative study of the different garnet-biotite geothermometers. They concluded that there are large variations in absolute temperatures and in precision of each calibration and that geothermometers based solely on $\ln K_D$ give more precise results than the calibrations that attempt to incorporate the non-Fe-Mg components. Samples that were collected from very proximal locations give similar temperatures to calibrations assuming ideal Fe-Mg mixing, but may give temperatures differences of more than 100°C when calculated with a thermometer attempting to incorporate the effects of diluents in the solution model. They point out rightly that any empirical calibration should be based on a very large dataset which includes a variety of chemical compositions. In their opinion, the Perchuk and Lavrent'eva thermometer yields the most precise and accurate results. But most importantly, they also concluded that although the actual values may differ from one calibration to the other, the regional trend remains much the same regardless of the calibration used.

A typical spread in temperature curves obtained from the application of different calibrations of the garnet-biotite thermometer on the same mineral compositions is shown in Figure 2-10. Temperature differences between calibrations for samples of the Scotia-Quaal belt vary from less than 100°C to almost 300°C. These large differences in temperature estimates emphasize the importance of choosing the best activity model to represent as closely as possible the mixing behaviour of the phases involved in the thermometer.

Because this study is aimed at comparing results from thermobarometry at different locations within the metamorphic belt, the same calibration, that of Hodges and Spear (1982), was used for all samples. Perchuk and Lavrent'eva's calibration is eliminated because it is calibrated experimentally in systems held around 0.6Fe/Fe+Mg and garnets from the Scotia-Quaal area have Fe/Fe+Mg equal to or greater than 0.7 and generally

Figure 2-10: Temperature curves obtained from a sample of the Scotia-Quaal area using various calibrations of the garnet-biotite exchange thermometer. The abbreviations are: FS = Ferry and Spear (1978), PL = Perchuk and Lavrent'eva (1981), HS = Hodges and Spear (1982), GS (sym and asym) = Ganguly and Saxena (1984) with sym for symmetrical model and asym for asymmetrical model, IM1 and IM2 = Indares and Martignole (1985).

greater than 0.8. These values are a lot closer to those used in the Ferry and Spear experimental calibration on which the Hodges and Spear calibration is based. High Ca contents in some of the Scotia-Quaal samples make it preferable to use a calibration incorporating some non-ideal mixing term for calcium. All garnets have Mn contents below the limit specified by Ferry and Spear (1978) and Hodges and Spear (1982) for use of their calibrations such that it is considered unnecessary to take into account the non-ideal behaviour of Mn as done by Ganguly and Saxena (1984). Indares and Martignole

calibration of the thermometer for granulite facies rocks and advised caution with respect to application of their calibration to samples metamorphosed to upper amphibolite facies which is inferred to be the highest metamorphic grade in the Scotia-Quaal area. The precision of the Hodges and Spear (1982) calibration is estimated at $\pm 50^\circ\text{C}$ or better based on propagation of assumed analytical errors. Uncertainties in activity-composition relationships and in experimental determinations of end-member reactions are not assessed.

Garnet-hornblende

This geothermometer is based on the following exchange reaction:

A first calibration of the garnet-hornblende geothermometer based on an amphibole - plagioclase thermometer was attempted by Perchuk (1966). His version was modified by Perchuk et al. (1985). Graham and Powell (1984) calibrated the Fe-Mg partitioning between garnet and hornblende as a function of P, T and $X_{\text{Ca,g}}$ against the garnet-clinopyroxene thermometer of Ellis and Green (1979). Their thermometer is applicable to rocks having undergone maximum thermal conditions of 850°C or less, formed at low a_{O_2} so that Fe^{3+} content of amphibole is not too high and containing Mn-poor garnet ($X_{\text{Mn,g}} < 0.1$) and amphiboles with $\text{Na}_{(\text{M}4)}$ greater than 0.09 and not too rich in $\text{Ca}_{(\text{M}4)}$. Temperature overestimates may result if hornblendes are unusually rich in Fe^{3+} or poor in $\text{Na}_{(\text{M}4)}$.

For samples of the Scotia-Quaal belt, temperature estimates calculated with the Perchuk et al. (1985) thermometer are lower than temperatures obtained using the calibration of

Graham and Powell (1984). The difference can be as high as 50°C when all the conditions for the application of Graham and Powell's calibration are fulfilled and more if $\text{Na}_{(\text{M4})}$ is too low. It was decided to use the Graham and Powell thermometer for the present study because the basic premises of the calibration and the restrictions of the method are better known and because Khon and Spear (1990) showed that simultaneous solution of the thermometer with their garnet-hornblende-plagioclase-quartz geobarometer gives results in agreement with thermobarometric data in pelitic systems. Graham and Powell (1984) estimate the precision of their thermometer at $\pm 50^\circ\text{C}$.

Garnet-plagioclase geobarometry

Garnet-plagioclase barometers are based on exchange of Ca between the anorthite component of plagioclase feldspar and the grossular component of garnet. All reactions based on this exchange make good barometers because they result in large volume changes. Since anorthite has a larger volume than grossular, the reaction favors anorthite at low pressure and grossular at high pressure. Problems are related to modelling the activity-composition relations in both garnet and plagioclase, to the temperature dependence of the barometers based on this exchange and to uncertainties stemming from structural inversions in the plagioclase solid solution series.

Equilibria in the pelitic system

The *garnet-plagioclase- Al_2SiO_5 -quartz* Ca exchange barometer is based on the reaction:

Ghent (1976) presented a first calibration of this barometer based on the assumption of ideal solution for garnet and plagioclase. The calibration was reviewed by Ghent et al.

(1979) who used an empirical method for estimating the effects of non-ideal solution of Ca in anorthite and grossular.

Later, new experimental data (Goldsmith, 1980 and Haselton and Newton, 1980) allowed Newton and Haselton (1981) to derive a new calibration of the barometer. They presented an analytical expression for calculating the partial molar volume of the grossular component in pyrope-grossular and almandine-grossular solutions. Their calibration ignores the effect of almandine-pyrope solution; this may lead to pressure overestimates. The geobarometer is restricted to garnets low in Mn. The activity of $\text{CaAl}_2\text{Si}_2\text{O}_8$ in plagioclase is calculated using a statistical mechanics "Al-avoidance" model developed by Kerrick and Darken (1975). Graham and Powell's calibration (1988) is also based on Goldsmith experimental data (1980) and results are comparable to those of Newton and Haselton.

Hodges and Spear (1982) based their calibration on that of Newton and Haselton (1981). They empirically derived activity coefficients and Margules parameters by comparison with metamorphic conditions inferred in the Mt. Moosilauke area based on the mineral assemblage. They recommend caution when using their calibration in high-grade (particularly granulite facies), slowly cooled, regional metamorphic terranes. Hodges and Royden (1984) used the same garnet solution model as Hodges and Spear, but a slightly lower anorthite activity coefficient. Hodges and Crowley's calibration (1985) uses the activity-coefficient relationships described by Hodges and Spear (1982) and Hodges and Royden (1984).

Ganguly and Saxena's calibration (1984) is based on a ternary subregular formulation (Wohl, 1953) of the activity coefficient of Ca in garnet and on Saxena and Ribbe's (1972) derivation of the activity of anorthite in plagioclase. They record better agreement with pressure calculated for different assemblages from the same locality than obtained using the

Newton and Haselton model. Application of their calibration to rocks of the Mt. Moosilauke area gives metamorphic conditions comparable to those obtained using Hodges and Spear's empirical calibration.

A recent experimental study of the anorthite breakdown reaction conducted by Koziol and Newton (1988) is said to reduce uncertainty in the calibration of the garnet-plagioclase- Al_2SiO_5 -quartz geobarometer. The formula gives slightly higher pressures (~75 MPa at 600°C) than obtained from the Newton and Haselton calibration.

The *garnet-plagioclase-muscovite-biotite* barometer is based on the reaction:

Ghent and Stout (1981), Hodges and Crowley (1985) and Hoisch (1990) all calibrated this barometer empirically based on pressures and temperatures estimated from the combined use of their favourite garnet-biotite and garnet-plagioclase- Al_2SiO_5 -quartz calibrations and using their favourite regression method. Ghent and Stout (1981) used linear least square regression analysis with pressures and temperatures estimated with the Ferry and Spear (1978) calibration of the garnet-biotite geothermometer in conjunction with the Ghent et al. (1979) garnet-plagioclase- Al_2SiO_5 -quartz barometer. Hodges and Crowley (1985) preferred to use a regression treatment by York (1969) for calculating ΔS and ΔH because the method takes into account the uncertainties in individual points which are large in comparison to the scatter of the points about a best-fit line. Their temperature and pressure estimates are based on calibrations by Hodges and Spear (1982) and Hodges and

Royden (1984). Multiple regression was used by Hoisch (1990) with metamorphic conditions estimated by solving simultaneously the Ferry and Spear (1978) thermometer and the Koziol and Newton (1988) garnet-plagioclase- Al_2SiO_5 -quartz barometer.

To calibrate the reaction, Powell and Holland (1988) used an internally consistent thermodynamic dataset (Holland and Powell, 1985 and Powell and Holland, 1985) derived using least square analysis of experimentally determined mineral equilibria. They obtain slightly higher pressures than obtained by Ghent and Stout (1981).

The *garnet-plagioclase-muscovite-quartz* equilibrium calibrated is the following:

It was calibrated empirically by Hodges and Crowley (1985) and Hoisch (1990) using the same method as for the garnet-plagioclase-muscovite-biotite equilibrium.

In spite of the availability of new experimental data produced by Koziol and Newton (1988), the calibrations of the various garnet-plagioclase barometers of Hodges and Crowley (1985) are used in the present study in order that barometric models be consistent with each other and with the thermometric garnet-biotite calibration of Hodges and Spear (1982) used to calculate temperatures. The calibrations are limited to samples in which garnet contains less than 25 mole% spessartine and biotite less than 20 mole% Al and less than 5 mole% Ti in the octahedral site. Minimum uncertainty is estimated by Hodges and Crowley (1985) at 100MPa for the garnet-plagioclase- Al_2SiO_5 -quartz barometer, at 220MPa (sillimanite-dependent reaction) and 270MPa (kyanite-dependent reaction) for the

garnet-plagioclase-muscovite-biotite barometer and at 250MPa (sillimanite) and 300MPa (kyanite) for the garnet-plagioclase-muscovite-quartz barometer.

Equilibrium involving amphibole

Kohn and Spear (1989 and 1990) empirically derived two calibrations of the *garnet-plagioclase-hornblende-quartz* barometer. Their first calibration (1989) was obtained by weighted least square linear regression of data from 19 natural samples that equilibrated between 520 and 800°C and 350 and 1400MPa. It is based on the following reactions:

This calibration uses the garnet activity expressions of Hodges and Spear (1982) and the activity model for the anorthite component in plagioclase from Hodges and Royden (1984). The activity for albite component in plagioclase is assumed ideal. The pargasite and ferro-pargasite exchanges for amphibole were modelled assuming partial local charge balance. Fe was calculated to a minimum value of Fe³⁺ consistent with amphibole stoichiometry using the method of Spear and Kimball (1984). No nonideal correction of

the amphibole activity was made for other amphibole components and the calibration is assumed only applicable to the compositional range employed for calibration of the barometer.

A second calibration by Kohn and Spear (1990) is based on data representing 37 natural samples equilibrated between 500-800°C and 250 and 1300MPa. The reactions of interest for this barometer are:

and

Activity models for garnet and plagioclase are identical to those used in the earlier calibration (1989), but the amphibole activity models are different. The same compositional criteria for use of the barometer apply.

The 1990 calibration was used for garnet-plagioclase-amphibole barometry in the Scotia-Quaal area because its internal consistency is considered superior to that of the 1989 calibration. Errors in pressure of ± 50 MPa are caused by analytical errors, uncertainty in temperature and errors in Fe³⁺ content. The calibration is consistent with other geothermobarometers used in the present study

Results

The location of the 12 samples analysed for geothermobarometry is shown in Figure 2-11. More precise location (at 1:50 000 scale) is shown in Appendix 1B and UTM coordinates are given in Appendix 2. Electron microprobe analyses on which P-T estimates are based can be found in Appendix 7. For each sample, a description, a discussion of compositional data, an outline of and justifications for the thermobarometric treatment and results are presented. Pressure and temperature calculations were done using the Macintosh version of the program "Thermobarometry" made available by Spear and Peacock (1990).

Sample 89-137-2

Sample 89-137-2 is a hornblende-biotite schist collected on Hawkesbury Island from the metasedimentary unit at a location proximal to the Ecstall pluton contact (Figure 2-11). Rocks on Hawkesbury Island are inferred to have been metamorphosed to kyanite grade (Runkle, 1979). The Ecstall pluton has possibly imposed a narrow contact aureole onto host rocks which have locally developed minor fibrolite. Sample 137-2 contains hornblende, biotite, garnet, anorthite, quartz and ilmenite.

Subhedral biotite laths have two ranges in size; fine grained biotite is approximately 0.1 mm in length and coarser grained biotite approximately 1.6 mm. They are oriented parallel to a foliation which is cut by garnet poikiloblasts.

Hornblende is subhedral to anhedral and ranges in size between 0.1 and 2 mm. It is also overgrown by garnet.

Garnet is euhedral and contains quartz and ilmenite inclusions that are distributed in what appears as a faint snowball pattern. The cores of garnet grains contain finer grained and more abundant inclusions. Garnet poikiloblasts are zoned and some dispersion in the

Figure 2-11: Geological map of the Scotia-Quaal metamorphic belt showing the location of garnet-bearing samples analyzed for geothermobarometry. MM = metamorphic.

zoning profiles (Figure 2-12) may result from diffusion, superimposition of different generations of garnet and/or from exchange with inclusions. Mn-content increases from rim to core. Fe initially decreases from the rim inward, but the zoning is reversed partway into the garnet and Fe content increases to a high in the core. The region of change in trend could mark the boundary of an older garnet overgrown by garnet from a second generation. For this reason, core measurements were not used for geothermobarometry.

The proportion of plagioclase is very low. None was analysed in or around garnet poikiloblasts. In the matrix it is fine grained, anhedral and anorthitic in composition (An₈₈₋₉₅). Such a composition is unusual in kyanite-grade semi-pelitic rocks such as this sample. It may not represent the plagioclase composition involved in peak or retrograde regional metamorphism, but its low proportion allows for plagioclase to have easily changed composition at a later time due to a release of Ca during a mineral reaction or a general increase in bulk rock Ca content through the action of a circulating fluid.

Nine garnet measurements were taken from the rims of 2 different garnets at a location where garnet is not in contact with biotite or hornblende. Garnet rim compositions are quite consistent and three of these (lowest Mn, highest Mn and lowest Fe/Mg) were used in conjunction with an average biotite matrix composition for temperature calculations giving a 100°C spread (Figure 2-13). Garnet-biotite temperatures were also calculated using garnet-biotite pairs in contact with each other. These vary more or less within the same temperature range. Garnet-hornblende thermometry was done in the same fashion using garnet rim and average matrix compositions and using mineral pairs in contact. Estimated temperatures are between 590 and 655°C; these results are comparable to those obtained from garnet-biotite thermometry.

Garnet-plagioclase-hornblende-quartz barometry gives pressures of the order of 400 to 500MPa, much lower than pressure estimates from the area based on the presence of

Figure 2-12: Compositional profile in garnet from sample 89-137-2. Inclusions consist of quartz and ilmenite.

Figure 2-13: Results of geothermobarometry on sample 89-137-2.

(A) Variation in garnet-biotite temperature depending on the mineral pair selected. The range in garnet hornblende temperatures, not shown in the figure, is comparable. Preferred temperature estimates shown in (B) are those obtained with low-Mn garnet composition in conjunction with matrix biotite and hornblende. Minimum pressure is taken as that at the sillimanite-kyanite curve based on the presence of kyanite in metapelites on Hawkesbury Island. Range in P-T estimate between 580°C-520MPa and 680°C-750MPa is based on intersection of lowest and highest garnet-biotite temperature curves in (A) with the sillimanite-kyanite curve..

kyanite. Because the plagioclase composition is outside the compositional limits of the minerals used for Kohn and Spear's (1990) barometric calibration, the pressures calculated are interpreted as minimum pressures. Moreover, there exists some doubt concerning equilibrium of the present plagioclase composition with other mineral compositions used for barometry. The sample is inferred to be at kyanite grade and minimum pressure is estimated based on the kyanite-sillimanite curve.

Calculated metamorphic conditions vary between 580°C-520MPa and 680°C-750MPa depending on the minerals selected. The mineral compositions inferred to most closely represent compositions in equilibrium with each other give an estimate of 650°C-650MPa. Estimates are interpreted as minimum metamorphic conditions and are comparable to 550-660°C and 600-800 MPa conditions inferred by Runkle (1979) based on metapelitic, amphibolite and calc-silicate assemblages.

Sample 88-54-1

This sample was collected along Douglas Channel, approximately 6km from the Quottoon pluton contact. From the layered gneiss unit, it is composed of hornblende, garnet, plagioclase, quartz, ilmenite, rutile, apatite and traces of epidote and titanite, the latter rimming the ilmenite.

Anhedral hornblende is generally less than 2 mm in length and averages 1mm. Hornblende alignment parallels the foliation. Hornblende composition is relatively consistent in the matrix and more variable in contact with garnet. Matrix hornblende is generally poorer in Fe and Al and richer in Ti and Mg than hornblende in contact with garnet. The differences in composition between matrix and contact hornblende and the wider spread in composition of hornblende in contact with garnet is attributed to retrograde exchange and possibly net transfer mechanisms between hornblende and garnet. Matrix hornblende is interpreted to approach more closely than contact hornblende the mineral

composition in equilibrium during peak metamorphism. An average matrix hornblende composition is used for geothermobarometry.

Quartz is rounded or elongate and is generally less than 1mm in length. Elongate quartz and quartz aggregates parallel the foliation.

Plagioclase occurs as anhedral augen-shaped grains up to 1.5 mm in length oriented parallel to the foliation. The anorthitic content of plagioclase varies between 0.34 and 0.42. A slight zoning occurs across plagioclase grains with cores slightly more enriched in Ca than rims. Plagioclase rim composition is used for barometry. Using average plagioclase composition (An₃₉) would result in a pressure estimate lower by less than 50MPa.

Garnet is squarish, has ragged edges and is approximately 10 mm in diameter. The poikiloblast contains numerous inclusions dominantly of quartz and lesser amounts of rutile, but rare plagioclase, hornblende and epidote occur (Figure 2-14). There is no appreciable zoning across garnet except, to a very small degree, at the rim (Figure 2-14). An inner rim shows a very slight decrease in Mn (from approximately 0.44 to 0.42) and increase in Ca (from approximately 1.24 to 1.26). An outer rim shows very faint reverse zoning maybe caused by garnet resorption at some point during the sample's retrograde history. The temperatures obtained by garnet-hornblende thermometry on a series of mineral pairs vary between 650 and 725°C (Figure 2-15). Strangely, temperatures from minerals in contact are higher than temperatures calculated using average matrix hornblende composition. This probably is due to a combination of exchange through diffusion and net transfer during garnet-consuming reaction. The outer garnet rim is likely to have been affected by late retrograde exchange to a larger degree than the inner rim and core. The inner rim composition is interpreted to give a temperature estimate that approaches most closely the sample's homogenization temperature which itself is the best lower estimate of

Figure 2-14: Typical compositional profile in garnet from sample 88-54-1. Quartz, rutile, and rarely plagioclase, hornblende, epidote and apatite occur as inclusions in garnet.

Figure 2-15: Results of geothermobarometry on sample 88-54-1. Unlabelled temperature curves are estimates obtained from minerals in contact with each other. Garnet plagioclase-hornblende-quartz barometry is based on the composition of garnet inner rim, hornblende matrix and rim matrix plagioclase.

temperature of metamorphism. A pressure of 840 ± 40 MPa is calculated based on a temperature of $670\pm 50^\circ\text{C}$.

Sample 88-104-1

Sample 88-104-1 is a garnet-hornblende gneiss collected from the layered gneiss unit less than 500 m from the Quottoon pluton contact. The sample contains hornblende, biotite, garnet, plagioclase, quartz, titanite, rutile and minor chlorite replacing hornblende in a garnet reaction zone.

Hornblende is abundant (>35%). It is subhedral to anhedral and averages 0.4, but may reach 2 mm in length. It is oriented parallel to the planar fabric and wraps around garnet poikiloblasts. The composition of hornblende in the matrix does not vary greatly. The composition of hornblende included in and in contact with garnet varies more substantially. It also differs slightly from the composition of matrix hornblende. Fe/Mg, K and Al contents in hornblende in contact with garnet are lower than or in the lower part of the range of matrix hornblende compositions.

Biotite occurs as subhedral to anhedral laths less than 0.8 mm in length and as fine intergrowth at hornblende rims. This mineral is also oriented parallel to the foliation. No biotite occurs with, or even in the vicinity of, garnet poikiloblasts. This is interpreted as evidence that biotite and garnet are not in equilibrium.

Garnet is anhedral, poikiloblastic and on average 2 mm in diameter. The poikiloblast's boundaries are serrated suggesting that it is in the process of being replaced, here by a mixture of quartz, plagioclase and hornblende forming a rim around garnet crystals (Figure 2-16). Compositional profiles reveal very little or no zoning across the garnet (Figure 2-16). Garnet is assumed to have undergone chemical homogenization and geothermobarometry will be interpreted as providing an estimate of conditions during homogenization.

Figure 2-16: Typical compositional profiles in garnet from sample 88-104-1. Quartz and rutile occur as inclusions in garnet. A quartz + plagioclase + hornblende rim surrounds garnet. Biotite does not occur in proximity of garnet.

Plagioclase is anhedral and interstitial to other minerals. Matrix plagioclase is generally smaller than 0.2 mm while plagioclase proximal to garnet reaches 0.6 mm. An content varies between 0.31 and 0.40 in the matrix and between 0.43 and 0.45 in the garnet reaction zone.

Thermometry based on an average composition of homogeneous garnet and matrix hornblende gives an estimate of $660 \pm 50^\circ\text{C}$ (Figure 2-17A), comparable to results of thermometry based on compositions of hornblende inclusions. A pressure estimate of $825 \pm 40\text{MPa}$ is obtained using this temperature and the composition of plagioclase in the matrix.

The results of geothermobarometry on minerals within a reaction zone around garnet are shown in Figure 2-17B. Temperature estimates ($715\text{-}740^\circ\text{C}$) are higher than those obtained with matrix minerals and homogenized garnet compositions. This may reflect a state of disequilibrium in that zone from which pressures and temperatures cannot be extracted meaningfully or it may represent an increase in temperature late in the thermal history of the sample. The presence of a young plutonic body less than 500 m away suggests that this last hypothesis cannot be rejected. A pressure estimate of $845 \pm 40\text{MPa}$ is obtained based on mineral compositions from the reaction zone. If the garnet reaction zone is the product of contact metamorphism at the time of intrusion of the Quottoon pluton, it is interesting to note that no significant change in pressure is recorded even though the Quottoon pluton is interpreted to have been emplaced at approximately 550MPa (Hollister et al., 1987). It may be that the sample experienced a very short-lived thermal effect, barely long enough for garnet and hornblende within a very small area to reequilibrate via Fe-Mg exchange, but not long enough to allow net transfer reequilibration.

Figure 2-17: Results of geothermobarometry on sample 88-104-1.

(A) Inferred regional metamorphic equilibration conditions based on average composition of homogenized garnet and composition of matrix hornblende and biotite. (B) Geothermobarometric estimates in a reaction zone around garnet inferred to represent a thermal pulse during cooling of the sample, possibly at the time of intrusion of the Quottoon pluton.

Sample 87-237-1

Sample 87-237-1 is a well foliated two-mica garnet schist from the quartzite unit. It was collected on the ridge immediately south of the Ecstall river a little more than 3 km west of the Quottoon pluton. It is composed of muscovite, biotite, megacrystic plagioclase, poikiloblastic garnet, quartz and minor opaque.

Muscovite is fine-grained (≤ 0.15 mm) and euhedral. It occurs in bands rich in felsic minerals including plagioclase megacrysts. Muscovite aggregates define a planar fabric with intense small-scale chevron folding which is interrupted by the plagioclase megacrysts.

Subhedral biotite laths are less abundant and coarser grained (≤ 1 mm) than muscovite. Biotite abundance and size is greatest close to garnet poikiloblasts. Rare biotite inclusions in garnet are too fine grained to be analysed.

Plagioclase occurs as rounded megacrysts of approximately 0.6 to 0.8 mm in diameter and as rare inclusions in garnet. The megacrysts vary in composition from core to rim; core An contents are below 0.40 and An content increases gradually to at least 0.60 at plagioclase rims. The maximum An content measured in plagioclase from this sample is 0.68. Plagioclase in contact with and included in garnet has low An contents between 0.38 and 0.46.

Garnet poikiloblasts are quite large (≤ 10 mm) and contain inclusion trails forming straight lines at an angle to the matrix foliation. Garnet growth is interpreted to have occurred between two deformation events. The smaller garnet grains show a faint normal compositional zoning (Figure 2-18A) with a large compositional plateau in the core and slight change in composition close to the rim. A compositional profile of this type suggests that the grains have undergone partial homogenization. One much coarser than average garnet poikiloblast exhibits a very pronounced normal zoning in a core region that can be

Figure 2-18: Compositional profiles in garnet from sample 87-237-1. Inclusions are dominantly quartz and very fine grained opaque minerals as well as minor plagioclase and biotite. Most garnet poikiloblasts (A) have a faint normal zoning with a large compositional plateau. A larger garnet poikiloblast (B) exhibits very pronounced normal zoning in the core region distinctive by its cloudy appearance.

identified petrographically by its cloudy appearance (Figure 2-18B). The difference in appearance and in composition of the two types of garnet suggests a complex metamorphic history. The compositional profiles are not consistent with diffusional homogenization of only the finer of garnets formed during a single growth event. The Fe- and Mg-depleted and Ca- and Mn-enriched cloudy core of the larger garnet is interpreted as a relic from an earlier garnet growth event. Very minimal garnet growth during this early event or post-growth garnet resorption explains the low proportion of the high-Mn garnet in the sample. Resumed garnet growth at a later time in the rock's history produced garnet richer in Fe and Mg and poorer in Ca and Mn than its older counterpart. The compositional zoning of the younger garnet appears to have been somewhat destroyed by diffusion during cooling of the rock. The older garnet, occurring as a small core inside a large garnet, appears to have been protected from much of this homogenization phase. The difference in composition between the two generations of garnet may reflect a change in bulk rock composition possibly through transport of elements in a fluid moving in the rock pile during metamorphism. Additional analytical work may help unravel the garnet growth history in this sample. Without any doubt, the garnet profiles reveal a complex metamorphic history and warn against using garnet core composition for thermobarometry. A second argument against attempting to calculate peak temperatures using core garnets and biotite matrix is the low proportion of biotite with respect to garnet. Rim mineral compositions will therefore be used for thermobarometry in this sample. These will provide a minimum estimate of peak metamorphic conditions.

All temperatures obtained from garnet rims and an average biotite matrix composition (Figure 2-19A) fall within the thermometer's precision ($\pm 50^{\circ}\text{C}$; Hodges and Spear, 1982) of each other and of temperature calculated from a garnet rim-biotite matrix pair for which the biotite measurement was taken within 2 mm of the garnet measurement. Biotite in

Figure 2-19: Results of geothermobarometry on sample 87-237-1.

(A) Temperature estimates for various mineral pairs. Biotite core and biotite rim compositions were obtained from the same biotite grain in its core and at its contact with garnet. The change in biotite composition within a single grain is interpreted to result from ionic exchange with garnet at a very small scale. The preferred mineral pair consists of garnet rim away from biotite and biotite matrix. The temperature estimate from this mineral pair is used in (B) in conjunction with garnet-plagioclase barometry for estimate of equilibration metamorphic conditions.

contact with garnet is compositionally zoned; it is enriched in Fe close to the garnet contact and is compositionally similar to matrix biotite away from it. On a compositional diagram, cross-cutting tie-lines between a garnet rim and the biotite with which it is in contact and between a second garnet rim not in contact with any biotite and biotite from the matrix suggest disequilibrium. The temperature obtained from the garnet and biotite in contact, although within precision of the thermometer, is located on the higher side of the temperature zone (Figure 2-19A). These observations may indicate that the assumption of chemical equilibrium at the 2 mm scale in this sample is unacceptable. In such a case, only minerals in contact with each other are in chemical equilibrium and can be used to calculate temperature. The result is then a minimum estimate of temperature since Fe-Mg exchange is likely to have occurred along the retrograde path of the rock. Alternatively, reequilibration by both exchange and net transfer mechanisms may have persisted for a longer time on the very small scale of minerals in contact with each other. In this case, minerals not in contact would have compositions closer to peak metamorphic compositions. The Fe enrichment in biotite in contact with garnet could result from Fe-Mg exchange between the two minerals if temperature increased or from transfer during a reaction consuming garnet if temperature decreased.

Based on the above discussion, the compositions of garnet rims and biotite grains from the matrix in the vicinity, but not in contact with the garnet, are inferred to represent equilibrium mineral compositions at some point during cooling of the sample. Muscovite compositions are quite consistent and an average of 11 measurements is used in the pressure calculations. Matrix rim plagioclase composition is inferred to best represent the plagioclase composition in equilibrium with the other mineral compositions selected. Plagioclase measurements from grains in contact with garnet have lower An contents than the rims of matrix plagioclase and may have been affected by retrogressive reaction

involving the garnet. The effect of choosing the more anorthitic plagioclase is to move the reaction curve towards lower pressure. The calculated pressure is interpreted as a minimum estimate.

As shown in Figure 2-19B, garnet-biotite thermometry in conjunction with garnet-plagioclase-muscovite-biotite and garnet-plagioclase-muscovite-quartz barometry gives a temperature of $680 \pm 50^\circ\text{C}$ and $830-850 \pm 250\text{MPa}$. The two barometers are in good agreement. These values are interpreted as lower estimates of metamorphic conditions.

Sample 87-195-3

Sample 87-195-3 was collected from a fine band of hornblende-biotite semi-schist in the quartzite unit approximately 2.8 km west of the Quottoon pluton contact. The sample contains biotite, hornblende, garnet, plagioclase, quartz, trace of zoisite, titanite, apatite and Fe-oxide.

Anhedral hornblende grains up to 1mm in length are oriented parallel to the foliation. Hornblende composition is constant throughout the thin-section except for the Fe/Mg ratio which is lower in hornblende included in garnet than in hornblende outside garnet.

Biotite occurs as subhedral to anhedral laths up to 1mm in length. The laths are oriented parallel to the foliation and some biotite grains are bent and kinked indicating that they were exposed to deformation and do not postdate it. The composition of biotite is constant throughout the thin-section.

Garnet occurs as rounded poikiloblasts of up to 6 mm diameter. Numerous inclusions consist of quartz, hornblende, opaque minerals and biotite (Figure 2-20). The foliation wraps around garnet poikiloblasts. Analytical traverses across a few grains reveal a marked normal zoning (Figure 2-20). Rim composition only is used for geothermobarometry. No attempt is made at estimating conditions represented by garnet

Figure 2-20: Typical compositional profile in garnet from sample 87-195-3. The poikiloblasts contain numerous inclusions of quartz, hornblende, Fe-oxide mineral and biotite.

core composition because it is not certain whether biotite or hornblende matrix compositions approach the composition of these minerals in equilibrium with core garnet.

Plagioclase is anhedral and does not exceed 1 mm in size. Elongate plagioclase grains and felsic mineral aggregates are oriented in the foliation plane. Plagioclase is locally partially sericitized. Plagioclase composition varies widely within the scale of the thin-section. Anorthite contents between 0.23 and 0.59 were obtained with the lowest value obtained from a plagioclase grain proximal to garnet and larger values from matrix plagioclase. It is assumed that plagioclase with low anorthite content is in equilibrium with garnet rim, although not enough measurements were made to confirm this. The effect of underestimating An-content is to give a maximum pressure estimate.

Temperature estimates from garnet-biotite and garnet-hornblende exchange do not coincide, but garnet-hornblende exchange gives a much lower temperature estimate (Figure 2-21). This may indicate that one of the minerals is not in equilibrium with garnet rim. The lowest temperature ($573 \pm 50^\circ\text{C}$) is used as a lowest estimate of metamorphism. A maximum pressure estimate of 940 ± 40 MPa is obtained from garnet-hornblende-plagioclase-quartz barometry.

Sample 87-150-7

Sample 87-150-7 is a metapelitic gneiss from the quartzite unit. The sample was collected approximately 800 m west of the Quottoon pluton contact. The sample is composed of garnet, biotite, kyanite, fibrolite, quartz, plagioclase and minor chlorite, ilmenite, rutile, apatite and chalcopyrite. Both rutile and chalcopyrite occur in trace amounts and exclusively as inclusions in garnet.

Kyanite and sillimanite occur in trace amounts. Kyanite is generally anhedral and up to 5 mm in size. Sillimanite occurs in the form of fibrolite intergrown with biotite. Both minerals are oriented within the foliation plane.

Figure 2-21: Results of geothermobarometry on sample 87-195-3.

Biotite forms elongate euhedral to subhedral laths reaching 4 mm in length. Biotite is oriented in the foliation plane and laths bend around the garnet porphyroblasts. In a few locations biotite is partly chloritized, but in general it is quite fresh. Biotite composition is unusual as it contains 2 to 3 wt% barium, the effect of which on geothermobarometry is unknown, but assumed to be minimal. Biotite in contact with garnet is richer in Fe and slightly poorer in Ti than biotite in the matrix. The composition of matrix biotite is quite consistent throughout the thin-section.

Garnet porphyroblasts reach 6 mm in diameter. They are rounded to augen-shaped and contain inclusions of quartz, biotite, ilmenite, rutile and rare chlorite which are distributed along straight lines not parallel to the present foliation (Figure 2-22). Garnet is unzoned except at the rim where Fe and Mn contents increase slightly and Mg content decreases slightly (Figure 2-22).

Plagioclase An content varies little (An33-35). The grains are anhedral and less than 0.6 mm in length. They form augen around which the foliation wraps. Andesine is mostly restricted to garnet-rich regions, without being in direct contact with garnet.

A moderate variation in temperature estimates is obtained from various garnet-biotite pairs (Figure 2-23A). The mineral pairs in contact with each other give the lowest temperature. Slightly higher temperatures are obtained from garnet rims not in contact with biotite and an average biotite matrix composition. The highest temperature estimate is obtained from garnet core and biotite matrix compositions. It may not be appropriate to use this last compositional pair for thermometry because biotite composition may have changed substantially since the time of equilibrium between garnet cores and the matrix.

A pressure estimate of $860-880 \pm 100$ MPa (Figure 2-23B) is calculated using the garnet-plagioclase-aluminosilicate-quartz barometer and temperatures obtained from garnet-biotite pairs in contact with each other (lowest temperature curve in Figure 2-23A). However,

Figure 2.12 Typical compositional profile in garnet from sample 87-156-7. Quartz, biotite, ilmenite, rutile and scarce calcite occur as inclusions in garnet.

Figure 2-23: Results of geothermobarometry on sample 87-150-7. (A) Range in temperature estimates obtained from different garnet-biotite pairs. In (B) the minimum temperature estimate is used in conjunction with the garnet-plagioclase-quartz- Al_2SiO_5 barometer in order to evaluate metamorphic conditions most likely to approach those of mineral equilibration.

since no plagioclase in contact with garnet and biotite was found for analysis, the plagioclase composition used for barometry may not be in equilibrium with the compositions of biotite and garnet in contact. It is therefore possible that the pressure estimate does not approach pressure conditions at the time when biotite and garnet in contact were in equilibrium. Other garnet-biotite pairs used in conjunction with matrix plagioclase composition results in pressure estimates higher than 860MPa, up to approximately 1000MPa. For this reason the sample is interpreted as having undergone metamorphism at high pressure ($>860 \pm 150$ MPa) and temperature ($\geq 740^\circ\text{C}$).

Sample 87-46-1

Sample 87-46-1 is a biotite-garnet-hornblende gneiss collected from within the metavolcanic unit in the Scotia valley, approximately 8 km away from the Quottoon pluton contact. The sample is composed of hornblende, garnet, biotite, chlorite, prehnite, titanite, ilmenite, plagioclase, quartz and apatite.

Hornblende is the most abundant mineral, making up approximately 50% of the sample. It is subhedral and reaches 0.5 mm in length. It occurs dominantly in the matrix. It is also found as inclusions in the garnet and more rarely at the garnet contact. It outlines a faint foliation which wraps around the garnet.

Garnet is also quite abundant (20%) and occurs as rounded to squarish poikiloblasts containing quartz, hornblende, titanite and opaque inclusions (Figure 2-24). Garnet size varies between 4 and 10 mm.

Most biotite occurs as anhedral laths, generally 0.5 to 1 mm in length. It is rarely present away from garnet and forms a rim, together with quartz, plagioclase and ilmenite, around the garnet and separating it from the hornblende. As shown in the sketches of garnet from this sample (Figure 2-24), the reaction zone between garnet and the matrix is composed of two rims. The inner rim consists of quartz and plagioclase with minor titanite

Figure 2-24: Typical compositional profiles in garnet from sample 87-46-1. Inclusions in garnet consist of quartz, hornblende, titanite and ilmenite.

and opaque minerals and disseminated traces of very fine-grained biotite and hornblende. The outer rim is composed of coarse-grained biotite and ilmenite. The hornblende-rich matrix occurs outward from the biotite rim. Trace amounts of chlorite replace biotite. Locally, biotite is intergrown with fine-grained prehnite. The presence of prehnite is probably due to the low potassium-content in the reacting phases.

Plagioclase occurs dominantly in the garnet corona. It is very sparse in the matrix. Grains are anhedral and of approximately 0.3 mm in length. The plagioclase is dominantly andesine (An 36 to 43) although 4 out of 14 analyses gave An compositions between 0.62 and 0.75 suggesting a bimodal distribution in plagioclase composition. The labradorite plagioclase contains approximately half as much K as the andesine. This high-Ca, low-K plagioclase may have formed during the reaction which formed the corona. Excess calcium could easily be accommodated in the plagioclase structure and the potassium needed for biotite crystallization could be released by the plagioclase.

Quartz inclusions in garnet are abundant. In the reaction zone, quartz is large grained, whereas in the matrix it is fine grained.

The corona textures suggest disequilibrium in the sample. Biotite appears to have formed during a reaction postdating garnet growth and will not be used in conjunction with garnet for thermobarometry. Garnet and hornblende probably grew in equilibrium with each other and later became unstable and reacted thus forming the corona. Garnet poikiloblasts are normally zoned to various degrees which appear to depend on the density of inclusions in the garnet. It is not known whether this zoning is of the usual type formed during the metamorphic path of the sample or if it results to a large extent from the mineral reactions that formed the corona. Garnet rims may have changed composition during the corona-forming reactions. Garnet core composition is interpreted as approaching most closely garnet composition during peak metamorphism. Due to the abundance of

hornblende in the sample, the composition of matrix hornblende is inferred to approach the amphibole composition in equilibrium with garnet core composition. This assumption is supported by the observation that hornblende inclusions in garnet have compositions comparable to matrix hornblende composition. Hornblende from the coronas show larger variations in composition probably reflecting participation of hornblende in the reactions forming the corona. Although no plagioclase was analysed in areas distant from garnet, andesine was taken as representing most closely the plagioclase composition in equilibrium with core garnet and matrix hornblende compositions. The reasons for this choice are that plagioclase of andesine composition is more widespread than the more anorthitic plagioclase, because the plagioclase in amphibolites is commonly andesine and because the difference in composition between the andesine and labradorite in the sample is consistent with the inference that plagioclase participation in the corona-forming reactions resulted in increasing Ca-content (liberated by garnet and plagioclase) and decreasing K-content (needed by biotite).

Temperature estimates obtained from core garnet and hornblende matrix compositions as well as from garnet-hornblende inclusion pairs vary between 675 and 705 (± 50)°C (Figure 2-25A). Low $\text{Na}_{(\text{M4})}$ content in hornblende from this sample may result in temperature being slightly overestimated. The assumption that Fe is all ferrous affects the results in same direction. Pressure conditions are estimated at 850-870 $\pm$ 40MPa (Figure 2-25B). These P-T conditions are consistent with the presence of kyanite in nearby metapelites (Krage, 1984) and more or less in agreement with 723°C-710MPa metamorphic conditions estimated by Krage (1984) from core garnet composition in a pelitic schist.

Sample 89-69-2

Sample 89-69-2 is a sillimanite migmatite gneiss from the quartzite unit collected in the northern region approximately 3 km west of the Quottoon pluton contact. The sample

Figure 2-25: Results of geothermobarometry on sample 87-46-1.

(A) Range in temperature estimates obtained from garnet core and matrix hornblende compositions as well as from the composition of hornblende inclusions and garnet in contact with each inclusion. In (B), the garnet core-matrix hornblende temperature is used in conjunction with a garnet-plagioclase barometer to calculate a best estimate of metamorphic conditions at the time of garnet core growth.

contains biotite, garnet, sillimanite, plagioclase, quartz, muscovite, chlorite, ilmenite, rare rutile inclusions in garnet and a trace of pyrite.

Biotite occurs as euhedral laths up to 1.5 mm in length. The laths are oriented in the foliation plane which wraps around garnet poikiloblasts. Biotite is locally partially chloritized. Fine grained muscovite occurs in the proximity of some garnet poikiloblasts; it may replace biotite. The composition of matrix biotite is constant at the scale of the thin-section. Biotite inclusions in garnet have lower Fe/Mg ratios than matrix biotite. Biotite in contact with garnet is more variable in composition than other biotite grains. This is probably due to varying degrees of reequilibration between garnet and biotite during cooling of the sample. Biotite matrix composition is assumed to most closely approach the biotite composition in equilibrium with garnet rim composition in places where garnet does not touch biotite.

Garnet poikiloblasts are rounded with locally very ragged boundaries (Figure 2-26). Grain size reaches 10 mm. Inclusions are very abundant; they consist of quartz, biotite, plagioclase, ilmenite and rare rutile. In some poikiloblasts the inclusions are oriented and distributed along straight lines at a large angle from the foliation outside the garnet. Garnet profiles are more or less straight with minor reverse zoning at garnet rims (Figure 2-26). This is a typical garnet profile in high grade rocks. Rim garnet not in contact with biotite is assumed to have a composition closest to equilibrium with the composition of biotite and plagioclase in the matrix.

Plagioclase is fine to coarse grained and anhedral to subhedral. The composition of plagioclase from the matrix varies between An₃₅ and An₃₈. Inclusions in garnet have virtually the same An content between An₃₆ and An₃₈ with highest values close to garnet core.

Figure 2-26: Typical compositional profiles in garnet from sample 89-69-2. Abundant inclusions consist of quartz, biotite, plagioclase, ilmenite and scarce rutile.

Figure 2-27: Results of geothermobarometry on sample 89-69-2. (A) Range in temperature estimates obtained from various garnet-biotite pairs. (B) Garnet rim-biotite matrix temperature is used in conjunction with a garnet-plagioclase barometer to obtain an estimate of equilibration metamorphic conditions.

Temperature estimates from this sample vary widely (Figure 2-27A) depending on the garnet-biotite pair used for thermometry. The garnet rim-biotite matrix curve is located on the high temperature side of all but one curve. Retrograde Fe/Mg exchange between two minerals in contact is likely to result in temperature estimates lower for mineral pairs in contact than for minerals proximal to each other, but not in contact. A temperature overestimate from a garnet-biotite pair in contact may result from net Fe or Mg transfer caused by local reaction such as chloritization of biotite. The garnet rim-biotite matrix temperature curve is assumed to most closely approach the temperature of peak metamorphism or the temperature of garnet homogenization, if homogenization occurred.

Garnet-plagioclase-sillimanite-quartz barometry on garnet rim and biotite and plagioclase matrix compositions give the P-T curve shown in Figure 2-27B. The pressure estimate is valid if equilibrium is maintained at the scale of the thin-section since sillimanite is present in the thin-section, although it does not occur in the immediate proximity of the minerals used for determination of pressure.

Metamorphic conditions are estimated at $815 \pm 50^\circ\text{C}$ and $700 \pm 100\text{MPa}$. This pressure estimate is somewhat lower than elsewhere in the Scotia-Quaal belt, but still within uncertainty limits of other results.

Other samples

In this section, preliminary results from additional samples are given. Data from these samples can only be used in a qualitative way because of either superficial analysis of the sample or problems with mineral compositions being outside the compositional bounds for the thermobarometers available.

Sample 89-106-3 is a biotite-hornblende gneiss from the metasedimentary clastic unit collected a little more than 2 km west of the Quottoon pluton contact. The sample is composed of hornblende, biotite, garnet, quartz, plagioclase, titanite and magnetite.

Anhedral hornblende averaging 0.2 mm in length is not noticeably aligned in a specific orientation. Matrix hornblende has consistent composition. Hornblende in contact with garnet shows a little more dispersion in composition and has a slightly higher Fe/Mg ratio than hornblende in the matrix. Fe/Fe+Mg ratios and Na contents are higher than prescribed appropriate for use of the minerals for garnet-hornblende-plagioclase-quartz barometry.

Biotite occurs as euhedral laths of approximately 0.1 mm length and as subhedral, slightly coarser grains (0.3 mm length). Fe/Mg ratios are higher and more dispersed in biotite in contact with garnet, and lower and constant in matrix biotite.

Garnet poikiloblasts are approximately 4 mm in diameter. They contain quartz, hornblende, opaque, titanite and rare plagioclase inclusions which are distributed along lines inferred to represent an earlier foliation plane which the garnet overgrew (Figure 2-28). Some warping of the matrix around the garnet is observed, but is not strong since fabric is not strongly developed in the sample. Garnet cores contain more inclusions which are finer grained and maybe helicitic; these may be relics of older garnets. Garnets are unzoned except for a small region in the core which shows increase in Mn and Fe and decrease in Ca (Figure 2-28). Plagioclase is anhedral and interstitial to other minerals. It reaches 0.2 mm in size. Plagioclase composition does not vary significantly throughout the thin-section. Anorthite contents vary between 0.13 and 0.19. Higher An values were measured in the proximity of garnet. This mineral barely meets the plagioclase compositional criteria for use of the garnet-hornblende-plagioclase-quartz barometer which requires the An content to exceed 0.15.

Thermobarometry using garnet rim, hornblende, biotite and plagioclase compositions for this sample give temperatures in the order of 780-815 (± 50)°C and pressures around 1200MPa. This sample's deviation from the compositional criteria apparently result in pressure and temperature overestimates.

Figure 2-28: Typical compositional profiles in garnet from sample 89-106-3. Quartz, hornblende titanite and scarce plagioclase occur as inclusions in the poikiloblasts.

Sample 86-4A-2 is a zoisite-biotite schist from the metavolcanic unit. It was collected approximately 3.5 km from the Quottoon pluton contact. The sample contains euhedral biotite, up to 0.8 mm in length, coarse grained (≈ 1.5 mm) prismatic zoisite, rounded garnet porphyroblasts (5-10 mm), chlorite after hornblende, anhedral augen-shaped, inclusion-rich plagioclase reaching 2 mm in length, granoblastic quartz and fine grained opaque minerals.

All unequant minerals are oriented in the foliation plane which wraps around garnet, and zoisite porphyroblasts. Garnets are normally zoned (Figure 2-29). Rim garnet compositions and matrix biotite give a temperature of equilibration of $600 \pm 50^\circ\text{C}$ for an assumed pressure of 800 MPa.

Sample 87-124-1 is a micaceous schist from the metavolcanic unit. It was collected on the same ridge as sample 86-4A-2, but farther west, approximately 5 km away from the Quottoon pluton contact. The sample contains what appears to be two generations of garnet. A first generation is fine grained (1.2 mm), anhedral and appears to have been partially resorbed. A second generation (Figure 2-30) is coarser grained (up to 10 mm), occurs in elongate clusters parallel to the foliation and overprinting the matrix minerals. Some variations in garnet compositional profiles occur, but they are not systematic with respect to the two garnet categories identified. Additional analytical work would be required to unravel the garnet growth history in this sample. However, the rim composition of all garnets analyzed is consistent and garnet rim composition will be used for thermometry.

Euhedral biotite varies in length between 0.5 and 1 mm. Biotite aggregates follow the foliation, but individual grains may be at an angle to the foliation. At least some biotite appears to have grown after development of the foliation. Fine grained (<0.2 mm) euhedral muscovite laths occur in trace amounts and are concentrated in bands rich in felsic

Figure 2-29: Compositional profile in garnet from sample 86-4A-2. Inclusions consist of quartz and opaque minerals.

Figure 2-30: Compositional profile in garnet from sample 87-124-1. Fine grained inclusions consist of quartz and opaque minerals.

minerals. Chlorite occurs as euhedral laths (<1 mm) and as spots in biotite. Plagioclase is albitic. It forms squarish to rectangular grains of approximately 0.1 mm size. Other minerals include quartz and ilmenite.

Since biotite is the only mica that is clearly in contact with garnet, it will be used in association with garnet for thermometry. A temperature of $690 \pm 50^\circ\text{C}$ is estimated from garnet rim-biotite matrix thermometry assuming a pressure of 800MPa.

Sample 87-111-2 is a gedrite-biotite schist from the quartzite unit. Sample location is approximately 9 km west of the Quottoon pluton contact and less than 200 meters east of the Ecstall pluton contact on the same ridge as the two previous samples. The sample contains abundant quartz ($\geq 60\%$) and biotite ($\approx 20\%$) and lesser gedrite, garnet and chlorite. Biotite is subhedral, up to 1 mm in length and oriented parallel to the foliation. Gedrite occurs as long and narrow porphyroblasts (≈ 4 mm long) also oriented parallel to the foliation; very elongate grains are bent indicating deformation after growth. Some pseudomorphs after gedrite are made up of fine grained chlorite. Garnet is anhedral and smaller or equal to 1mm in diameter. It contains quartz and ilmenite inclusions. Ilmenite also occurs in the matrix. A few crystals of fine grained kyanite and staurolite are present in the thin-section. They are interpreted as relics. Oligoclase plagioclase is not abundant.

A rim temperature of $590 \pm 50^\circ\text{C}$ is obtained from garnet-biotite thermometry assuming a pressure of 800MPa.

Discussion of results

A summary of pressure and temperature estimates obtained from garnet-bearing samples throughout the Scotia-Quaal metamorphic belt is presented in Figure 2-31. All samples record high pressure estimates, mostly around 800-850MPa. The agreement in pressure estimates indicates that the whole belt was metamorphosed at the same depth of at least 30 km and was uplifted sufficiently rapidly for pressure conditions under which the

Figure 2-31: Geological map of the Scotia-Quaal metamorphic belt summarizing results from geothermobarometry on garnet-bearing samples collected throughout the area. MM = metamorphic.

minerals equilibrated to be preserved. The compatibility between the core pressure estimate from sample 87-46-1 and rim pressure estimates from the other samples suggests that this represents peak pressure of the last metamorphic event. Also, the uniformity in pressure estimates emphasizes dramatically the consistency between the various barometers used in the study.

Exchange reactions on which the thermometers are based are likely to close at lower temperature than the net transfer reactions governing the barometers utilized. This is true because of the volume increase associated with retrogression of mineral assemblages by net transfer. For this reason, temperature estimates may have been affected to various degrees by reequilibration during cooling of the samples. Temperature estimates vary between 580°C and 815°C, and generally increase from west to east and are higher in the northern region than in the central and southern regions. It must be remembered that the absolute numbers for temperature are dependant on the calibration used for a particular thermometer; the significant result is the temperature gradient across the Scotia-Quaal metamorphic belt. On a ridge in the central region, temperatures are lower at the western margin of the Scotia-Quaal belt and higher further east. They are lower again close to the Ecstall deposit on its eastern side and are highest on the eastern side of the belt. This pattern of temperature change across the ridge is identical to the pattern recorded by mineral assemblages in mafic metavolcanic rocks on the same ridge. It is interpreted as representing an easterly increasing regional metamorphic gradient overprinted in the vicinity of the Ecstall deposit by a retrogressive event facilitated by influx of fluids along the zone containing the Ecstall mineral deposit. In the northern region, temperatures on the eastern side of the belt are also higher than on the western side of the belt. Temperatures in the northern region are higher than in the central region.

Hints of reequilibration at high temperatures found in sample 88-104-1 may be the result of heat input from the east. It is interesting to note that samples very close to the Quottoon pluton contact (88-104-1 and 87-150-7) do not show signs of having reequilibrated to lower pressures even though the Quottoon pluton was interpreted by Hollister et al. (1987) to have been emplaced at a depth corresponding to a pressure of approximately 550 MPa, and pressures in the metamorphic rocks of the Central Gneiss Complex east of the Quottoon pluton are around 500 MPa (Kenah, 1979; Selverstone, 1978; Selverstone and Hollister, 1980 and Douglas, 1986). This observation suggests that the thermal impact, with respect to the thermobarometric systems studied, of hot rocks east of the study area on the Scotia-Quaal metamorphic belt was not very significant, possibly because the thermal boost was very short-lived. Sample 89-69-2 records a slightly lower (although within uncertainty) pressure which may result from contact metamorphism occurring for a longer time period to the north than in the south.

Two samples (89-137-2 and 87-195-3) contain both biotite and hornblende in equilibrium with garnet. For both, garnet-biotite temperature estimates are higher than those obtained using the garnet-hornblende assemblage, although in the case of sample 89-137-2, the temperature estimates are within error range of each other. Both samples were collected in the proximity of a bounding pluton. The discrepancy in temperatures may result from unidentified disequilibrium between garnet and one of the two mafic minerals, from lower closure temperature of Fe-Mg exchange in hornblende than in biotite or from thermal reequilibration at the time of Ecstall (89-137-2) and Quottoon (87-195-3) intrusion affecting the garnet-biotite and garnet-hornblende systems differently. The closure temperature of Fe-Mg exchange in biotite is believed lower than in hornblende. The temperature differences between the two thermometers, if significant, could be interpreted to result from lack of internal consistency between the two thermometric calibrations or

from contact metamorphism at temperatures above closure for the biotite system, but not for the hornblende system.

Three generations of garnet have been identified texturally and analytically. In most samples the garnet porphyroblasts are wrapped around by the foliation and many contain inclusion trails forming straight lines at an angle to the matrix foliation. These garnets are interpreted to have formed during the last regional metamorphic event. Many of them contain older cores that are distinguished by their different appearance in thin-section; garnet cores have a distinctly cloudy appearance, they contain finer and more abundant inclusions than the rest of the garnet or exhibit an inclusion distribution pattern different from the straight inclusion trails in the younger part of the garnet. These textural differences are accompanied by abrupt change in composition. The garnet cores are interpreted to result from an earlier metamorphic event than that responsible for the growth of the rest of the garnet. This earlier metamorphic event is herein called "M1" because it is the oldest metamorphic event recognized, even though it may not be the first metamorphic event experienced by rocks of the Scotia-Quaal belt.

The garnet poikiloblasts hosting the "M1" cores are interpreted to have grown during a later "M2" metamorphic episode which, as mentioned above, is the last regional metamorphic event in the Scotia-Quaal area. It is responsible for the attainment of the metamorphic conditions expressed by the mineral assemblage and by mineral compositions.

Garnets in sample 89-137-2 collected on Hawkesbury Island close to the Ecstall pluton contact overprint the foliation and are interpreted to result from a "M3" contact metamorphic event. No garnet growth related to intrusion of the Quottoon pluton was identified. This is consistent with the inference of only short-lived thermal impact of Quottoon emplacement on metamorphic rocks of the Scotia-Quaal belt.

The timing of these metamorphic episodes with respect to deformation is discussed in Section 2.6.

Thermobarometric evidence supports the postulate that the northeasterly metamorphic gradient is dominantly regional in nature. A small aureole occurs at the Ecstall pluton contact. The Quottoon pluton appears to have had little effect on temperature and none on pressure of mineral equilibration in the Scotia-Quaal metamorphic belt.

2.5 Aluminum in hornblende geobarometry in the Ecstall pluton adjacent to the Scotia-Quaal belt

Four samples from the eastern margin of the Ecstall pluton which intrudes metamorphic rocks of the Scotia-Quaal belt were studied for aluminum content in hornblende in order to assess any latitudinal gradient in plutonic emplacement pressure. The Al in hornblende barometer is based on a positive correlation between Al content in igneous hornblende and pressure of crystallization of the mineral. The barometer was calibrated empirically by Hammarstrom and Zen (1986) and Hollister et al. (1987) and experimentally by Johnson and Rutherford (1989) and Rutter and Willie (1989).

Al in hornblende geobarometer - calibration

The initial calibration, put forth by Hammarstrom and Zen (1986), is based on a compositional study of hornblende from 5 calc-alkalic, quartz-normative plutons, 2 of which were interpreted as having been emplaced under low pressure conditions (≈ 200 MPa) while the other three are inferred to have been emplaced at no less than 800 MPa, based on the presence of magmatic epidote and on the nature of metamorphic assemblages in rocks adjacent to the pluton. The calibration requires that the plutonic rock be composed of the assemblage oligoclase to andesine plagioclase, quartz, potassium feldspar, biotite, hornblende, titanite, apatite and magnetite or ilmenite. Moreover, hornblende must have

crystallized from a SiO₂-rich magma; this condition is thought to be fulfilled if hornblende shows textural evidence of coexistence with quartz. A 23-oxygen anhydrous formula was used for hornblende and Fe was assumed all ferrous. In an attempt to only use hornblende compositions resulting from primary magmatic crystallization, the dataset was limited to hornblende with Si ≤ 7.5, a compositional limit for "igneous" hornblende proposed by Leake (1971), and with Ca ≥ 1.6. Because amphibole composition is a function of not only pressure, but also temperature, f_{O2} and bulk composition, compositional factors related to temperature of crystallization such as Ti content in hornblende and plagioclase composition should be monitored. The effect of f_{O2} on amphibole composition is considered negligible based on experimental results by Helz (1973) and Spear (1981) which imply that differences in Al content resulting from oxygen fugacity differences are small compared to those produced by pressure differences. Changes in bulk composition are thought to be accommodated by changes in modal proportion of phases. Hammarstrom and Zen's (1986) linear correlation between aluminum content and crystallization pressure is described by the following equation:

$$P (\pm 3 \text{ kbar}) = -3.92 + 5.03 (\text{Al}^{\text{T}}); r^2 = 0.80$$

where P is the pressure in kbar (1 kbar = 100 MPa)

and Al^T is the total aluminum content in hornblende (Al^{IV} + Al^{VI})

Hollister et al. (1987) refined the barometer by examining hornblende data from plutons interpreted, based on pressure estimates in metamorphic country rock, to have equilibrated over the whole range (200-800 MPa) of pressures. They reiterate the importance of the mineral assemblage and propose that only rim compositions of hornblende be used for barometry. Other conditions for reliable results from the empirical barometer are that pressure should be above ~200 MPa and plagioclase composition be between An₂₅ and An₃₅. The equation of the linear fit they obtained is the following:

$$P (\pm 1 \text{ kbar}) = -4.76 + 5.64 (\text{AlT}); r^2 = 0.97$$

where P is the pressure in kbar (1kbar = 100MPa)

Johnson and Rutherford (1989) calibrated the geobarometer experimentally, based on the composition of hornblende in equilibrium with glass (melt) obtained from equilibration over the pressure range of 200 to 800MPa at 740 to 780°C of natural volcanic and plutonic samples containing the required phase assemblage. Linear regression of their experimental data points yields the following equation:

$$P(\pm 0.6 \text{ kbar at } 8 \text{ kbar, } \pm 0.5 \text{ at lower } P) = -3.46(\pm 0.24) + 4.23(\pm 0.13) (\text{AlT}); r^2 = 0.99$$

where P is the pressure in kbar (1kbar = 100MPa)

The same equation is obtained by regressing the experimental data using hornblende compositions calculated on the basis of 23 oxygens (Fe assumed all ferrous) and on the basis of 15 cations (ferrous and ferric iron calculated by charge balance). Hornblende from experiments which failed to stabilize quartz had higher aluminum contents than hornblende equilibrated at the same pressure in the presence of quartz. This calibration gives lower pressures than those obtained by application of the empirical calibrations.

Another experimental study conducted on amphiboles crystallized in a garnet tonalite at 1000MPa (Rutter et al., 1989) gives results consistent with the extrapolated empirical curve of Hollister et al. (1987). The authors conclude that as long as the conditions specified by Hammarstrom and Zen (1986) and Hollister et al. (1987) are satisfied, the hornblende geobarometer curve may be used with some confidence.

Sample description

Samples of the Ecstall pluton were collected from four locations bordering the Scotia-Quaal belt to the west and distributed along the length of the study area from the northern end of the pluton to the southern end of the study area. Three sample locations are shown in Figure 2-32. The fourth sample was collected outside the area shown on the location

Figure 2-32: Sample location map for Al-in-hornblende geobarometry at the eastern margin of the Ecstall pluton. MM = metamorphic.

map. The location and UTM coordinates of all sample collection sites are given in Appendices 1B and 2 respectively. These samples were selected because they fulfilled the conditions specified by Hammarstrom and Zen (1986) and Hollister et al. (1987), because their location spans the length of the Scotia-Quaal belt and because they were collected relatively close to the eastern margin of the pluton where it is in intrusive contact with the metamorphic rocks of the Scotia-Quaal belt. Pressure conditions in the Ecstall pluton are taken to represent the pressure conditions in the neighboring metamorphic host rock at the time of intrusion.

Sample 87-19-1 was collected along the Terrace-Prince Rupert highway at Rainbow Pass Summit at the northern end of the Ecstall pluton. At this location, the Ecstall pluton is a coarse grained, fresh and only very weakly foliated tonalite. The rock contains anhedral hornblende up to 3 mm in length and euhedral to subhedral biotite laths reaching 2 mm in length. Both mafic minerals are somewhat aligned along a vague foliation plane. Plagioclase is abundant and occurs as randomly oriented prismatic 1 to 4 mm long grains. The larger grains are euhedral and the smaller ones subhedral with serrate boundaries. The anorthite content of plagioclase varies between 0.24 and 0.35. Potassium feldspar is present in trace amounts. Other minerals are quartz, anhedral epidote, trace of calcite in plagioclase, and traces of titanite, apatite, zircon, rutile and ilmenite.

Sample 87-107-1 was collected on the ridge immediately north of the Ecstall river in the central region of the Scotia-Quaal belt. At this location the Ecstall pluton is medium grained, fresh and foliated. It is composed of anhedral hornblende up to 4 mm in length and subhedral biotite laths less than 2.5 mm in length. Alignment of mafic minerals define the foliation. Abundant coarse grained plagioclase (4 mm) exhibits oscillatory zoning with anorthite content between 0.30 and 0.34. Potassium feldspar makes up approximately 3%

of the rock. Other minerals present include quartz, anhedral epidote, titanite, apatite, zircon and fine grained ilmenite.

Collected south of the Ecstall river, *sample 87-96-1* is a medium grained, fresh and moderately foliated quartz diorite. The plutonic rock contains subhedral to anhedral hornblende (2 mm length) and subhedral biotite (3 mm length) aligned along the foliation plane. Coarse grained plagioclase is zoned with anorthite content increasing from 0.34 at the rims to 0.50 in the cores. Potassium feldspar occurs in trace amount. Other rock-forming minerals are quartz, epidote, euhedral white mica, titanite, apatite, zircon and magnetite.

Sample 89-139, collected on Hawkesbury Island in the southern region of the study area, consists of a coarse grained, fresh and unfoliated quartz diorite. It is composed of euhedral to subhedral hornblende (0.8 mm length) and coarse grained (4 mm), subhedral to anhedral and partially chloritized biotite. Coarse grained (≤ 4 mm) plagioclase has anorthite content varying between 0.29 and 0.37 with more Ca-rich compositions in the mineral's cores, although a systematic increase in Ca content from rim to core was not observed. Potassium feldspar, quartz, epidote, titanite, apatite and magnetite also compose the sample.

Analytical procedure

Hornblende grains in all four samples were analyzed for Si, Al, Fe(total), Mg, Mn, Cr, Ti, Na, K and Ca using Carleton University's Cambridge Microscan 5 instrument (electron microprobe procedure outlined in Appendix 5). Analyses were calculated on the basis of 23-oxygen anhydrous formula. At least two hornblende crystals per sample were analyzed in detail. Detailed analysis consists of at least 5 measurements at the grain's rim and 4 measurements in the crystal's apparent core. Additional measurements were made on at least four other hornblende grains to ensure that hornblende composition does not vary

dramatically at the scale of the thin-section. Each pressure estimate is based on the a minimum of 12 analyses of hornblende rims.

Results

Hornblende analyses and average core and rim compositions for each grain are presented in Appendix 8. The average hornblende rim composition for each sample is given in Table 2-4. It can be seen that the average Ti content does not vary greatly (0.010-

Table 2-4: Average rim compositions of hornblende, Ecstall pluton

Hornblende	87-19-1 N=20	87-107-1 N=12	87-96-1 N=13	89-139 N=13
SiO ₂	40.57	42.18	41.32	40.20
Al ₂ O ₃	12.80	11.97	12.55	12.49
TiO ₂	0.85	0.84	0.86	0.92
FeO	18.43	17.73	19.15	20.13
MnO	0.52	0.35	0.39	0.37
Cr ₂ O ₃	0.01	0.02	0.01	0.01
MgO	9.21	9.82	9.00	7.91
CaO	11.20	11.79	11.77	11.45
K ₂ O	1.47	1.34	1.40	1.48
Na ₂ O	1.61	1.36	1.33	1.50
Total	96.67	97.38	97.78	96.45
23 O				
Si	6.26	6.41	6.31	6.27
Al ^{IV}	1.74	1.59	1.69	1.73
	8	8	8	8
Al ^{VI}	0.58	0.55	0.56	0.57
Ti	0.10	0.10	0.10	0.11
Fe	2.38	2.25	2.45	2.63
Mn	0.07	0.04	0.05	0.05
Cr	0.00	0.00	0.00	0.00
Mg	2.12	2.22	2.05	1.84
	5.25	5.17	5.21	5.19
Ca	1.85	1.92	1.93	1.91
K	0.29	0.26	0.27	0.29
Na	0.48	0.40	0.40	0.45
	2.62	2.58	2.59	2.66
Al Total	2.33	2.14	2.26	2.30

0.011) between samples. This is interpreted as an indication that temperature of final hornblende crystallization did not vary significantly from south to north along the eastern margin of the pluton. This is consistent with the observation of a relatively restricted compositional range for plagioclase rims from these four samples (An 24 to 37).

The average rim aluminum content for each sample is interpreted as the best estimate of aluminum content in hornblende for each specimen. Aluminum content does not vary significantly for three of the samples (Figure 2-33 and Appendix 8). As can be observed from Figure 2-33, in all samples Al content in hornblende cores is slightly lower than at hornblende rims, although the ranges overlap greatly. For individual grains, pressure estimates may be lower by as much as 150 MPa if core values are used rather than rim values. This is surprising because any pressure change that may be reflected in differing Al content across a hornblende grain during emplacement would produce an increase in Al content from core to rim, the opposite of what is observed here. Crystallization of hornblende cores not in equilibrium with all phases or changes in hornblende core composition through diffusion after crystallization may explain the small decrease in Al content between rims and cores. Non-equilibrium with quartz would produce an increase in Al content for the same pressure of crystallization (Johnson and Rutherford, 1989). The effect of non-equilibrium with other minerals is not known. Changes in temperature and oxygen fugacity during crystallization may also affect Al content of hornblende. Titanium content in amphiboles analyzed suggests that amphibole cores crystallized at slightly higher temperatures than amphibole rims (Table 2-5). The magnitude of temperature change expressed by changes in Ti content is not known. Neither is the exact effect of temperature change on Al content in amphibole. These uncertainties underline the importance of satisfying the restriction specified by Hollister et al. (1987) that rim compositions only be used.

Figure 2-33: Bar diagrams showing the range in aluminum content in igneous amphiboles from four samples of the Ecstall pluton.

Table 2-5: Average Ti content based on 23-oxygen anhydrous formula in amphibole of four samples from the Ecstall pluton

Sample #	Average Ti _{rim}	Average Ti _{core}	Δ
87-19-1	.099	.122	.023
87-107-1	.096	.129	.033
87-96-1	.099	.106	.007
89-139	.108	.115	.007

Table 2-6 provides a summary of average Al content at hornblende rims in each of the four samples and pressure estimates obtained from the calibrations of Hammarstrom and Zen (1986), Hollister et al. (1987) and Johnson and Rutherford (1989). Errors in pressure estimates induced by standard error in Al content fall within the uncertainty of each calibration. Pressure estimates based on the empirical calibrations (P_{HZ} and P_H) are within uncertainty of each other and higher than estimates obtained from the experimental curve (P_{JR}).

Table 2-6: Average Al content and pressure estimates from four samples of Ecstall pluton on the western side of the Scotia-Quaal metamorphic belt. P_{HZ} is based on Hammarstrom and Zen (1986); P_H on Hollister et al. (1987) and P_{JR} on Johnson and Rutherford (1989).

Sample #	Location	Average Al 23O	Standard Deviation	P_{HZ} (± 300)MPa	P_H (± 100)MPa	P_{JR} (± 50)MPa
87-19-1	Rainbow Pass Summit Terrace-Prince Rupert Highway	2.33	± 0.06	780	838	640
87-107-1	Ridge north of Ecstall river central region	2.14	± 0.15	684	731	559
87-96-1	Ridge SW of Ecstall river central region	2.26	± 0.04	745	799	610
89-139	Hawkesbury Island southern region	2.30	± 0.06	765	821	627

Johnson and Rutherford (1989) suggested that the disagreement between the two types of calibrations (empirical and experimental) is caused by errors in pressure estimated for the plutonic bodies used in the empirical calibration. They pointed out that the argument made by Zen and Hammarstrom (1988) for the presence of igneous epidote implying pressures of at least 800MPa is not proven since the argument is based on experimental studies conducted at 800 and 200MPa, but not in the intervening range. They also rightly pointed out that the r^2 value reported by Hollister et al. (1987) only reflects the precision of the data, but not the accuracy of individual data points, i.e the uncertainty of the thermobarometric method(s) used to define the metamorphic pressure estimates which are inferred to equal equilibration pressure of the pluton. However, Johnson and Rutherford's experimental results are in contradiction with results from the experimental study of Rutter and Wyllie (1989) on garnet tonalite at 1000MPa which gave results in agreement with the calibration by Hollister et al. (1987). Additional experimental studies are needed to resolve this controversy.

Of the empirical calibrations, the one by Hollister et al. (1987) has a lower error in pressure due mainly to the use of a larger dataset for defining the best linear fit. This calibration is based mainly on pressure estimates at localities close to the Scotia-Quaal area within the Coast Plutonic Complex. For these reasons, the calibration of Hollister et al. (1987) is preferred over that of Hammarstrom and Zen (1986). Pressure estimates from the eastern margin of the Ecstall pluton are inferred to vary between approximately 730 and 840 (± 100) MPa (Table 2-6). This is consistent with pressure estimates in the Scotia-Quaal metamorphic belt. This result indicates that the Scotia-Quaal belt remained, after the end of metamorphism, at a depth of approximately 30 km until the time of intrusion of the Ecstall pluton.

If, on the other hand, the 550 to 640 MPa pressure estimates obtained using the experimental calibration of Johnson and Rutherford (1989) more closely approach the true pressure experienced by the Ecstall pluton at the time of its emplacement into rocks of the Scotia-Quaal metamorphic belt, then some uplift of the Scotia-Quaal belt would have had to occur between the end of regional metamorphism and the intrusion of the Ecstall pluton.

Finally, a most important result, no matter which calibration is used, is that no significant latitudinal pressure gradient exists.

2.6 Timing relationship between metamorphism and deformation

In chapter 1, it was concluded based on field evidence that deformational features in the Scotia-Quaal belt (except those spatially and temporally related to emplacement and/or deformation of the Quottoon pluton) predate the intrusion of the Ecstall pluton, because the pluton cuts units and fabrics of the Scotia-Quaal metamorphic belt. Petrographic and geothermobarometric evidence indicate that deformation resulting in the present disposition of units and orientation of fabrics not only preceded intrusion of the Ecstall pluton, approximately 94 Ma ago (Chapter 3), but also preceded the end of the last regional metamorphic event (M2), approximately 110 Ma ago (Chapter 3) in order for similar pressure estimates to be recorded in samples throughout the Scotia-Quaal metamorphic belt.

Growth of M2 garnets must have occurred prior to or synchronously with the last regional deformation in order to allow the foliation to wrap around these garnets and for some M2 garnets to be deformed. Other M2 porphyroblasts such as plagioclase, gedrite, kyanite, sillimanite, hornblende and zoisite are generally oriented parallel to the foliation and are locally bent indicating that they grew before the end of deformation. Biotite plates parallel the regional planar fabric, but generally are undeformed; they probably have been

annealed after deformation. Quartz has consistently undergone annealing recrystallization. Based on these observations, it is inferred that the last regional episode of deformation and metamorphism occurred prior to 110 Ma ago (hornblende K-Ar date representing cooling below the closure temperature of hornblende after M2 metamorphism; chapter 3), that growth of most metamorphic minerals either predated or occurred synchronously with a deformational event, and that reactions between minerals continued after the end of deformation in order to allow for all samples of the Scotia-Quaal belt to equilibrate at similar pressures, around 800 MPa. As discussed in chapter 1, this last episode of regional deformation is either that which formed F1 folds, or is a distinct event of unknown nature which occurred subsequently to F1 folding.

Straight inclusion trails in M2 garnets, oriented at an angle to the current foliation suggest that M2 garnets overgrew a preexisting foliation. Some M2 garnets contain cores which differ in appearance and composition from the rest of the garnet and probably grew during an M1 metamorphic episode, older than M2. Although they are not abundant, M1 garnet cores are widespread throughout the belt, suggesting that M1 metamorphism was regional in nature. Inclusions within M1 garnets form an helicitic pattern, implying that M1 metamorphism may have occurred concurrently with a deformational event.

In summary, petrographic analysis of thin-sections from the Scotia-Quaal metamorphic belt provides evidence for two episodes of regional metamorphism and two, possibly three, episodes of deformation. Helicitic inclusion trails in M1 garnets may result from a syn-metamorphic deformational episode. Strait inclusion trails in M2 garnets suggest that they overgrew a preexisting foliation which may have formed during growth of M1 garnets (in which case helicitic inclusion trails in M1 garnets result from the same episode of deformation as that responsible for formation of strait inclusion trails in M2 garnets) or after M1 garnet growth. Growth of M2 garnet occurred prior to the last regional

deformational event, but exchange between garnets and surrounding minerals continued after the end of the last regional metamorphic event.

Garnets in samples collected within 300 meters of the Ecstall pluton contact overprint the foliation and are interpreted to result from a M3 contact metamorphic event. No garnet growth related to intrusion of the Quottoon pluton was identified. At one location, coarse garnet poikiloblasts with strait inclusion trails show evidence of rotation consistent with east-side-up movement. The timing of this rotation is unknown; it may be related to deformation in the Quottoon pluton or to the last regional deformational event. Evidence for deformation in the Scotia-Quaal belt close to the Quottoon pluton contact is given mainly by strongly deformed leucocratic dykes of approximately the same age (Chapter 3) as the Quottoon pluton.

2.7 Summary and conclusion

Mineral assemblages in mafic rocks indicate metamorphic conditions in the Scotia-Quaal belt between epidote-amphibolite and upper amphibolite facies. Metapelitic assemblages are consistent with kyanite-staurolite and sillimanite grades of metamorphism. Garnet geothermobarometry reveals metamorphic equilibration temperatures between approximately 580 and 815°C and pressures generally around 800-850MPa (Figure 2-34). It must be remembered that the absolute numbers for temperature are dependent on the calibration used for a particular thermometer; the significant result is that mineral assemblages and compositions as well as temperature estimates are consistent with a northeasterly increase in metamorphic grade across the belt. Pressure estimates are surprisingly uniform throughout the Scotia-Quaal belt and the eastern margin of the Ecstall pluton. They are interpreted to represent peak pressure conditions during the last regional

Figure 2-34: Geological map of the Scotia-Quaal belt summarizing pressure and temperature estimates obtained from geothermobarometry in metamorphic rocks and the Ecstall pluton. MM = metamorphic.

metamorphic event (M2) to have affected, at least 110 Ma ago (see Chapter 3) the Scotia-Quaal area, then at a depth of approximately 30 km.

Uplift of the Scotia-Quaal metamorphic belt to a shallower depth may have started between the end of regional metamorphism and the time of emplacement of the Ecstall pluton. This is suggested by pressures of approximately 600 MPa obtained using Johnson and Rutherford's (1989) calibration of the Al in hornblende barometer in the Ecstall pluton. However, different pressure estimates, around 800 MPa, are obtained using the empirical calibration of the barometer from Hollister et al. (1987). This later pressure estimate would suggest that the Scotia-Quaal metamorphic belt remained at approximately 30 km depth until the time of intrusion of the Ecstall pluton.

There is textural and compositional evidence for 3 garnet growth episodes. M3 represents contact metamorphism in a narrow aureole around the Ecstall pluton. M2 is the last regional metamorphic episode. It was accompanied by deformation which started after growth of many metamorphic minerals and ended prior to final equilibration of samples at pressures around 800 MPa. M1, which is evidenced by the presence of relic garnets in cores of "M2" garnets, is the oldest metamorphic event recognized, although it need not be the first metamorphic episode experienced by the Scotia-Quaal belt.

While mineral assemblages in a zone less than 300 m in width at the western margin of the belt are consistent with the development of a contact aureole around the $\approx$ 94 Ma (van der Heyden, personal communication, 1991; Woodsworth et al., 1983) Ecstall pluton, the thermal impact of rocks east of the Scotia-Quaal belt on the eastern margin of the study area appears minimal, at least with respect to net transfer mechanisms. Rocks at the easternmost margin of the belt may retain petrological evidence of a short-lived thermal pulse postdating regional metamorphism, but no samples appear to have reequilibrated at pressures lower

than those characteristic of the belt, except maybe at the northeasternmost end of the belt where a pressure estimate is somewhat lower than in the rest of the area.

Part of the metavolcanic belt east of the Ecstall deposit in the central region may have undergone a retrogressive episode caused by fluid influx along the deposit zone, possibly at the time of intrusion of the Quottoon pluton.

Metamorphic conditions within the Scotia-Quaal belt are comparable to those estimated by Lappin (1976) and Lappin and Hollister (1980) in an area situated along trend north of the Skeena river (locality 3; Figure 2-1). Pressure estimates in the Scotia-Quaal belt contrast sharply with inferred pressures of approximately 550 MPa in the Quottoon pluton and 450-550 MPa estimates in the Central Gneiss Complex. The Scotia-Quaal belt forms the eastern margin of a high pressure and high temperature region extending from the Prince Rupert shear zone to the eastern margin of the Scotia-Quaal area and thereby spanning most of the western belt of the Coast Plutonic Complex (Figure 2-1). The fact that the Quottoon pluton marks a major change in pressure between rocks having equilibrated around 800 MPa in the western region and gneisses giving pressure estimates of approximately 500 MPa in the Central Gneiss Complex is consistent with the postulate, based on contrasting K-Ar dates between the western Coast Plutonic Complex and the Central Gneiss Complex and based on field evidence that Late Paleocene-Early Eocene fabrics are localized in and near the western margin of the Quottoon pluton, that a major Late Paleocene-Early Eocene structural zone is located within or near the western edge of the Quottoon pluton. Because pressure estimates in samples collected near the eastern margin of the Scotia-Quaal belt, within the band of rock that has been affected by Late Paleocene-Early Eocene deformation, are consistent with pressure estimates elsewhere in the Scotia-Quaal belt, Late Paleocene-Early Eocene deformation did not result in any significant vertical movement within the Scotia-Quaal metamorphic belt. Therefore, vertical

movement between the western and central regions of the Coast Plutonic Complex must be concentrated in the Quottoon pluton.

An apparent inconsistency in metamorphic facies indicated by pelitic and mafic assemblages may be partly blamed on the poor distribution of pelitic rocks in the Scotia-Quaal area. Most metapelitic rocks in the southern region and the western part of the central region occur in proximity to the Ecstall pluton which has been shown to have produced a narrow aureole of slightly higher metamorphic grades. It may also result from the poor definition of the epidote amphibolite-amphibolite boundary which is marked by the disappearance of chlorite. The effect of bulk rock composition, pressure and oxygen fugacity on the stability of chlorite is poorly understood and certain conditions may allow chlorite to persist at higher grade than usually observed. In fact, little is known about metabasites formed in the pressure range experienced by mafic rocks of the Scotia-Quaal area. The effect of pressure on chlorite and amphibole composition is poorly understood, as illustrated in Figure 2-5 by the Al^{VI} -Si relationships in amphiboles from the Scotia-Quaal area which are consistent with pressures at or slightly above 500MPa and in disagreement with thermobarometric results which establish pressure conditions around 800MPa. It must be concluded that the pressure dependence of the Al^{VI} content in metamorphic amphiboles is not as simple as assumed by Raase (1974).

Chapter 3 - U-Pb and K-Ar geochronology

3.1 Objectives

This chapter is dedicated to the presentation and discussion of geochronologic data acquired from samples of the Scotia-Quaal belt, an area located in a part of the Coast Plutonic Complex where little is known about depositional and metamorphic ages of units. The importance of zircon U-Pb work in the Scotia-Quaal area resides primarily in obtaining protolith ages for comparison with ages of units in neighbouring terranes and for estimating ages of magmatic episodes related to indicate periods of tectonic activity in that part of the Coast Plutonic Complex. U-Pb dating is also aimed at constraining the ages of bounding plutons which provide a younger limit on regional metamorphism and deformation across the Scotia-Quaal area and an older limit on deformation localized in the Quottoon pluton and the easternmost part of the Scotia-Quaal belt. A hornblende K-Ar traverse across the central region documents timing of cooling below the hornblende K-Ar closure temperature after the last regional metamorphic event, evaluates the thermal impact of the bounding plutons on the Scotia-Quaal area and provides an estimate of the minimum age of ultramafic rocks in the area.

3.2 Previous work

This section summarizes the geochronologic data already available in the western Coast Plutonic Complex at the latitude of Terrace-Prince Rupert. It is not exhaustive and the reader is referred to van der Heyden (1989) for a more detailed and encompassing review of geochronologic data from the Douglas Channel-Hecate Strait area and to Armstrong (1988) and Woodsworth et al. (1990) for discussion of ages of igneous rocks in the

Canadian Cordillera. The present section focuses on data in the immediate vicinity of the Scotia-Quaal belt that are significant in the context of the geological history and the geographic extent of the units occurring in the area.

Published U-Pb and K-Ar dates in locations proximal to the Scotia-Quaal area are shown in Figure 3-1. Uncertainties on dates and references are given in the accompanying figure caption. The Ecstall pluton has been interpreted as an intrusion of early Late Cretaceous age based on zircon U-Pb dating of samples collected both at the northern end of the body (locality 5; Figure 3-1) and farther south along Douglas Channel (localities 7 and 8; Figure 3-1). Woodsworth et al. (1983) have interpreted data from two zircon fractions in a sample collected at locality 5 to indicate a 98 ± 4 Ma emplacement age for the Ecstall pluton. Two zircon fractions from the Kitkiata pluton (locality 7; Figure 3-1) herein considered part of the Ecstall pluton were interpreted by van der Heyden (1989) to indicate an age between 94 and 110 Ma. The most recent U-Pb data is provided by 6 zircon fractions from a sample collected at locality 8 (Figure 3-1). All fractions are concordant and give a 93.5 ± 1 Ma date (van der Heyden, personal communication 1991) interpreted as the age of the Ecstall pluton. This date is preferred over the 98 ± 4 Ma date because more fractions were analyzed, all points overlap, and the results are more precise than those for fractions from the sample at locality 5. The age of all intrusive rock forming the Ecstall pluton between Douglas Channel and the northern end of the intrusive body is inferred in this study to be 93.5 Ma, even though it is possible that the northern end of the body be slightly older than the part exposed along Douglas Channel. An identical age was obtained by van der Heyden (1989) from the Butedale pluton (locality 9; Figure 3-1) located along the southern continuation of the Ecstall pluton. Hornblende K-Ar cooling dates of approximately 90 Ma were obtained from samples in the southern half of the Ecstall pluton

Figure 3-1: Map of the Coast Plutonic Complex at the latitude of Terrace and Prince Rupert showing location of previous geochronologic studies. Approximate sample location is shown by number in a white circle. Results of study summarized on the upper left-hand side of sample location. Zr refers to U-Pb analyses on zircons, Hb refers to K-Ar analyses on hornblende and Bt refers to K-Ar analyses on biotite.

Dates and references are:

1) 382±14 Ma U-Pb Zr	van der Heyden, 1989	(Swede Point pluton)
2) 90±1 Ma ⁴⁰ Ar/ ³⁹ Ar Hb	Sutter and Crawford, 1985	(metamorphic rock)
3) 68±4 Ma K-Ar Bt	Hutchison, 1982	(metamorphic rock)
4) 64±8 Ma K-Ar Bt	Hutchison, 1982 after Wanless et al., 1967	(Ecstall pluton)
5) 98±4 Ma U-Pb Zr	Woodsworth et al., 1983	(Ecstall pluton)
6) 89±8 Ma K-Ar Hb and 72±7 Ma K-Ar Bt	van der Heyden, 1989 after Wanless et al., 1968	(Ecstall pluton)
7) 94-110 Ma U-Pb Zr	van der Heyden, 1989	(Ecstall pluton)
8) 93.5±1 Ma U-Pb Zr	van der Heyden, personal communication 1991	
90.0±3.2 Ma K-Ar Hb and 75.9 ±2.7 K-Ar Bt	van der Heyden, 1989	(Ecstall pluton)
9) 94 Ma U-Pb Zr	van der Heyden, 1989	(Butedale pluton)
69±2.5 Ma K-Ar Bt	van der Heyden, 1989 after Wanless et al., 1966	(Butedale pluton)
10) 50±2.5 K-Ar Bt	van der Heyden, 1989 after Wanless et al., 1966	(metamorphic rock)
11) 49±7 Ma K-Ar Hb and 44±5 Ma K-Ar Bt	Wanless et al., 1968	(Quottoon pluton)
12) 48±9 Ma K-Ar Hb and 50±5 Ma K-Ar Bt	Wanless et al., 1968	(Quottoon pluton)
13) 60 Ma U-Pb Zr	Armstrong and Runkle, 1979	(Quottoon pluton)
49.6±1.1 Ma K-Ar Hb and 43.2±0.8 K-Ar Bt	Harrison et al., 1979	(Quottoon pluton)
14) 65-75 Ma U-Pb Zr	Woodsworth et al., 1983	(metamorphic rock)
15) 43±5 Ma K-Ar Bt	Hutchison, 1982 after Wanless et al., 1967	(Kasiks pluton)
16) 44±4 Ma K-Ar Bt	Hutchison, 1982 after Wanless et al., 1967	(Alastair Lake pluton)
17) 66 Ma U-Pb Zr	Woodsworth et al., 1983	(metamorphic rock)
18) 139 Ma minimum U-Pb Zr	Hill, 1984	(metamorphic rock)
19) 108-171 Ma U-Pb Zr	Woodsworth et al., 1983	(metamorphic rock)
20) 71 Ma U-Pb Zr	Woodsworth et al., 1983	(metamorphic rock)
21) 83 Ma U-Pb Zr	Woodsworth et al., 1983	(metamorphic rock)

(localities 6 and 8; Figure 3-1). Biotite K-Ar cooling dates vary between 64 Ma in the north (locality 4; Figure 3-1) and 76 Ma along Douglas Channel (locality 8; Figure 3-1); additional dating may show a north-south trend of increasing biotite K-Ar ages.

Few dates exist from metamorphic rocks west of the Ecstall pluton. An orthogneissic body west of Grenville Channel gave a U-Pb zircon date of 382 ± 14 Ma (locality 1; Figure 3-1) different from plutonic ages typical of Alexander terrane inferred to make up, with Wrangellia, the western part of the Coast Plutonic Complex. Van der Heyden (1989) tentatively correlated this pluton with Devonian volcanic rocks of the Alexander terrane and magmatic rocks of Wrangellia.

A 90 ± 1 Ma ^{40}Ar - ^{39}Ar hornblende date (locality 2; Figure 3-1) obtained from a metamorphic rock having undergone kyanite grade metamorphism was interpreted as the age of biotite through kyanite grade metamorphism in the vicinity of Prince Rupert (Crawford et al., 1987). Metamorphic rocks near the northern end of the Ecstall pluton (close to locality 5; Figure 3-1) have been interpreted as having undergone high pressure metamorphism and deformation synchronously with the emplacement of the Ecstall pluton (Crawford et al., 1987). A 68 Ma biotite K-Ar date east of Prince Rupert indicates that the metamorphic rocks from this region had cooled below approximately 250-300°C by the end of the Cretaceous.

Rocks located east of the Scotia-Quaal metamorphic belt are within the so-called 50 to 43 Ma K-Ar "plateau" indicative of rapid Eocene uplift and cooling of the Central Gneiss Complex (discussed by Harrison et al., 1979; Hutchison, 1970; Parrish, 1983; Roddick, 1970 and van der Heyden, 1989). In this area, both hornblende and biotite K-Ar dates from igneous and metamorphic rocks are in the 50-43 Ma range. Rapid uplift of the Central Gneiss Complex was interpreted by Parrish (1983) as the result of crustal thickening due to compression and perhaps plutonic underplating. Van der Heyden (1989)

and Heah (1991) proposed mid-crustal extension as an alternative process responsible for rapid cooling of the central region of the Coast Plutonic Complex. The Work Channel lineament and its southern continuation was suggested by van der Heyden (1989) as the possible western boundary of an extensional complex. Geochronologic work in the Scotia-Quaal area is instrumental in locating the exact position of a young structural feature bounding the Central Gneiss Complex between the Skeena river and Douglas Channel, and in evaluating the regional significance of such a structural zone.

A 60 Ma U-Pb zircon date from the Quottoon pluton south of Douglas Channel (locality 13; Figure 3-1) is interpreted as the pluton's emplacement age. According to van der Heyden (1989), at least part of the Quottoon pluton is approximately 80 Ma old, based on a 80 Ma U-Pb date from an intrusive rock located along a trend with the Quottoon pluton, but more than 35 km south of Douglas Channel.

U-Pb zircon dating at four locations within the Central Gneiss Complex north of the Skeena river (localities 14, 17, 20 and 21; Figure 3-1) yielded concordant dates between 65 and 85 Ma. These were interpreted by Woodsworth et al. (1983) as approaching the age of peak metamorphism in amphibolite to granulite facies rocks from the Central Gneiss Complex. A minimum protolith age for rocks from the eastern part of the Central Gneiss Complex is given by a U-Pb zircon 139 Ma date obtained from a leucogneiss collected in the Redcap Mountain area (locality 18; Figure 3-1).

The geochronologic data from igneous rocks in the Coast Plutonic Complex at the latitude of the Scotia-Quaal metamorphic belt is consistent with emplacement and cooling of Early Cretaceous to early Tertiary plutons in an eastward younging succession (Hutchison, 1982 and van der Heyden, 1989). The Scotia-Quaal metamorphic belt is located east of an Ecstall zone defined on the basis of K-Ar dates (van der Heyden, 1989). This Ecstall zone was divided into two parts (van der Heyden, 1989); in the western part hornblende K-Ar

dates vary between 108 and 94 Ma (Figure 3-1), and in the eastern part dates are between 91 and 74 Ma (Figure 3-1). Rocks located east of the Scotia-Quaal area, which have yielded K-Ar dates between 50 and 43 Ma, belong to the eastern zone of Hutchison (1982). Little is known about the age and association of high grade metamorphic rocks in the Coast Plutonic Complex.

3.3 U-Pb geochronology

Analytical procedure

All U-Pb analyses were done by the author in the Geochronology Laboratory of the Geological Survey of Canada. The analytical procedure is that described by Parrish et al. (1987). Zircons were separated from samples of approximately 25 kg. Mineral separation involved standard crushing, grinding, Wilfley table and heavy liquid (methylene iodide) which were performed in the facilities of the University of British Columbia and of Carleton University. Initial separation was followed by magnetic separation and sieving in ethyl alcohol into a number of size fractions. Zircons were selected for analysis by handpicking in alcohol. Selection criteria included clarity of zircons, lack of cracks and minimum quantity of inclusions. An attempt was made at identifying variations in zircon morphologies within individual samples and analyzing at least one fraction from each morphological type. No visible cores were observed within zircons from samples of the Scotia-Quaal metamorphic belt. The majority of the zircon fractions were air abraded using the method of Krogh (1982). Abraded fractions were leached in lukewarm 3N HNO₃ for approximately 10 minutes.

Sample weighing, U-Pb spiking, dissolution and column chemistry were done in a clean chemistry laboratory with environmental conditions and purity of water and acids as

cited in Parrish (1987). The zircons were spiked with a small amount of mixed ^{233}U - ^{235}U - ^{205}Pb tracer made by the Geological Survey of Canada (Parrish and Krogh, 1987) with the assistance of Atomic Energy of Canada Limited. A zircon dissolution and chemistry method after Krogh (1973), described by Parrish (1987) was used. Zircons were dissolved in 48% HF at 230-240°C for 30 to 60 hours. Anion exchange chemistry was done as outlined in Roddick et al. (1987). Procedural blanks were approximately 10 pg Pb and less than 2 pg U. Isotopic compositions of Pb and U were measured, as described by Roddick et al. (1987), by staff of the Geological Survey of Canada, on a Finnigan-MAT 261 multicollector mass spectrometer. Corrections for common Pb were made based on model Pb isotopic compositions derived from the growth curve of Stacey and Kramers (1975). Propagation of uncertainties followed the procedure outlined by Roddick (1987). Analytical errors for results presented in Table 2-1 refer to one standard error of the mean, whereas errors in ages of samples are quoted as two standard errors of the mean. Error ellipses in Figure 3-3 to 3-8 represent two standard errors of the mean. Decay constants from Steiger and Jäger (1977) were used. Linear regressions were done based on the method of York (1969). Analyses with error ellipses substantially overlapping the concordia curve were taken as concordant and with these analyses an age estimate was obtained from the mean of the intersection of the error ellipse(s) with concordia. The error was calculated from the deviation of the error ellipse(s) intersections from the mean.

Sample description and results

Seven samples were analyzed for zircon U-Pb dating. Sample locations are shown in Figure 3-2 and in Appendices 1A and 1B. Results are presented in Table 3-1.

Figure 3-2: Geological map of the Scotia-Quaal area showing zircon U-Pb sample locations. MM = metamorphic.

Table 3-1: Zircon U-Pb data for samples from the Scotia-Quaal metamorphic belt and the adjacent Quotatoon pluton.

Analysis number, size ^a	wt. mg	U ppm	Pb b ppm	206Pb c 204Pb	Pb c d pg	208Pb b %	238U %	206Pb ± 1SEM % ^e	207Pb ± 1SEM % ^e	235U	207Pb ± 1SEM % ^e	206Pb	207Pb age, error / 206Pb Ma
87-172-2													
1a +149 A (m,c)	0.337	427	20.7	1387	322	9.0	0.04873 ± 0.14%	0.3615 ± 0.20%	0.05379 ± 0.11%				362.4 ± 4.9
1b +149 A (m,fr)	0.316	437	22.7	3859	119	8.5	0.05258 ± 0.10%	0.3893 ± 0.12%	0.05370 ± 0.05%				358.6 ± 2.2
1c +149 A (l,fr)	0.309	290	16.9	5891	55	10.0	0.05766 ± 0.10%	0.4300 ± 0.12%	0.05408 ± 0.04%				374.3 ± 1.7
1d +149 A (c)	0.311	469	24.8	3476	141	9.2	0.05309 ± 0.12%	0.3934 ± 0.14%	0.05374 ± 0.05%				360.3 ± 2.3
1e -149+105 (c)	0.728	399	20.5	2999	315	9.2	0.05135 ± 0.13%	0.3806 ± 0.15%	0.05376 ± 0.06%				360.9 ± 2.5
1f -149+105 A (l,s,fr)	0.093	258	12.4	1830	41	8.0	0.04907 ± 0.09%	0.3611 ± 0.13%	0.05337 ± 0.07%				344.4 ± 3.1
1g -149+105 A (l,s,fr)	0.074	511	23.7	928	123	8.3	0.04707 ± 0.10%	0.3450 ± 0.20%	0.05315 ± 0.15%				335.1 ± 6.6
88-140-2													
2a +105 A (m,c)	0.018	266	13.9	750	20	12.6	0.05042 ± 0.09%	0.3710 ± 0.15%	0.05337 ± 0.10%				344.6 ± 4.5
2b +149 (an)	0.011	198	10.7	166	47	14.7	0.05066 ± 0.27%	0.3661 ± 1.0%	0.05241 ± 0.90%				303.3 ± 1.6
2c +105 A (l,s,c)	0.020	369	19.1	1320	18	14.5	0.04880 ± 0.10%	0.3598 ± 0.13%	0.05347 ± 0.07%				348.9 ± 3.3
87-139-5													
3a +149 A (l,f,c)	0.381	537	15.8	29754	12	11.4	0.02877 ± 0.11%	0.1985 ± 0.12%	0.05004 ± 0.03%				197.0 ± 1.4
3b +149 A (l,s,c)	0.409	504	14.8	28010	13	11.3	0.02881 ± 0.14%	0.1985 ± 0.15%	0.04996 ± 0.03%				193.0 ± 1.4
3c -149+105 (l,s,c)	0.934	619	18.0	13777	75	11.9	0.02836 ± 0.30%	0.1953 ± 0.30%	0.04995 ± 0.03%				192.5 ± 1.4
3d -149+105 (m,f,c)	1.007	638	18.6	40806	28	12.4	0.02829 ± 0.31%	0.1949 ± 0.31%	0.04996 ± 0.03%				193.3 ± 1.3
3e -149+105 A (l,s,c)	0.059	337	10.0	1988	18	11.5	0.02919 ± 0.09%	0.2011 ± 0.17%	0.04997 ± 0.12%				193.5 ± 5.7
3f -149+105 A (l,s,c)	0.068	408	12.2	1901	27	12.4	0.02905 ± 0.09%	0.2001 ± 0.15%	0.04995 ± 0.10%				192.5 ± 4.6
87-218-2													
4a +149 A (l,f,c)	0.386	883	26.3	43463	14	11.5	0.02917 ± 0.12%	0.2007 ± 0.13%	0.04991 ± 0.03%				191.0 ± 1.3
4b +149 A (l,s,c)	0.464	944	28.1	54461	15	11.1	0.02933 ± 0.14%	0.2020 ± 0.14%	0.04994 ± 0.03%				192.4 ± 1.3
4c -149+105 (l,f,c)	0.485	1121	33.2	43013	23	11.4	0.02903 ± 0.22%	0.1999 ± 0.22%	0.04994 ± 0.03%				192.2 ± 1.3
4d -149+105 (l,f,c)	0.940	1139	34.1	64928	31	11.7	0.02929 ± 0.57%	0.2016 ± 0.57%	0.04992 ± 0.03%				191.4 ± 1.3
4e -149+105 A (l,s,c)	0.147	511	15.7	8213	17	13.5	0.02949 ± 0.10%	0.2029 ± 0.11%	0.04991 ± 0.04%				190.6 ± 2.0
4f -149+105 A (l,s,c)	0.096	565	17.3	6221	16	13.8	0.02929 ± 0.09%	0.2015 ± 0.11%	0.04990 ± 0.05%				190.4 ± 2.4

Table 3-1 (end)

Analysis number, size ^a	wt. mg	U ppm	Pb ^b ppm	206Pb ^c 204Pb	Pb ^{c,d} pg	208Pb ^b %	206Pb ± 1SEM % ^e 238U	207Pb ± 1SEM % ^e 235U	207Pb ± 1SEM % ^e 206Pb	207Pb age, error ^f 206Pb Ma
88-108-2										
5a +149 A (m,s,cd)	.014	650	19.5	847	21	6.9	0.03018 ± 0.09%	0.2074 ± 0.14%	0.04983 ± 0.09%	187.3 ± 4.1
5b +149 A (l,s,cd)	.029	247	7.3	307	48	8.0	0.03033 ± 0.16%	0.2083 ± 0.47%	0.04981 ± 0.37%	186.1 ± 17.4
5c -149+105 A(m,s,c)	.079	360	10.6	3128	17	8.0	0.03014 ± 0.08%	0.2075 ± 0.10%	0.04994 ± 0.04%	192.0 ± 1.8
5d -149+105 A (l,s,c)	.018	497	14.9	877	19	8.8	0.03022 ± 0.10%	0.2079 ± 0.15%	0.04990 ± 0.10%	190.3 ± 4.7
87-140-2										
6a +149 (l,c)	.570	323	2.9	9692	11	4.2	0.009500 ± 0.12%	0.06212 ± 0.13%	0.04743 ± 0.03%	70.7 ± 1.5
6b -149+105 (l,c)	.392	828	7.5	9218	22	4.3	0.009702 ± 0.19%	0.06354 ± 0.20%	0.04750 ± 0.03%	74.3 ± 1.5
6c -105+74 (l,s,c)	.784	884	8.1	2054	211	4.7	0.009729 ± 0.28%	0.06371 ± 0.30%	0.04749 ± 0.08%	73.9 ± 3.7
6d -105+74 (l,f,c)	.323	889	10.5	750	308	5.8	0.012276 ± 0.15%	0.08273 ± 0.27%	0.04888 ± 0.19%	141.9 ± 9.0
6e -105+74 (l,s,c)	.045	546	4.9	556	27	4.9	0.009454 ± 0.12%	0.06170 ± 0.42%	0.04733 ± 0.36%	66.1 ± 17.2
87-246-1										
7a +149 A (l,s,c)	.331	195	1.7	1469	25	10.1	0.008853 ± 0.10%	0.05772 ± 0.14%	0.04728 ± 0.08%	63.5 ± 4.0/ -4.0
7b +149 A (m,f,c)	.714	178	1.6	1656	44	8.9	0.008893 ± 0.13%	0.05790 ± 0.17%	0.04722 ± 0.08%	60.4 ± 4.0/ -4.0
7c -149+105 (l,s,c)	.530	217	1.9	1645	40	8.9	0.008874 ± 0.11%	0.05782 ± 0.15%	0.04726 ± 0.08%	62.3 ± 4.0/ -4.0
7d -149+105 (e,an,c)	1.331	191	1.9	1455	112	8.1	0.009917 ± 0.15%	0.09265 ± 0.17%	0.06775 ± 0.07%	861.0 ± 3.0/ -3.0
7e -149+105 A (m,f,c)	.217	189	1.7	839	28	9.3	0.008855 ± 0.09%	0.05756 ± 0.16%	0.04715 ± 0.11%	56.7 ± 5.3/ -5.3
7f +149 A (m,an,c)	.061	179	1.6	84	94	8.8	0.008842 ± 0.75%	0.05733 ± 2.6%	0.04702 ± 2.1%	50.4 ± 99.2/ -105.5

Sample location shown in Figure 2-2 and in appendix X. Sample's UTM coordinates are given in Appendix X.

^a Letters refer to Figures 2-3 to 2-8; sizes (e.g., +149) refer to aspect of zircons in microns; "A" identifies abraded zircons, letters in parentheses describe the appearance of zircons: l: long prismatic, >2:1 length to width ratio, m: stout prismatic <2:1 length to width ratio, e: equant, s: square cross-section, f: flat cross-section, an: anhedral, c: clear, cd: cloudy, fr: frosty.

^b Radiogenic Pb.

^c Measured ratio, corrected for spike and fractionation.

^d Total common Pb in analysis corrected for fractionation and spike.

^e Corrected for blank Pb and U, common Pb.

^f Corrected for blank and common Pb.

Errors are 1 std. error of mean in % except 207/206 age errors which are 2 std. errors in Ma.

Big Falls orthogneiss

Sample 87-172-2 is a typical sample of the orthogneissic Big Falls body. It was collected towards the middle of the central region (Figure 3-2 and Appendices 1A and 1B) and consists of homogeneous, strongly foliated augen gneiss composed dominantly of plagioclase (50%), quartz ($\approx 25\%$), muscovite ($\approx 10\%$) and biotite (5%). Andesine is anhedral and reaches 1.5 mm in length. Anhedral quartz, less than 0.5 mm in size, shows undulose extinction and signs of polygonization. Light brown to dark greenish brown biotite occurs as euhedral to anhedral laths reaching 0.5 mm in length and showing very minor chloritization. Euhedral muscovite is associated with biotite and parallels the foliation, and anhedral muscovite occurs in association with plagioclase and cross-cuts the fabric. Calcite occurs in minor amount interstitially to other minerals. Accessory minerals include titanite, apatite and zircon.

The zircons are generally euhedral with bipyramidal terminations, usually angular and rarely slightly rounded. Zircon length to breadth ratio varies from slightly less than 2:1 to approximately 5:1. Cross-sections are rectangular. The crystals vary from thick to thin and platy. All zircons are clear and most have a light pink tint. Some fractions were composed of zircons with a frosty surface which was removed during abrasion. All fractions but one were abraded. Time of abrasion varied between 5 and 6 hours. U concentrations for this sample are between 258 and 511 ppm (Table 3-1).

All points are discordant and 5 of the 7 points are well aligned with each other (Figure 3-3). A York (1969) regression line of the 5 colinear points yields upper and lower intercept dates of approximately 385 ± 4 Ma and 171.8 ± 13.8 Ma (MSWD = 0.18) which are interpreted respectively as the best estimates of intrusive age and timing of Pb loss. Including all points in the regression analysis decreases the upper intercept date to approximately 381 Ma, a date within uncertainty of the result obtained using only 5 data

Figure 3-3: Isotope ratio plot for zircons from the Big Falls orthogneiss. Letters identifying data points correspond to those of Table 3-1.

points, but increases substantially the mean square weighted deviates to 13.33. The two points which are not aligned with the other points lie slightly below the best fit line. The fact that fraction "E" was not abraded may explain its slight deviation from best fit. Fraction "A" consisted of pink colored, euhedral prismatic zircons of size greater than 149 microns which were abraded for 6 hours. The deviation of fraction A from the best fit line may result from the presence of inherited cores in zircons from this fraction. If the location of points E and A on the concordia diagram results solely from Pb loss, then the Pb loss episode is younger than that calculated using only the 5 colinear points. The effect of including these two points in the regression calculation is to pull the regression line towards a lower value for the age of the inferred Pb loss episode to a date of ca. 145 ± 45 Ma.

Quartz dioritic orthogneiss

In the northern region, a weakly foliated quartz dioritic rock (sample 88-140-2) outcrops within the layered gneiss unit (Figure 3-2 and Appendices 1A and 1B) over a small area less than 100 meters in diameter. Because of the relatively undeformed state of the rock, the unit was interpreted as a young intrusive rock. Obtaining a date from this rock was deemed important for constraining the location of the boundary between middle Cretaceous and Tertiary plutons.

The sample collected for U-Pb dating is composed predominantly of plagioclase ($\approx 75\%$), quartz ($\approx 10\%$), biotite ($\approx 5\%$) and hornblende ($\approx 3\%$). Plagioclase grains are anhedral and generally coarse grained (1 to 3 mm). Quartz is anhedral and does not exceed 1 mm in size. Biotite occurs as euhedral to anhedral laths up to 1 mm long. Hornblende is anhedral with serrate edges. The average length of hornblende is 1 mm, but the grains can reach 2 mm. Other minerals present are titanite, apatite, opaque and zircon.

Two fractions from this sample were composed of clear and colorless, euhedral prismatic zircons with slightly rounded terminations. These zircons have length to breadth

3

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
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ratios around 2:1 and have square to thick rectangular cross-sections. These two fractions were abraded for 5 hours. They have U concentrations of 266 and 369 ppm (Table 3-1). A third fraction consists of 1 pink anhedral zircon containing many fine inclusions. Its U concentration is 198 ppm (Table 3-1).

The two abraded fractions are discordant (Figure 3-4) and the upper intercept of a line through these two points gives a date ca. 337 Ma. The single zircon has a large error ellipse which intersects concordia between 317 and 320 Ma. It gives a $^{207}\text{Pb}/^{206}\text{Pb}$ date of 303 ± 41 Ma. These results, although inadequate for a precise age constrain, refute the initial assumption of young age and indicate a Paleozoic age for the rock. The orthogneiss could be comagmatic with the Big Falls body.

The relatively undeformed state of the rock is atypical of Scotia-Quaal metamorphic rocks older than Early Jurassic age and can be explained in various ways. The deformational state of the unit may have been misjudged because of the small size of the area of exposure. Deformational features may have been eradicated during recrystallization due to contact metamorphism of the rock, caused by a young intrusive body which does not outcrop. Alternatively, the absence of deformational features may be an effect of competency differences between the Paleozoic granitoid and surrounding well-layered gneisses.

Figure 3-4: Isotope ratio plot for zircons from a quartz dioritic orthogneiss. Letters identifying data points correspond to those of Table 3-1.

Johnson Lake orthogneiss

The Johnson Lake orthogneiss was sampled for U-Pb dating in two locations. Sample 87-139-5 was collected towards the southern end of the body, approximately 1 km west of the Quottoon pluton contact (Figure 3-2 and Appendices 1A and 1B). At that location, the orthogneiss forms a narrow band, concordant with the regional foliation, at the contact between the clastic metasedimentary and quartzite units.

The sample consists of a strongly foliated and lineated hornblende gneiss composed mainly of plagioclase ($\approx 50\%$), quartz ($\approx 20\%$) and hornblende ($\approx 25\%$). The plagioclase has An content around 0.27 and is anhedral, randomly oriented and slightly sericitized. The size of plagioclase grains averages 0.4 mm, but the largest grains are 1 mm in diameter. Rounded quartz, which does not exceed 0.5 mm in size, occurs in the matrix and as fine inclusions in oligoclase. Anhedral hornblende averages 1 mm in length and is oriented parallel to the foliation and lineation. Minor anhedral biotite occurs as inclusions in hornblende and is considerably chloritized. Accessory minerals include zoisite, titanite, opaque and zircon.

In this sample, zircon is clear and generally colorless except for one fraction in which some zircons had a faint yellow color. Most zircons are euhedral with slightly rounded terminations. Some zircons have square cross-sections while others are quite thin. U concentrations vary between 365 and 638 ppm (Table 3-1).

Five fractions are well aligned (Figure 3-5) along a regression line giving an upper intercept of $192 \pm 8.7 / -3.5$ Ma (MSWD = 0.28). Fraction A lies slightly below and to the right of the best fit line. This fraction contained clear, euhedral, elongated and thin zircons that were abraded for 4 hours. The slight deviation from the best fit line for this sample probably results from minor inheritance. A value of -2.4 ± 85 Ma is obtained for the lower intercept of the regression line.

Figure 3-5: Zircon isotope ratio plot for sample 87-139-5 from the Johnson Lake orthogneiss. Letters identifying data points correspond to those of Table 3-1.

Sample 87-218-2 was collected at the northern end of the small elongate orthogneissic body more than two km away from the Quottoon pluton contact (Figure 3-2 and Appendices 1A and 1B). At that location, the metamorphosed intrusive rock exhibits a strong lineation and only a weak foliation. The sample collected for U/Pb dating is composed of approximately 55% plagioclase, 20% quartz, 13% hornblende and 5% biotite. Anhedral plagioclase up to 1 mm in length has a An content averaging 0.30. Rounded fine grained (≤ 0.05 mm) quartz occurs as inclusions in plagioclase and slightly coarser (≈ 0.5 mm) rectangular quartz is present in the matrix. Alignment of coarse grained (≈ 1 mm long) anhedral hornblende forms the strong lineation. Anhedral biotite less than 1.0 mm in length is partially chloritized. Accessory minerals include epidote, titanite, apatite and zircon.

Zircons from this sample are clear and colorless. They are euhedral, prismatic grains with terminations rounded only to a very small extent. Their cross-sections vary from square to very thin. U concentrations vary between 554 and 1139 ppm (Table 3-1). Four out of six fractions were abraded between 5.5 and 7 hours. Two fractions composed of thin platy zircons were left unabraded because of their fragility.

One of the unabraded fractions shows greatest Pb loss while the other has an error ellipse spanning the whole range produced by ellipses from all other fractions (Figure 3-6). The best fit regression line for all fractions analyzed gives an upper intercept of approximately $190 \pm 6.0 / -1.6$ Ma and a lower intercept of $-61 \pm 146 / -250$ Ma (MSWD = 1.09). The upper intercept date is within error limit of that obtained from sample 87-139-5. The negative lower intercept value is probably due to varying proportions of an inherited Pb component in each fraction.

A best fit line through eleven fractions from samples 87-139-5 and 87-218-2 give an upper intercept date of $190.5 \pm 1.2 / -0.9$ Ma (MSWD = 0.73) interpreted as the age of the

Figure 3-6: Zircon isotope ratio plot for sample 87-218-2 from the Johnson Lake orthogneiss. Letters identifying data points correspond to those of Table 3-1.

Johnson Lake orthogneiss, and a lower intercept of -50.7 ± 37.1 Ma interpreted as resulting from minor inheritance in some or all zircon fractions.

Foch Lake orthogneiss

A sample (88-108-2) from the Foch Lake orthogneiss was collected in the southern region, approximately 2.3 km west of the Quottoon pluton contact (Figure 3-2 and Appendices 1A and 1B). The Foch Lake orthogneiss is a strongly foliated and lineated metatonalitic body characterized by the widespread occurrence of plagioclase megacrysts. Sample 88-108-2 is mainly composed of plagioclase ($\approx 45\%$), quartz ($\approx 30\%$), epidote ($\approx 15\%$) and biotite ($\approx 10\%$). Plagioclase is generally anhedral, equant and ranges in size up from very fine to 1.5 mm. It is very slightly sericitized and contains numerous epidote inclusions. Polygonized quartz reaches 1 mm in size. Euhedral to anhedral epidote is twinned and zoned. It varies in size from very fine grained to 0.6 mm length. In association with biotite it is concentrated in thin bands alternating with felsic bands. Subhedral biotite laths up to 1.8 mm long are subparallel to the compositional layering. Accessory minerals include titanite, apatite, opaque and zircon.

In this sample zircons are colorless to slightly pink. They are generally clear, but contain dispersed fine clear and opaque inclusions. Zircons are prismatic either with length to breadth ratios less than 2:1 and hexagonal to rounded cross-sections or with length to breadth ratios exceeding 2:1 and square cross-sections. U concentrations are between 247 and 650 ppm (Table 3-1).

All fractions are nearly concordant and one fraction has a disproportionately large error ellipse and is not plotted. The $^{207}\text{Pb}/^{206}\text{Pb}$ dates for the other three fractions range between 187.3 and 192 Ma. A date of 191.7 ± 0.6 Ma is obtained from the mean of the intersection of the error ellipses of the two most concordant fractions (Figure 3-7, C and D) with concordia. This date is interpreted as the emplacement age of the Foch Lake body.

Figure 3-7: Isotope ratio plot for zircons from the Foch Lake orthogneiss. Letters identifying data points correspond to those of Table 3-1.

Leucocratic dyke

Sample 87-140-2 was collected from one of many coarse to pegmatitic dykes intruding the eastern 2.5 km of the Scotia-Quaal belt. These dykes occur in increasing abundance and show increasing degree of deformation and parallelism with the regional fabric towards the Quottoon pluton contact (See Plate 3, Chapter 1). The U-Pb sample location is approximately 1 km west of the Quottoon pluton contact (Figure 3-2 and Appendices 1A and 1B). The sample consists of a strongly foliated, coarse grained, equigranular, leucocratic quartz dioritic rock. It contains mainly plagioclase ($\approx 80\%$), quartz ($\approx 13\%$) and biotite ($\approx 7\%$). Oligoclase is partly sericitized and replaced by epidote, and it occurs mostly as anhedral grains between 1 and 1.5 mm in size. Quartz occurs in the form of polygonized up to 1 mm long grains. Biotite laths are subhedral and are mostly between 0.2 and 1 mm long, but can reach 2 mm in length. Chlorite replaces biotite and a trace of muscovite is intergrown with biotite. Zoisite, apatite, allanite, an opaque mineral and zircon occur as accessory minerals.

Zircons from this sample are generally very fine grained. They are clear and colorless. They are euhedral and very long with a length to breadth ratio anywhere between 2:1 and 10:1. The zircons have square or very thin cross-sections. The very thin zircons are somewhat fragile and were left unabraded. U concentrations vary between 323 and 889 ppm (Table 3-1).

Only one fraction gave a concordant result (Figure 3-8) corresponding to a date of 60.7 ± 0.1 Ma. Other points are discordant and give results consistent with incorporation of old Pb in the zircons. A regression line fitted through all points gives a lower intercept of 59.0 ± 0.7 Ma and an upper intercept around 299.1 ± 54.5 Ma taken as the age of inherited

Figure 3-8: Isotope ratio plot for zircons from a leucocratic dyke on the east side of the Scotia-Quaal metamorphic belt. Letters identifying data points correspond to those of Table 3-1.

zircons. The difference between the 60.7 ± 0.1 Ma date obtained from the concordant zircon fraction and the $59.0 +0.7/-1.0$ Ma lower intercept date obtained from a York fit through all fractions could be due to minor Pb loss in some of the fractions with an inherited component. A small inherited component could also be present in the concordant zircon fraction. This would have for effect to shift very slightly the ellipse to the right of concordia and up; if this were true, the age of the dyke would be slightly younger than the 60.7 Ma date. However, because the error ellipse of the concordant fraction substantially overlaps concordia, an inherited component to the concordant zircon fraction is considered to be minimal and the 60.7 Ma date is interpreted as the age of the dyke.

Incorporation of Paleozoic zircons is plausible because the leucocratic dyke from which the zircons were drawn intrudes a rock package with oldest units at least Middle Devonian in age and youngest components, Early Jurassic. The old radiogenic Pb component could come from cores in zircons, although these were not observed, or from the presence, in all but one fraction, of a few older zircons undistinguishable from zircons formed at the time of crystallization of the dyke.

Quottoon pluton

Sample 87-246-1 is a sample of Quottoon diorite collected approximately 3.75 km east of the contact between the Scotia-Quaal belt and the Quottoon pluton (Figure 3-2). The sample is weakly foliated and composed principally of plagioclase ($\approx 78\%$), hornblende ($\approx 10\%$), biotite ($\approx 7\%$) and quartz ($<3\%$). Subhedral prismatic andesine varies between 1 and 5 mm length and has been slightly sericitized. Quartz is anhedral, shows undulose extinction and varies in size between 0.3 and 0.6 mm. Hornblende is subhedral to anhedral, prismatic and varies in length between 1 and 7 mm. It contains numerous opaque, quartz and biotite inclusions. Biotite is euhedral to subhedral and less than 2 mm long. Other minerals are apatite, an opaque mineral and zircon.

Zircons from this sample are clear and colorless or, rarely, pink. They are either euhedral with square to flat cross-sections or anhedral and relatively spherical in shape. They contain numerous fine inclusions. Two fractions were left unabraded and 4 other fractions were abraded for a period of time between 4.5 and 7 hours. U concentrations are between 178 and 217 ppm (Table 3-1).

Out of 6 fractions 5 are nearly concordant with error ellipses on or slightly below concordia. One of these fractions has a very large error ellipse and does not contribute in better constraining the result; it is not used for age determination. The four other nearly concordant fractions are plotted in Figure 3-9. The most concordant fraction gives a date of 56.8 ± 0.1 Ma interpreted as the age of the Quottoon pluton. The other points plot slightly below concordia, but to the right of the concordant fraction. This may indicate that fractions A, B and C contain a very small amount of inherited radiogenic Pb or that the zircons from these fractions were initially deficient in ^{230}Th . The strongly discordant fraction D which gives a $^{207}\text{Pb}/^{206}\text{Pb}$ date ca. 861 Ma suggests that inheritance is the cause of discordancy.

PCA-87-246-1

Figure 3-9: Isotope ratio plot for zircons from the Quottoon pluton. Letters identifying data points correspond to those of Table 3-1.

3.4 K-Ar geochronology

Analytical procedure

Hornblende separation was performed by standard crushing, grinding, sieving to mesh size 70-100 and heavy liquid techniques in the facilities of the University of British Columbia. This procedure was followed by magnetic separation and cleaning in 2N HNO₃ for 10 minutes. Remaining impurities in the hornblende separates were removed by handpicking.

Potassium and argon analyses were done by staff of the Geochronology Laboratory of the Geological Survey of Canada. Potassium concentrations were determined by atomic absorption spectrometry on duplicate dissolutions of the samples. Ar concentrations were measured by isotope dissolution spectrometry using a ³⁸Ar spike.

Analytical errors for analyses presented in Table 3-2 refer to one standard error and quoted errors in ages are the estimated analytical uncertainty at two standard deviations. Decay constants from Steiger and Jäger (1977) were used in the age calculation.

Results

The location of the five samples analysed for hornblende K-Ar dating is shown in Figure 3-10 (See also Appendices 1A & B for location of samples on geological maps and Appendix 2 for UTM coordinates) and the results are summarized in Table 3-2. All samples were collected in the central region of the metamorphic belt and four samples came from a ridge which is perpendicular to the trend of the metamorphic belt and extends across the whole of the belt. Analysis of samples at different locations along the ridge allows to evaluate the effect of the regional metamorphic gradient and of the two bounding plutons on

Figure 3-10: Geological map of the Scotia-Quaal area showing hornblende K-Ar sample locations. MM = metamorphic.

hornblende dates. The fifth sample was collected on a ridge approximately 10 km south of the ridge on which the four other samples were collected.

Table 3-2: Hornblende K-Ar data for samples from the Scotia-Quaal metamorphic belt.

Sample number	%K $\pm 1\sigma\%$	Rad ^{40}Ar $\text{cm}^3/\text{g } 10^{-7} \pm 1\sigma\%$	%Atmos $^{40}\text{Ar}\alpha$	Age $\pm 2\sigma$ Ma
88-67-2	.358 $\pm .523\%$	14.25 $\pm .76\%$	18.0	99.6 ± 1.8
88-80-2	.174 $\pm 1.653\%$	7.67 $\pm 1.1\%$	28.7	110 ± 4.3
88-73-2	.335 $\pm .701\%$	13.29 $\pm .65\%$	22.4	99.3 ± 1.9
88-84-2	.725 $\pm .888\%$	16.17 $\pm .88\%$	54.5	56.5 ± 1.4
88-147-1	.393 $\pm .506\%$	18.17 $\pm .67\%$	19.3	115.2 ± 1.9

σ = standard error; cm^3/g is determined at standard temperature and pressure.

α = corrected of a line blank of $2 \times 10^{-7} \text{ cm}^3$ atmospheric Ar.

A K-Ar date of 115.2 ± 1.9 Ma was obtained from a sample of coarse, rusty weathering hornblende (88-147-1) from a mafic-ultramafic body (See Plate 2B in Chapter 1) which intrudes metamorphic rocks on the western side of the Scotia-Quaal belt (Figure 3-10). This 115 Ma date is interpreted as the minimum age of emplacement of the mafic-ultramafic body. Such an age is consistent with inference of Jurassic or Cretaceous age for the mafic-ultramafic unit based on the relatively undeformed state of the small bodies and their relationship to the surrounding country rock (see Chapter 1). The date is interpreted as a minimum estimate because the K-Ar system may have been partially reset in the middle to Late Cretaceous at the time of intrusion of the Ecstall pluton to which the mafic-ultramafic body from which the sample was collected is quite proximal. Moreover, because the unit was emplaced into metamorphic rocks at temperature probably above the hornblende K-Ar closure temperature ($\approx 550^\circ\text{C}$), as indicated by K-Ar dates from metamorphic rocks, the rate of cooling of the magmatic body is likely to have been initially relatively slow. On the other hand, the coarse grain size, of approximately 2 cm, could have impeded diffusion; this would have the effect of allowing hornblende to retain Ar at

higher temperature than in finer grained hornblende and would result in an older date than that obtained from the metamorphic rocks. A date from the ultramafic rock older than dates from metamorphic rocks of the area could also result from excess argon in hornblende from the ultramafic sample.

Of the four samples collected along a west to east section, sample 88-80-2 gave the oldest date. The sample was collected from a location approximately 3.7 km east of the Ecstall pluton and more than 6 km west of the Quottoon pluton (Figure 3-10). It is a hornblende gneiss from the metavolcanic unit and dominantly contains medium to coarse grained, euhedral to subhedral hornblende and fine granoblastic quartz. Hornblende, which is sometimes oriented parallel to the foliation and sometimes at an angle to it, is chloritized very slightly. The hornblende separate was very clean with less than 1% impurities and no biotite or chlorite. Analysis of the hornblende separate gave a date of 110 ± 4.3 Ma (Table 3-2). Because the sample came from a location well distanced from both the Ecstall and the Quottoon plutons and because petrographic and electron microprobe work (see detailed study of metabasic rocks along the same ridge in Chapter 2) indicates that no thermal event affected the rocks from that location after the end of the last regional metamorphic event (M2; see Chapter 2), this date is interpreted as the age of cooling of the sample below closure temperature of hornblende after the last regional metamorphic event.

Dates from the other 3 samples are less than 110 Ma; this may be due to differences in the timing of cooling after M2 metamorphism across the metamorphic belt, to partial resetting of the K-Ar system during thermal events postdating regional metamorphism or to variations in hornblende closure temperature stemming from differences in hornblende composition and size. Sample 88-67-2, for example, is an amphibolite within a semi-pelitic rusty weathering rock of the quartzite unit located at the western margin of the metamorphic belt, less than 100 metres east of the Ecstall pluton contact. Hornblende from

this sample is euhedral, clear and inclusion-free. The hornblende separate gave a date of 99.6 ± 1.8 Ma which is between the 110 Ma date inferred to represent a lower estimate on the age of regional metamorphism and the early Late Cretaceous age of the Ecstall pluton. This date is interpreted as resulting from substantial resetting of the K-Ar system at the time of intrusion of the Ecstall pluton. This interpretation is supported by evidence for a thermal aureole in metamorphic rock proximal to the Ecstall pluton (see Chapter 2).

Collected near the middle of the metamorphic belt (Figure 3-10), sample 88-73-2 gave a date of 99.3 ± 1.9 Ma. The sample is a garnetiferous biotite-hornblende-chlorite schist in which chlorite appears to have formed largely by retrogressive replacement of biotite. Medium grained euhedral to subhedral hornblende is only chloritized to a very small extent, although it is surrounded by chlorite. The hornblende separate contained minor impurities and hornblende grains contained some inclusions. Because the sample was collected from a location more than 5.5 km away from the Ecstall pluton, its K-Ar systematics are believed to not have been affected by the intrusion of the Ecstall pluton. The 10 Ma difference between the date obtained from this sample and that obtained from sample 88-80-2 may reflect a true difference in timing of cooling of the rock below the hornblende Ar retention temperature, or it may be explained by the presence of impurities in the separate, different closure temperatures for hornblende from these two samples or diffusion of argon during a thermal disturbance in the area from which the sample was collected. Petrological work and thermobarometry in samples from the same ridge as the K-Ar samples (see Chapter 2) demonstrate an easterly increase in metamorphic grade across the Scotia-Quaal area in the central region. If regional metamorphism ceased at the same time throughout the central region, rocks to the east, brought to higher temperatures, would likely cool to the closure temperature of hornblende later than rocks farther west which were metamorphosed to a lower grade. Minor post-regional metamorphic diffusion of argon may have occurred

during a late retrograde event which appears to have affected the part of the ridge from which sample 88-73-2 was collected (see Chapter 2). Although the presence of impurities in the separate may have altered the result, the effect was probably not substantial. It is not possible with our present grasp of the effect of mineral composition on closure temperature to evaluate the impact that differences in hornblende compositions have had on the present results. The interpretation of Ar diffusion during late retrograde metamorphism is favoured.

Finally, a 56.5 ± 1.4 Ma date was obtained from sample 88-84-2, a medium grained biotite-hornblende gneiss from the metasedimentary clastic unit. The sample is composed of abundant euhedral to anhedral hornblende, up to 5 mm, but generally between 0.5 and 2 mm long. Anhedral salite occurs within hornblende. The hornblende separate was clean, with no impurities and few inclusions. This sample was collected close to the eastern margin of the Scotia-Quaal belt, approximately 900 meters away from the Quottoon pluton contact, within a 2.5 km wide zone intruded by numerous Late Paleocene (-Early Eocene?) dykes (Figure 3-10). This date is basically identical to the 56.8 Ma U-Pb age of the Quottoon pluton and comparable to the age of one dyke dated at 59 Ma. It is interpreted to represent complete resetting of the K-Ar system at the time of intrusive activity at the eastern margin of the Scotia-Quaal metamorphic belt. The near correspondence of the hornblende K-Ar date with the zircon U-Pb dates indicate that heat influx in metamorphic rocks of the Scotia-Quaal area at the time of intrusion of the Quottoon pluton was very short-lived.

Figure 3-11: Map of the Scotia-Quaal area summarizing geochronologic data.
MM = metamorphic.

3.5 Summary and discussion of geochronologic data

Results from zircon U-Pb and hornblende K-Ar analytical work on samples of the Scotia-Quaal metamorphic belt are summarized on the geological map shown in Figure 3-11.

The 385 Ma age of the Big Falls orthogneiss indicates that part of the Scotia-Quaal metamorphic belt is at least as old as Middle Devonian. Such an age contrasts sharply with documented protolith ages of rocks in the vicinity of the Scotia-Quaal metamorphic belt. Douglas (1986), for example, inferred the Khutzymateen (Figure 3-1) assemblage to be correlative with Gravina-Nutzotin rocks and therefore to have been deposited in Middle Jurassic to Early Cretaceous time. Farther east in the Central Gneiss Complex a minimum protolith age is given by a 139 Ma U-Pb zircon date (Hill, 1984), but evidence for Paleozoic ages was not noted. West of the Scotia-Quaal area, there exist one Middle Devonian occurrence which was only documented recently; it is the 382 Ma old (van der Heyden, 1989) Swede Point pluton located west of Grenville Channel, at approximately the same latitude as the Big Falls orthogneiss. The age correspondence of these two orthogneissic bodies suggests that rocks west of Grenville Channel and rocks of the Scotia-Quaal metamorphic belt formed a coherent rock package in Middle Devonian time.

The Early Jurassic dates obtained from the Johnson Lake and Foch lake orthogneisses which are interpreted as emplacement ages of the metaplutonic bodies, are the first documented occurrence of Early Jurassic plutons in the western part of the Coast Plutonic Complex. As discussed in Chapter 1, Early Jurassic plutonism in the Scotia-Quaal area is believed to suggest that the Scotia-Quaal belt may have shared a common history, at least from Early Jurassic time on, with rocks of Stikine terrane.

A Jurassic lower intercept date obtained from zircons of the Big Falls orthogneiss may indicate that the Early Jurassic plutons may have had a thermal impact on the country rock or may have intruded a rock package undergoing metamorphism. As discussed in Chapter 2, the Scotia-Quaal metamorphic belt has undergone at least two episodes of regional metamorphism prior to the intrusion of the 93.5 Ma Ecstall pluton. The last regional metamorphic event (M2) is inferred to have been synchronous with the last regional deformational event, which occurred after the intrusion of the Johnson Lake and Foch Lake orthogneisses in Early Jurassic time. M1 metamorphism is also inferred to have occurred synchronously with a regional deformation episode. The age of M1 metamorphism is unknown. If a lower intercept date in the Big Falls orthogneiss represents the age of a metamorphic event, then this metamorphic event could be M1. If this were true, then the Early Jurassic represents a time of metamorphism, deformation and magmatism in the Scotia-Quaal metamorphic belt.

The 56.8 ± 0.1 Ma age of the Quottoon pluton is consistent with the 60 Ma date obtained by Armstrong and Runkle (1979) as well as 64 to 67 Ma dates (Gehrels et al., 1983) obtained from the "foliated tonalite sill", the Quottoon pluton correlative in southeastern Alaska (Brew and Ford, 1978). The 56 to 67 Ma range for the Quottoon pluton north of Douglas Channel and the "tonalite sill" in southeastern Alaska differs significantly from a 80 Ma date obtained by van der Heyden (1989) from a sample collected along trend with the Quottoon pluton at the latitude of the study area, but more than 35 km south of the southern end of the Scotia-Quaal metamorphic belt.

The deformed dyke gave a slightly older age of ca. 60 Ma interpreted as the emplacement age of the dyke. The age of a il leucocratic, coarse to pegmatitic, undeformed to mylonitic dykes intruding the easternmost 2.5 km of the Scotia-Quaal metamorphic belt may be the same or may span a time period starting before intrusion of the Quottoon pluton

and continuing until the time of Quottoon intrusion or maybe later. Late Paleocene (-Early Eocene?) dykes in the Scotia-Quaal metamorphic belt, which are increasingly deformed towards the Quottoon pluton contact, indicate that the Late Paleocene-Early Eocene deformation that has affected the Quottoon pluton has also affected the easternmost margin of the Scotia-Quaal metamorphic belt. However, as discussed in chapter 2, there is no pressure gradient recorded in the metamorphic rocks of the Scotia-Quaal belt that would indicate major movement of one part of the belt with respect to the rest of the belt after middle Cretaceous time.

K-Ar dates from metamorphic rocks of the Scotia-Quaal area do not fit the previously defined distribution pattern. Indeed the 115 to 99 Ma dates obtained from the western side of the Scotia-Quaal belt differ from 91 and 74 Ma hornblende K-Ar dates from the eastern zone of the Ecstall belt, but are closer to ranges obtained from rocks west of Grenville Channel. The ca. 56 Ma date obtained from a metamorphic rock located on the east side of the Scotia-Quaal area is older than the 50-43 K-Ar plateau observed in rocks east of the Scotia-Quaal area.

Based on a K-Ar date from a sample collected near the middle of the Scotia-Quaal metamorphic belt, cooling below the hornblende K-Ar closure temperature after the last regional metamorphic event is inferred to have occurred approximately 110 Ma ago. This K-Ar date indicates that regional metamorphism preceded the intrusion of the 93.5 Ma Ecstall pluton. This is consistent with evidence for a thermal aureole in westernmost rocks of the Scotia-Quaal area, at least in the southern and central regions. It is interesting to note that northwest of the Ecstall pluton, regional metamorphism was inferred (Crawford et al., 1987) to be synchronous with the intrusion of the Ecstall pluton. Farther west, in the Prince Rupert area, a hornblende ^{40}Ar - ^{39}Ar date of 90 Ma was interpreted as the age of metamorphism in that region (Sutter and Crawford, 1985) which would have been caused

by emplacement of high temperature, high pressure metamorphic rocks from the east onto the lower grade rocks to the west (Crawford et al., 1987). These data suggest a decrease in age of regional metamorphism from east to west in the western belt of the Coast Plutonic Complex between the Scotia-Quaal area and Prince Rupert. It is consistent with a westward migration of deformation and metamorphism during crustal thickening accomplished by folding, transport and stacking of rock packages (proposed by Crawford et al., 1987). Finally, the apparent decrease in ages of metamorphism from east to west is opposite to the K-Ar distribution pattern documented for igneous rock of the western Coast Plutonic Complex. The igneous rock's K-Ar pattern overprints the apparent pattern in metamorphic rock; the latter can only be observed at locations where the K-Ar system was not reset at the time of intrusion of Cretaceous and Tertiary plutons.

Metamorphic rock at both margins of the Scotia-Quaal belt have experienced resetting of their K-Ar system to various degrees at the time of intrusion of the bounding plutons. On the western margin, a date of 99.6 Ma, younger than the 110 Ma minimum age of metamorphism, but older than the 93.5 Ma age of the Ecstall pluton, is interpreted to result from Ar loss during contact metamorphism related to the intrusion of the Ecstall pluton. This is consistent with petrographic evidence (see chapter 4) for contact metamorphism within approximately 100 metres of the Ecstall pluton contact.

A 56.5 Ma K-Ar date from a sample close to the eastern margin of the Scotia-Quaal belt in the central region reflects resetting of the K-Ar system at the time of intrusion of the Quottoon pluton and related dykes. The fact that this date differs from the 50-43 Ma K-Ar dates in the Central Gneiss Complex, but is identical to the U-Pb age of the Quottoon pluton suggests that heat influx at the time of Quottoon intrusion was intense, but short-lived. This is consistent with observations in metamorphic rocks close to the Quottoon pluton of disequilibrium textures apparently created during a short-lived high temperature

event postdating regional metamorphism (see Chapter 2). A ≈ 57 Ma ^{40}Ar - ^{39}Ar date on hornblende from a sample collected farther north close to the Work Channel lineament (Sutter and Crawford, 1985) suggests that rocks immediately west of the Central Gneiss Complex have been affected in the same manner at different latitudes along the boundary between the Central Gneiss Complex and the western belt. The thermal impact of the Quottoon pluton (and maybe other parts of the Central Gneiss Complex) on metamorphic rocks to the west appears to have been localized in a band at most 2.5 km wide adjacent to the pluton, and to have been intense on rocks within 1 km of the Quottoon pluton contact, but short-lived.

A 99.3 Ma hornblende K-Ar date obtained from a sample (88-73-2) in the middle of the central region of the Scotia-Quaal belt can be interpreted in various ways. First it is possible for this date to represent the age of cooling below the hornblende K-Ar closure temperature after regional metamorphism. If this is the case and if the closure temperature of hornblende in this sample does not differ greatly from the closure temperature of hornblende in sample 88-80-2 which gave a date of 110 Ma, then cooling of metamorphic rocks occurred earlier on the west side of the metamorphic belt than on its eastern side. Because metamorphic grade increases to the east, such an interpretation is plausible, although it is not known whether the difference in metamorphic grade between the two samples in question was enough to result in a difference in cooling ages of approximately 10 Ma. Of course, differences in closure temperature for hornblende in the two samples may have also had an impact on the K-Ar date. The younger date for sample 88-73-2 could also result from Ar loss during a retrograde metamorphic event postdating regional metamorphism. Retrograde metamorphism is inferred to have occurred in the approximate region from which sample 88-73-2 was collected (see chapter 4). An alternative explanation could be that excess argon is present in samples which have given dates older

than the 99.3 Ma date obtained from sample 88-73-2. It is probable that several of the factors discussed above have contributed to various degrees to the K-Ar pattern across the Scotia-Quaal's central region.

The 115 Ma hornblende K-Ar date obtained from a sample of the mafic-ultramafic unit in the central region of the Scotia-Quaal belt is interpreted as the minimum emplacement age of the body. This 115 ± 1.9 Ma date is slightly older than the 110 ± 4.3 Ma age of cooling of metamorphic rocks after M2 regional metamorphism. This difference in age may only be apparent since the two dates are within errors of each other and the closure temperature of hornblende in each sample is unknown. It is likely that hornblende from the coarse grained ultramafic rock began retaining Ar before finer hornblende from the metamorphic rock or that it contains excess argon. Finally, the mafic-ultramafic body probably cooled very slowly because it was emplaced into metamorphic rocks that were at temperatures above the hornblende K-Ar closure temperature. For this reason, the 115 Ma date may be younger than the emplacement age of the body.

Chapter 4 - Nd and Sr isotopic data

4.1 Introduction

While a better understanding of the post-Triassic history of the Coast Plutonic Complex in western-central British Columbia is being acquired through an increasingly large data base (e.g. Crawford and Hollister, 1982; Crawford et al., 1987; Harrison et al., 1978&1979; Heah, 1990; Hill, 1983; Hollister, 1982; Parrish, 1983; van der Heyden, 1989, Woodsworth et al., 1983 and this study) the early history hidden in the high-grade core of the Coast Plutonic Complex remains a mystery. Multiple high-grade metamorphic events and intense deformation are responsible for destroying much of the evidence needed to reconstruct this older history. A secret which may be critical to our understanding of the nature of the Insular/Intermontane boundary is the terrane affiliation of the high-grade core of the Coast Mountains.

Is the central part of the Coast Plutonic Complex composed, as it has been suggested (e.g. van der Heyden, 1989), of Alexander and Stikine strata and metasedimentary rocks deposited in a Bowser Lake Group/ Gravina belt overlap assemblage (Brew et al, 1966) linking Stikine and Alexander? Evidence from the eastern and western margins of the high-grade core is in agreement with such an hypothesis. Correlation of schists and gneisses from Redcap Mountain area (Figure 4-1) with sediments of the Late Jurassic Bowser Group (Hill, 1985) suggests that Stikine terrane extends into the eastern portion of the Central Gneiss Complex. Douglas (1986) observed similarities between lithologies of the Khutzeymateen area (Figure 4-1) and rocks of the Gravina belt. Lithologies west of Prince Rupert, in the Randall-Dunira area (Figure 4-1; Woodsworth and Orchard, 1985)

Figure 4-1: (A) Simplified terrane map of the northwestern Canadian Cordillera. After Wheeler and McFeely (1987). (B) Generalized geological map of part of the Coast Plutonic Complex between 53 and 55° N. After Roddick (1970), Hutchison (1982) and Gareau (1991 and this report).

have been interpreted to correlate with Middle Jurassic to Early Cretaceous Gravina sediments and inferred to overlie Paleozoic and Triassic strata of the Alexander terrane.

In chapter 1, a new angle to the discussion of terrane affiliation of metamorphic rocks between Terrace and Prince Rupert was introduced based on lithological information acquired in the Scotia-Quaal metamorphic belt located inboard of Alexander correlatives in the Randall-Dunira area and outboard of the westernmost documented extension of Stikine terrane. The lithological data suggested that rocks of the Scotia-Quaal metamorphic belt correlate with rocks assigned to Nisling terrane (Wheeler and McFeely, 1987). Because Nisling terrane has been shown to be isotopically distinct from Alexander and Stikine terranes (Samson et al, 1989a and b), Sm/Nd and Rb/Sr analyses were performed on samples from the Scotia-Quaal metamorphic belt in order to confirm the lithological correlation between rocks of the Scotia-Quaal metamorphic belt and Nisling terrane. The following pages are dedicated to a presentation and discussion of this data.

4.2 Previous work

Figure 4-2 summarizes the available Sr and Nd isotopic data for terranes of the Canadian Cordillera. Armstrong (1988) has presented Sr analytical data from igneous rocks showing the Cordillera to consist of two broad categories: a first group composed of the Insular, Coast and Intermontane belts and characterized by low $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios (≤ 0.704 ; Figure 4-2) is differentiated from a second group comprising the Omineca and Rocky-Mackenzie Mountains belts and typically exhibiting initial Sr ratios above 0.704 (Figure 4-2).

Within the first group, the northern Coast Plutonic Complex has yielded Sr ratios slightly higher than other parts of that group. The transition from $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios

Figure 4-2: Summary diagram of Nd and Sr isotopic data in the Canadian Cordillera. Insular, Coast, Intermontane, Omineca and Rocky-Mackenzie Mountains refer to the five main belts of the Canadian Cordillera. Broad characterization of the Sr isotopic signature of each belt was presented by Armstrong (1988). Wrangellia, Alexander and Stikine refer to terranes in northwestern British Columbia and southeastern Alaska. Nd and Sr isotopic data for these terranes was obtained from Samson et al. (1990) for Wrangellia and from Samson et al. (1989b) for Alexander and Stikine terranes. Nd data for Yukon-Tanana terrane was obtained from Bennett and Hansen (1988) and Sr ratios from Mortensen (in press). Gravina, Taku, Nisling and CMB refer to assemblages in a transition zone between Alexander and Stikine terranes in southeastern Alaska and northwestern British Columbia. Samson et al. 1989a use CMB to refer to rocks of the Coast Mountain Batholith. Nd data for these assemblages was taken from Samson (1989a).

below 0.704 in the southern Coast Plutonic Complex and those between 0.704 and 0.706 in the northern Coast Plutonic Complex has been identified (Armstrong, 1988) to coincide with a change in terrane basement from Wrangellia in the south to Alexander in the north.

For rocks of the Omineca belt and Yukon Territory east of the Coast Plutonic Complex, the Sr isotopic signature is not only a reflection of tectonostratigraphic terrane, but also of time (Armstrong, 1988). Igneous rocks of Jurassic and early Cenozoic age generally have an initial Sr range between 0.704 and 0.712, whereas Cretaceous initial ratios are generally above 0.710 and go as high as 0.730 (Armstrong, 1988).

Analytical data presented by Samson and others (1989a and b, 1990) and summarized in Figure 4-2 further characterizes tectonostratigraphic terranes and rocks packages in central- and north-western British Columbia. Rocks of Wrangellia terrane on the Queen Charlotte Islands exhibit initial ϵ_{Nd} values and Sr ratios (Figure 4-2) characteristic of unevolved, juvenile material (Samson et al., 1990). Alexander terrane in southeastern Alaska and Stikine terrane in northwestern British Columbia also have high positive ϵ_{Nd} values and low Sr initial ratios (Samson et al., 1989b) characteristic of juvenile material and taken by Samson and others to indicate that these terranes were formed in a volcanic-arc setting away from any source of continental-sediment contamination. Close to the southeastern Alaska-northwestern British Columbia border north of Prince Rupert, rocks in a transition zone between documented Alexander and Stikine terranes have been divided into four assemblages based on lithological differences and ϵ_{Nd} values (Samson et al., 1989): Gravina assemblage rocks generally gave positive ϵ_{Nd} values, undifferentiated Coast Mountain Belt rocks gave moderately negative to positive values and rocks of Nisling and Taku terranes yielded a wide range of values from strongly negative to positive (Figure 4-2). The strongly negative values differ significantly from anything observed in the surrounding terranes. They suggest an older crustal material contribution to these

terrane and are comparable to values obtained from the Yukon-Tanana terrane (Figure 4-2) farther north in the Cordillera.

Previous work in the Scotia-Quaal metamorphic belt and its immediate vicinity was conducted by Armstrong and Runkle (1979) on samples from the Ecstall and Quottoon plutons as well as on metamorphic rocks from Hawkesbury Island and three locations in the Central Gneiss Complex. A summary of their results is given in Figure 4-3. Samples from the Ecstall pluton yielded relatively low initial Sr ratios between 0.7044 and 0.7048 typical of values in the northern Coast Plutonic Complex, but analysis of Ecstall pegmatite and leucocratic dykes thought to represent late-stage magma resulted in higher values between 0.7051 and 0.7059 interpreted as probably indicative of radiogenic Sr contamination. Initial Sr ratios in the Quottoon pluton were found to be around 0.7045.

A suite of metamorphic rocks from Hawkesbury Island formed an elongate cluster between isochrons of 115 and 171 Ma (Figure 4-3) and fairly low (≈ 0.704) initial strontium ratios except for 1 point with an anomalously high Sr content which was interpreted by Armstrong and Runkle (1979) as the result of contamination with Sr from sea-water. Banded gneiss near Kwinitsa, on the Terrace-Prince Rupert highway were found to have a fairly radiogenic Sr isotopic composition around 0.7056 and were also interpreted (Armstrong and Runkle, 1979) to contain a component of oceanic sea-water Sr. A suite of three samples collected on a ridge south of the Skeena River and east of the Quottoon pluton falls within the Hawkesbury cluster with the exception of one point showing anomalous Sr enrichment again suspected (Armstrong and Runkle, 1979) to be due to contamination with oceanic sea-water Sr.

Figure 4-3: Regional map of the Coast Plutonic Complex between 53 and 55°N summarizing Rb-Sr data of Armstrong and Runkle (1979) for samples collected in the vicinity of the Scotia-Quaal belt. Values given for the Ecstall and Quottoon plutons refer to ranges in initial $^{87}\text{Sr}/^{86}\text{Sr}$ values calculated from results of a suite of samples.

4.3 Analytical procedure

All Nd and Sr analyses were performed by Dita Runkle in the Geochronometry Laboratory at the University of British Columbia. The following descriptions of analytical procedures are based on notes kindly provided by Dr. R.L. Armstrong (personal communication, 1991).

Whole rock powders were obtained by standard jaw crusher and disc mill primary reduction and by fine grinding using an agate mortar. The same powders were used for both Nd and Sr analyses.

Sm-Nd

Sample dissolution was done using teflon dissolution bombs of Krogh (1973) heated at 200°C for 24 hours or until complete dissolution. Initial separation of REE was done using 3N HCl in 100-200 mesh Dowex 50-X8 ion exchange resin columns, followed by stripping with 6N HCl.

The sample fraction used for isotope dilution analyses was spiked with a ^{149}Sm - ^{150}Nd mixture calibrated using SPEX Sm and Nd oxides. The REE sample was further purified by elution with 5N HCl as described by McCullough (1980). The dried heavy REE fraction was then analysed using a VG Isomass 54R mass spectrometer in a single collector mode (Faraday cup). The precision is approximately 2% (1σ) for the Sm and Nd and 0.5% (1σ) for ratios. Analyses of California Institute of Technology (CIT) standards indicate an accuracy of 0.1% or better for Sm/Nd ratios of the spike calibrations and of 1.3% for Sm and Nd concentrations. The concentrations reported are averages of duplicate or triplicate analyses.

Nd and Sm in the sample fraction used for isotope composition runs were separated from other elements and from each other using 2 methyl-lactic acid columns as described by Whitford et al. (1978). Isotope ratio measurements ($^{144}\text{Nd}/^{143}\text{Nd}$, corrected for ^{144}Sm interference via ^{147}Sm , and $^{146}\text{Nd}/^{143}\text{Nd}$) were made on the VG Isomass 54R mass spectrometer. The measurements were repeated until a 2σ isotope precision of 30 ppm or better was obtained. Ratios were normalized to a $^{146}\text{Nd}/^{144}\text{Nd}$ ratio of 0.7219 (O'Nions et al., 1979) and adjusted so that analyses of the BCR-1 basalt standard give a $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of 0.512665 ± 0.000020 (2σ error).

The in-house Nd oxide standard gives a corrected ratio of 0.511544 ± 0.000032 . The corrected Sm/Nd ratio for the CIT standard is 0.511909 ± 0.000044 , compared to CIT measurements of 0.511928 ± 0.000008 (normalized to $^{146}\text{Nd}/^{144}\text{Nd} = 0.7129$) (Wasserburg et al., 1981). The corrected LaJolla standard ratio is 0.511868 ± 0.000024 , compared to 0.511861 ± 0.000022 (CIT; Wasserburg et al., 1981), 0.511866 ± 0.000002 (University of Alberta, unpublished compilation of runs, 1987-1988), 0.511853 ± 0.000010 (La Jolla; Carlson, 1980) and 0.511866 ± 0.000002 (University of Arizona; Samson et al., 1989b). The corrected value for the Nd oxide standard of the University of Alberta (provided by Min Sun) is 0.511082 ± 0.000010 , compared to University of Alberta value of 0.511069 ± 0.000003 (normalized to 0.7129 and adjusted so that $\text{BCR-1} = 0.512656$).

The present value of $^{147}\text{Sm}/^{144}\text{Nd}$ for CHUR is taken as 0.1967 (Fletcher and Rosman, 1982) and the accepted value of the decay constant is $6.54 \times 10^{-12} \text{ year}^{-1}$ (Lugmair and Marti, 1978).

Blanks for Sm and Nd are approximately 0.8 and 4 nanograms respectively.

Rb-Sr

Rb and Sr concentrations were determined by triplicate analysis of pressed powder pellets using X-ray fluorescence. United States Geological Survey rock standards were used for calibration; mass absorption coefficients were obtained from MoK α Compton scattering measurements. Precision is 5% (1 σ) for Rb and Sr concentrations and 2% (1 σ) for Rb/Sr ratios. The Sr isotopic concentration was measured on unspiked samples, prepared with a standard ion exchange techniques, using a VG Isomass 54R single collector Faraday cup mass spectrometer.

The data were normalized to a $^{86}\text{Sr}/^{88}\text{Sr}$ ratio of 0.1194 and adjusted to give a $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.71019 ± 0.00004 (2 σ) for the the NBS Sr standard and a ratio 0.70800 ± 0.00004 (2 σ) for the Eimer and Amend Sr standard. The precision of a single $^{87}\text{Sr}/^{86}\text{Sr}$ measurement is 0.00010 (2 σ). The Rb decay constant is taken as $1.42 \times 10^{-11} \text{ year}^{-1}$.

4.4 Results

Sm-Nd and Rb-Sr data obtained from 4 samples collected in the Scotia-Quaal area at locations shown in Figure 4-4 are presented in Table 4-1. Precise locations (1:50000 scale) are shown in Appendix 1B and UTM coordinates given in Appendix 2. Results are also presented in the form of an initial ϵ_{Nd} versus age diagram in Figure 4-5 and of a $^{87}\text{Rb}/^{86}\text{Sr}$ vs $^{87}\text{Sr}/^{86}\text{Sr}$ plot in Figure 4-6.

Big Falls orthogneiss

Sample 89-133-2 is a typical specimen of the Middle Devonian orthogneissic Big Falls body. The strongly foliated and lineated biotite-plagioclase augen gneiss was collected in the central region of the Scotia-Quaal belt approximately 2.5 km east of the Ecstall pluton.

Figure 4-4: Sample location map for Nd and Sr isotopic data in the Scotia-Quaal belt.
MM = metamorphic.

Table 4-1: Sm-Nd and Rb-Sr data for samples from the Scotia-Quaal metamorphic belt.

Sample #	Rock type	Sm* (ppm)	Nd* (ppm)	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$ δ § measured	ϵ_{Nd} age=385/190Ma	Rb δ (ppm)	Sr δ (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$ δ † present day	$^{87}\text{Sr}/^{86}\text{Sr}$ age=385/190Ma
89-68-3	Quartzite	1.24	5.47	0.1371	0.51249 $\pm$ 3	-2.9 $\pm$ 0.6	7.4	19.6	1.099	0.70727 $\pm$ 10	0.7012/0.7043
89-95-3	Metapelite	4.04	22.84	0.1070	0.51256 $\pm$ 3	-1.5 $\pm$ 0.6	44.8	384	0.337	0.70795 $\pm$ 10	0.7061/0.7070
89-98-4	Quartzite	1.91	8.01	0.1435	0.51241 $\pm$ 3	-4.5 $\pm$ 0.6	5.2	17.6	0.851	0.70991 $\pm$ 10	0.7052/0.7076
89-133-2	Orthogneiss	4.09	25.13	0.0983	0.51218 $\pm$ 3	-8.9 $\pm$ 0.6	43.0	470	0.265	0.70848 $\pm$ 10	0.7070/...

$\epsilon_{\text{Nd}} = [(^{143}\text{Nd}/^{144}\text{Nd})_{\text{sample}} / (^{143}\text{Nd}/^{144}\text{Nd})_{\text{bulk earth}} - 1] \times 10^4$; it is a comparison of the Nd isotope ratio of a sample relative to the present-day bulk Earth (CHUR) value of 0.512638.

* 1 σ errors for Sm and Nd concentrations are 2% and $^{147}\text{Sm}/^{144}\text{Nd}$ are 0.5%.

δ 1 σ errors for Rb and Sr concentrations are 5% and Rb/Sr ratios are 2%

† Errors are $\pm 2\sigma$.

§ Ratios normalized to $^{146}\text{Nd}/^{144}\text{Nd}=0.7219$. $^{143}\text{Nd}/^{144}\text{Nd}=0.511868\pm 24$ (2 σ) for La Jolla standard during period of study.

† Ratios normalized to $^{86}\text{Sr}/^{88}\text{Sr}=0.1194$. $^{87}\text{Sr}/^{86}\text{Sr}=0.71019\pm 4$ (2 σ) for NBS-987 standard and 0.70800 ± 4 (2 σ) for Elmer and Amend standard during period of study.

Figure 4-5: Initial ϵ_{Nd} values versus age for samples of the Scotia-Quaal metamorphic belt. Depleted mantle line is after DePaolo (1981). CHUR refers to the chondrite uniform reservoir and is equivalent to bulk earth.

Figure 4-6: Rb-Sr plot for samples of the Scotia-Quaal metamorphic belt. A range in initial ratios is shown for the metasedimentary rocks because their depositional age is unknown; they are at least 190 Ma old, but are probably closer to 385 Ma in age.

The sample is composed dominantly of quartz ($\approx 40\%$), plagioclase ($\approx 35\%$), biotite ($\approx 13\%$), zoisite ($\approx 7\%$), muscovite ($\approx 2\%$) and accessory titanite, zircon and an opaque mineral. Quartz and plagioclase grains are anhedral and vary in size between 0.2 and 1 mm. Plagioclase is slightly sericitized. Biotite occurs as euhedral laths, up to 1 mm in length. Muscovite is generally intergrown with biotite, but is also present as rare euhedral laths growing across the foliation. Minor chlorite replaces biotite. Anhedral zoisite of less than 0.3 mm diameter is concentrated in layers with biotite or dispersed along the foliation plane.

Whole rock Sm-Nd analysis of the sample yielded a present-day ϵ_{Nd} value of -8.9 (Table 4-1). An initial ϵ_{Nd} value of -4.1 is calculated based on an age of 385 Ma (zircon U-Pb date, see chapter 3) and on the assumption that the Sm-Nd system remained resistant to isotopic resetting throughout the rock's history. These negative values indicate that a component of old crustal material was included in the Big Falls magma. The present-day ϵ_{Nd} value differs from typical values for Alexander and Stikine terranes and Gravina belt (Figure 4-2). It fits within the rather wide range of values obtained from samples from Taku and Nisling terranes (Figure 4-2) and is somewhat less negative than typical values for Yukon-Tanana terrane.

Rb-Sr analysis of the sample gave an initial $^{87}Sr/^{86}Sr$ ratio of 0.7070, based on a 385 Ma age and on the assumption that the sample has remained closed to Rb and Sr since the time of emplacement of the pluton. This value is higher than typical ratios for igneous rocks in the Coast Plutonic Complex (Figure 4-2). It is at the upper end of the range defined by values obtained from samples of igneous, sedimentary and metamorphic rocks from Alexander terrane and higher than values given by various lithologies from Stikine terrane (Figure 4-2).

In his discussion of strontium isotopic composition of igneous rocks in the Canadian Cordillera, Armstrong (1988) refers to ratios greater than 0.706 as indicative of assimilation of, or genesis from older crust. Assimilation of older, more radiogenic crust by the Big Falls magma is in agreement with a correlation between the Scotia-Quaal belt and Nisling terrane which is defined in northern British Columbia (Wheeler and McFeely, 1987) to be partly composed of continental margin material inferred by Wheeler and McFeely to be of Proterozoic age.

Metasedimentary rock

The three other samples are metasedimentary rocks, two white quartzite and a sillimanite metapelite, belonging to the quartzite unit (Figure 4-4). The age of this unit is unknown, but as it is locally cut by the late Early Jurassic Johnson Lake orthogneiss, it is interpreted to be at least as old as 190 Ma and could be as old as, or older than the Big Falls orthogneiss with which it is in depositional, intrusive or faulted contact. Initial ϵ_{Nd} values and Sr ratios for each of these samples are calculated based on these two ages (Table 4-1). If the samples have remained closed to Rb and Sr since deposition, an initial Sr ratio calculated based on a 190 Ma age gives a maximum value for the initial ratio. Because the age of the unit is assumed closer to Middle Devonian than to Early Jurassic time, an initial Sr ratio calculated on the basis of a 385 Ma depositional age probably more closely approaches the true initial Sr ratio of the rock if Sr has remained immobile since the sample's deposition.

Sample 89-95-3 is a strongly foliated medium grained biotite semi-schist collected in the central region of the Scotia-Quaal belt, approximately 250 meters west of the Quottoon pluton contact. The specimen contains approximately 40% quartz, 25% plagioclase, 20% biotite, 8% fibrolite and sillimanite, 5% garnet and minor opaques. Quartz is anhedral, reaches 2 mm in size and has a spherical to elongate shape. Anhedral plagioclase is

rounded to augen-shaped, reaches 2 mm in size and is slightly sericitized. Subhedral biotite laths are generally around 0.8 mm in length, but can reach 1.6 mm. Fibrolite and sillimanite are intergrown with biotite. Minor chlorite replaces biotite. An opaque mineral occurs in minor amounts.

The metapelitic rock yielded a slightly negative present-day ϵ_{Nd} value of -1.5 from which a positive initial ϵ_{Nd} value is calculated (Table 4-1 and Figure 4-5). It is not possible to interpret this result with respect to the terrane affinity of the sample because the ϵ_{Nd} value fits within the range of values for Wrangellia, Alexander and Stikine terranes, as well as for the Gravina belt and Taku and Nisling terranes (Figure 4-2).

The sample gave an initial $^{87}Sr/^{86}Sr$ value probably around 0.7061 based on a 385 Ma age, but no greater than 0.7070, a value calculated using a 190 Ma date, the youngest possible age for the unit. Such initial Sr ratios are relatively high for the Coast Plutonic Complex, but coincide with the upper limit of the range for Alexander terrane.

Sample 89-98-4 is a white quartzite also collected in the central region, but this time, along the western margin of the metamorphic belt approximately 1 km east of the Ecstall pluton contact. The sample is composed dominantly of granoblastic quartz, less than 1 mm in size. Other minerals include zoisite ($\approx 5\%$), cummingtonite ($\leq 2\%$), muscovite ($\leq 1\%$) and carbonate ($\leq 1\%$). Zoisite is anhedral and less than 0.2 mm in size. Subhedral cummingtonite reaches approximately 0.3 mm in length. Muscovite is anhedral and less than 0.2 mm long. The carbonate mineral occurs as anhedral grains approximately 0.1 mm in size and interstitial to other minerals; it seems to be a late replacement mineral.

The present-day ϵ_{Nd} value for this sample equals -4.5 and the initial ϵ_{Nd} value is calculated to be between -1.8 and -3.2 (Table 4-1 and Figure 4.5). These values are outside the ranges given for Wrangellia, Alexander and Stikine terranes (Figure 4-2) and

are in agreement with data from Nisling terrane. The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio is around 0.705 - 0.707 depending on the inferred age for the unit (Table 4-1 and Figure 4-6).

Sample 89-68-3, also a white quartzite, was collected in the northern region of the Scotia-Quaal belt, approximately 5 km south of the Skeena river and 1.5 km west of the Quottoon pluton contact. The quartzite specimen contains granoblastic quartz approximately 1 cm in diameter and minor (<2%) fine (0.2 mm) and partially chloritized biotite plates concentrated along paper-thick (<<< 1 mm) sheets parallel to the regional foliation, occurring interstitially to quartz grains or as inclusions in quartz.

Like all other samples, this sample gave a negative present-day ϵ_{Nd} value (present-day $\epsilon_{\text{Nd}} = -2.9$ and initial $\epsilon_{\text{Nd}} = 0/-1.4$; Table 4-1 and Figure 4-5), but the initial $^{87}\text{Sr}/^{86}\text{Sr}$ values calculated based on ages of 385 and 190 Ma are much lower than values obtained from the other samples. Such low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, less than 0.7043, are not atypical of Wrangellia, Alexander and Stikine terranes (Figure 4-2). However, the sample is believed to belong to the same sedimentary package as the quartzite and metapelitic samples collected farther south and the Sm-Nd data supports this interpretation. The calculated initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio may differ from the true initial ratio for this sample, because the Rb-Sr whole rock system may have been reset during high-grade metamorphism (see for example Wickham, 1990 and Graham, 1985) or during deformation (see for example Black, 1988). It has been previously observed (Wickham, 1990) that $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in high-grade metasedimentary rocks are often lower than would be expected given the depositional age and the Rb/Sr ratio of these rocks and that $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in high grade metasedimentary terranes have often been homogenized. These observations emphasize the mobility of strontium in the crust and indicate that major changes in Sr isotopic compositions may occur during prograde metamorphism, even at conditions lower than anatexis. In the northern region of the Scotia-Quaal belt, ample evidence for partial melting

is given by a high degree of migmatization in the region's gneisses and is consistent with high temperatures obtained from geothermobarometry (Chapter 2).

4.5 Summary and Discussion

All four samples from the Scotia-Quaal metamorphic belt record negative present-day ϵ_{Nd} values. The Middle Devonian Big Falls orthogneiss records the most negative present-day ϵ_{Nd} value, a value which does not overlap with values typical of Wrangellia, Alexander or Stikine terranes, but is similar to values characteristic of Nisling terrane. The present-day ϵ_{Nd} values for the two quartzites from the Scotia-Quaal belt are also distinct from present-day ϵ_{Nd} ranges typical of Wrangellia, Alexander and Stikine terranes and differ from values characteristic of the Gravina belt. They are encompassed in the wide range obtained from rocks of Nisling and Taku terranes which have been interpreted (Samson et al., 1989a) to have formed through mixing of juvenile and isotopically evolved crust. It is not possible to define the terrane affinity of the metapelitic sample based on its ϵ_{Nd} value which is within limits of the ranges of all terranes involved in the comparative study.

Initial Sr ratios for three of the samples are higher than initial ratios typical of Wrangellia terrane and are at the upper limit of ranges for Alexander and Stikine terranes. By itself this data does not allow to exclude the Scotia-Quaal belt from either terrane, but neither does it contradict other lines of evidence, such as the Sm-Nd data, the Middle Devonian U-Pb date for the Big Falls orthogneiss and the lithological differences between the Scotia-Quaal belt and Alexander and Stikine terranes, which suggest a correlation of the Scotia-Quaal metamorphic belt with Nisling terrane rather than with Alexander or Stikine terranes.

The calculated initial Sr ratio for the fourth sample (68-3) is much lower than the values obtained from the other three samples and this is in disagreement with the negative present-

day ϵ_{Nd} value obtained for this sample, which is within the range of values obtained from the metasedimentary samples. The quartzite is believed to belong to the same sedimentary package as the other metasedimentary rocks and the Rb-Sr data is interpreted to result from resetting of the Rb-Sr whole rock system during metamorphism and/or deformation.

With respect to determining the terrane affiliation of the Scotia-Quaal metamorphic belt, all lines of evidence other than the Rb-Sr data are deemed more reliable than Sr values because the Rb-Sr system has been shown to be affected by metamorphism (Graham, 1985; Wickham, 1990) and deformation (Graham, 1985), and rocks of the Scotia-Quaal metamorphic belt have undergone at least two episodes of regional metamorphism, have locally been submitted to thermal effects related to magmatic activity, and have been affected by a complex polydeformational history.

Data obtained by Armstrong and Runkle (1979) from samples collected at the southern end of the Scotia-Quaal metamorphic belt, on Hawkesbury Island exemplify the significant impact of thermal activity onto the Rb-Sr system. Rocks on Hawkesbury Island are identical to lithological units located farther north along trend. There is no reason to separate these rocks from the rest of the Scotia-Quaal metamorphic belt. The only significant difference with rocks farther north lies in the close spatial relationship of the metamorphic rock on Hawkesbury Island with the 93.5 Ma Ecstall pluton and associated dykes (discussed in chapter 1), and in petrographical and thermobarometric evidence for extensive Ecstall contact metamorphism on Hawkesbury Island. The results of Armstrong and Runkle's (1979) Rb-Sr analyses are shown in Figure 4-3. The metamorphic samples from Hawkesbury Island form an elongate cluster close to a 115 Ma isochron giving a fairly low initial Sr ratio around 0.704, except for 1 point with an anomalously high Sr content interpreted by Armstrong and Runkle (1979) to result from oceanic Sr contamination. Because rocks of the Scotia-Quaal metamorphic belt including those on

Hawkesbury Island are at least as old as Early Jurassic in age, the relatively good fit of the Hawkesbury Island samples to an approximate 115 Ma isochron is herein reinterpreted as resulting from partial resetting of the Rb-Sr system at the time of Ecstall intrusion. The apparent low initial Sr ratios in the metamorphic rock are inferred to represent an effect of mixing of a high- ^{87}Sr reservoir represented by the metamorphic unit and a low ^{87}Sr reservoir represented by the Ecstall magma. Within this line of thought, the higher initial Sr ratio given by the one "anomalous" point (Figure 4-3) would more closely approach the initial Sr ratio of the unit before intrusion of the Ecstall pluton. This is consistent with the observation that the initial Sr value from this point is similar to values obtained from the quartzite and the metapelitic samples collected in the central region of the Scotia-Quaal metamorphic belt, away from the Ecstall pluton. While metamorphic rocks on Hawkesbury Island exhibit anomalously low initial Sr ratios, the middle Cretaceous (van der Heyden, 1989) Kitkiata pluton (herein interpreted to be part of the Ecstall pluton) yielded Rb-Sr data consistent with an age of 165 Ma or local enrichment in radiogenic Sr.

Additional Rb-Sr data presented by Armstrong and Runkle (1979) and summarized in Figure 4-3 shows some lithologies east of the Scotia-Quaal area, in the Central Gneiss Complex to have fairly radiogenic Sr isotopic compositions. These were interpreted by Armstrong and Runkle (1979) as resulting from contamination with sea-water Sr, but could also indicate the presence of units belonging to the same package as rocks of the Scotia-Quaal belt or could be a consequence of resetting of the Rb-Sr whole rock system involving both units relatively enriched in ^{87}Sr , and units with lower Sr ratios, more typical of the Coast Plutonic Complex. West of the Scotia-Quaal belt, high initial Sr ratios obtained from samples of dykes interpreted to represent late-stage Ecstall magma (Armstrong and Runkle, 1979) probably indicate contamination of late magma with fairly radiogenic country rock.

Units of the Scotia-Quaal metamorphic belt for which Sm-Nd and Rb-Sr data is available have isotopic signatures more consistent with those of Nisling terrane than with those of Alexander and Stikine terranes. Additional analytical work is needed to define the geographical extent of the Nisling-like package at the latitude of the Scotia-Quaal area. Description of lithologies to the north and south of the Scotia-Quaal belt by Hutchison (1982) and Roddick (1970) suggests that it may continue to the north along Work Channel and possibly south of Hawkesbury Island. Contamination of Ecstall dykes with radiogenic Sr suggests that the Ecstall pluton may have intruded the Scotia-Quaal package which may extend to the west, presumably at least as far as the location of the Middle Devonian Swede Point pluton. The eastern boundary of the "Nisling-like" package is as yet undefined.

Chapter 5 - Summary and discussion

The Scotia-Quaal metamorphic belt comprises: layered, epidote-bearing, hornblende-biotite gneiss; a quartzite unit of white to grey quartzite interlayered with semi-pelite to pelite; an epidote-rich, hornblende-biotite unit interpreted as metasedimentary on the basis of locally observed clastic texture; a mafic to intermediate metavolcanic unit in gradational contact, and therefore possibly comagmatic with the Middle Devonian Big Falls tonalitic augen orthogneiss; epidote-bearing, biotite-hornblende metatonalitic bodies of Early Jurassic age; and a mafic-ultramafic complex of pre-Albian (115 Ma) age. The metamorphic belt is bounded by the early Late Cretaceous (van der Heyden, personal communication 1991 and Woodsworth et al., 1983) Ecstall pluton on the west and by the Paleocene to Eocene (Armstrong and Runkle, 1979 and this study) Quottoon pluton on the east.

The Scotia-Quaal assemblage correlates best with rocks assigned to Nisling terrane. This correlation is based on lithological and age similarities between the Scotia-Quaal metamorphic belt and Nisling terrane in northern British Columbia (Currie, 1990a, 1990b and 1991) and in the Yukon Territory (Mortensen et al., in press), added to dissimilarities between the Scotia-Quaal belt and proximal Wrangellia and Alexander terranes to the west and Stikine terrane to the east (Refer to Table 1-1). Rb-Sr and Sm-Nd data are in agreement with this correlation.

The geographical extent of the "Nisling-like" strata at the latitude of the Scotia-Quaal area is as yet undefined. Description of lithologies to the north and south of the Scotia-Quaal belt by Hutchison (1982) and Roddick (1970) suggests that the Scotia-Quaal package continues to the north along Work Channel, and possibly south of Hawkesbury Island. Contamination of Ecstall dykes with radiogenic Sr suggests that relatively radiogenically-

enriched rocks, like the Scotia-Quaal strata, may extend to the west, presumably at least as far as the location of the Middle Devonian (van der Heyden, 1989) Swede Point pluton. Additional mapping and analytical work are necessary before questions about the eastern extent of the "Nisling-like" Scotia-Quaal strata and the nature of the Scotia-Quaal/Stikine boundary can be addressed. Based on the occurrence of Early Jurassic plutons in the Scotia-Quaal belt, a speculation is made that the Scotia-Quaal belt and Stikine terrane may have shared a common history, at least from Early Jurassic time on. If so, this would imply that no post-Early Jurassic suture exists between the Scotia-Quaal metamorphic belt and the Intermontane belt. The Scotia-Quaal package could form a basement to Stikine terrane or could be an unrelated package juxtaposed to Stikine terrane during tectonism.

Strong generally steeply-dipping planar and steeply-plunging linear fabrics, intense folding and scarcity of kinematic indicators characterize the structure in the area. Development of a strong foliation and of at least three types of folds (Fi, Fm and Fl) postdate the emplacement of the Middle Devonian Big Falls orthogneiss, but predate early Late Cretaceous Ecstall intrusion. This conclusion is based on the observation of strong planar and linear fabrics as well as all three types of folds in the Big Falls orthogneiss, and on the cross-cutting relationship of the Ecstall pluton and units and fabrics along the western margin of the Scotia-Quaal metamorphic belt. In addition, on Hawkesbury Island, as well as at a few other locations in the central and northern regions (refer to Appendix 1A), undeformed igneous rocks, identical to Ecstall quartz diorite and inferred to belong to the Ecstall pluton, overlie steeply-dipping units of the Scotia-Quaal metamorphic belt; this indicates that not only the westernmost part, but at least a major section, of the Scotia-Quaal area was cross-cut by the Ecstall pluton. Early Jurassic plutonism precedes the formation of at least two types of folds (Fm and Fl) and may coincide with an episode of metamorphism in the Scotia-Quaal belt.

The distribution of units on the map plane and the abundance of z-folds along the eastern margin of the Scotia-Quaal metamorphic belt suggest that the dominant regional structure of the long and narrow belt is a tight to isoclinal synform of either the F1 generation or postdating F1. The large scale synformal structure would have formed during post-late Early Jurassic / pre-early Late Cretaceous east-west compressional deformation. Steepening of units and fabrics in the Scotia-Quaal metamorphic belt is assumed to have occurred late in the deformational history of the belt. It could have occurred during or after the last folding event in the area, but must have taken place prior to emplacement of the early Late Cretaceous Ecstall pluton because undeformed igneous rock identical to Ecstall quartz diorite overlies the steeply dipping belt on Hawkesbury Island. It would also have had to occur prior to the end of the last regional metamorphic event (M2) because consistent pressure estimates are recorded by mineral compositions throughout the Scotia-Quaal belt indicating that there has been no significant tilting, folding or other deformation which would result in movement of one section of the belt with respect to another section after the end of M2 metamorphism.

There is no major Tertiary displacement or structural break within the Scotia-Quaal belt. Post-early Late Cretaceous deformation is restricted to the easternmost 1.5 km of the Scotia-Quaal belt, increases in intensity towards the east and is associated with deformation in the Quottoon pluton. Fabrics in the Quottoon pluton suggest that it was emplaced prior to or synchronously with deformation. If a major Late Paleocene-Early Eocene shear zone separates the western and central Coast Plutonic Complex, then it does not traverse the Scotia-Quaal metamorphic belt, but must be located within the Quottoon pluton, probably near its western margin.

It has been suggested (Crawford and Hollister, 1982) that the fault along which Eocene uplift of the Central Gneiss Complex occurred may coincide with the location of an older

fault. Although an Eocene shear zone along which the Central Gneiss Complex was uplifted is largely localized in the Quottoon pluton, it is possible that this Eocene zone coincides with an older, much wider (because deeper?) shear zone which would have affected the whole Scotia-Quaal belt. The effect of a pre-mid Cretaceous shear zone could have been to align many of the preexisting fabrics into the steep orientation so striking in the Scotia-Quaal belt and farther north along Work Channel. Unfortunately, kinematic indicators which would allow to document such a shear zone are absent in the Scotia-Quaal area.

Mineral assemblages are interpreted to have formed during the last regional metamorphic event (M2) to affect the Scotia-Quaal belt; in mafic rocks they indicate metamorphic conditions between epidote-amphibolite and upper amphibolite facies. Metapelitic assemblages are consistent with kyanite-staurolite and sillimanite grades of metamorphism. Garnet geothermobarometry reveals metamorphic equilibration temperatures between approximately 580 and 815°C and pressures of 800-850 MPa. A northward increase in proportion of migmatites in all units, the gradual disappearance towards the north of primary features and compositional layering inferred as depositional in nature, and differences in mineral assemblages and compositions as well as temperature estimates are consistent with a northeasterly increase in metamorphic grade across the belt which is interpreted as resulting dominantly from regional M2 metamorphism. Pressure estimates are surprisingly uniform throughout the Scotia-Quaal belt. They are interpreted to represent peak pressure conditions during M2 metamorphism which affected, approximately 110 Ma ago (hornblende K-Ar date), the Scotia-Quaal belt, then at a depth of approximately 30 km. M2 metamorphism is inferred to have been accompanied by, and have outlasted latest regional deformation in the Scotia-Quaal metamorphic belt.

Evidence of an older regional metamorphic event (M1) is recognized petrographically through identification of relic garnets in cores of M2 garnets. Helicitic inclusion trails in M1 garnet suggest that M1 metamorphism has taken place concurrently with a deformational event. M1 metamorphism need not be the first metamorphic episode experienced by the Scotia-Quaal belt.

Pressure estimates in the Ecstall pluton are equal to (≈ 800 MPa) or lower (≈ 600 MPa) than pressure estimates in the Scotia-Quaal belt, depending on the Al-in-hornblende calibration used for geobarometry. Based on these results, uplift of the Scotia-Quaal metamorphic belt from a 30 km depth to approximately 20 km may have occurred before or after emplacement of the Ecstall pluton.

In a zone less than 300 metres in width at the western margin of the belt, mineral assemblages (fibrolite in pelitic rocks and absence of chlorite in mafic rocks) and a 100 Ma hornblende K-Ar date, younger than the inferred 110 Ma age of regional metamorphism in the central region, are consistent with the development of a contact aureole (M3) around the ≈ 94 Ma (van der Heyden, personal communication, 1991; Woodsworth et al., 1983) Ecstall pluton.

The thermal impact of rocks east of the Scotia-Quaal belt on the eastern margin of the study area appears to have been intense, but short-lived such as to affect mineral assemblages and compositions minimally while allowing complete resetting of the hornblende K-Ar system (56.5 Ma date) at the time of intrusion of the Quottoon pluton. This statement is based on the assumption that the Quottoon pluton was emplaced at a depth corresponding to approximately 550 MPa pressures as inferred by Hollister et al. (1987) and on results of geobarometry which show no evidence of mineral (re)equilibration at depth corresponding to pressures below approximately 800 MPa.

The lack of reequilibration of metamorphic minerals from samples in the proximity of the Quottoon pluton is in marked contrast with observations by Himmelberg et al. (1991) of partial reequilibration under pressures of 500-600 MPa, of schists near Juneau, Alaska along trend with the Scotia-Quaal metamorphic belt, during uplift in response to final emplacement and crystallization of the tonalite sill (Alaskan equivalent, with respect to age and location, to the Quottoon pluton). They attribute lower pressure reequilibration of metamorphic minerals to emplacement of the tonalite sill plutons. In a first model, the role of the tonalite sill plutons is restricted to post-metamorphic reequilibration of minerals in bounding metamorphic rocks. Their second model suggests that the tonalite sill magma is the primary heat source for the inverted metamorphic gradient. Their main argument for this second model which they prefer over the first one, is the temporal and spatial relationship between peak metamorphism and emplacement of the tonalite sill plutons, although they do note that the isograds are truncated north of Juneau, suggesting that peak metamorphic conditions were obtained prior to final emplacement of plutons of the sill. They also indicate that the age of the high-pressure metamorphism is poorly constrained. In the Scotia-Quaal area, there is no evidence for reequilibration of minerals at 500-600 MPa depth and hornblende K-Ar dates from metamorphic rocks suggest an age of metamorphism considerably older (≈ 110 Ma) than the age of the Quottoon pluton (56.8 ± 0.1 Ma zircon U-Pb). At this latitude, the fact that the metamorphic isograds parallel the Quottoon pluton contact does not appear to imply that the plutonic body is responsible for the metamorphic gradient. The isograds in the Scotia-Quaal area, parallel the strong planar fabric in metamorphic rocks of the area. In turn, the contact between the Quottoon pluton and Scotia-Quaal units parallels this fabric; this is inferred to indicate that the long and narrow plutonic body was emplaced along a zone of weakness parallel to the regional fabric, and therefore incidentally parallel to the isograds. The apparent absence of

widespread post-early Late Cretaceous deformational features within the Scotia-Quaal metamorphic belt and the preservation of high-pressure mineral assemblages and compositions suggestive of rapid uplift of the belt are more consistent with a model of crustal thickening of the western Coast Plutonic Complex accomplished by westward and northwestward thrusting of rock packages separated by shear zones as proposed by Crawford et al. (1987) than with a model of thickening by horizontal shortening during compression as proposed by Himmelberg et al. (1991).

Pressure estimates in the Scotia-Quaal belt contrast sharply with inferred pressures of approximately 550 MPa in the Quottoon pluton and 450-550 MPa estimates in the Central Gneiss Complex. The Scotia-Quaal belt forms the eastern margin of a high pressure and high temperature region extending from the Prince Rupert shear zone to the eastern margin of the Scotia-Quaal area and thereby spanning most of the Coast Plutonic Complex's western belt. The fact that the Quottoon pluton marks a major change in pressure between rocks having equilibrated around 800MPa in the western region and gneisses giving pressure estimates of approximately 500MPa in the Central Gneiss Complex is consistent with the postulate that a major Late Paleocene-Early Eocene structural zone is located within the Quottoon pluton. Rapid uplift of the Central Gneiss Complex (as postulated earlier by Hollister, 1982) along the Late Paleocene-Early Eocene structural zone and juxtaposition of the Central Gneiss Complex to the already relatively cool (less than approximately 500°C) Scotia-Quaal belt is consistent with the intense, but short-lived thermal effect observed along the eastern margin of the Scotia-Quaal belt.

Hornblende K-Ar dates from the metamorphic rocks in the Scotia-Quaal area do not fit within the previously defined (Roddick, 1970 and van der Heyden, 1989) distribution pattern of hornblende K-Ar dates (Figure 3-1). 110 and 115 Ma K-Ar dates in the Scotia-Quaal area away from the two bounding plutons are older than hornblende K-Ar dates

between 91 and 74 Ma obtained in the region between Grenville Channel and the Work Channel structural zone, and older yet than 108 to 94 Ma dates west of Grenville Channel. The previously defined hornblende K-Ar pattern dominantly represents cooling ages of igneous bodies and of metamorphic rocks located near igneous bodies and in which the hornblende K-Ar system was partially to completely reset at the time of igneous intrusion.

The 110 Ma date from the Scotia-Quaal metamorphic belt is interpreted as a minimum estimate of the age of the last regional metamorphic event in the area because M2 metamorphic temperature estimates are higher than the Ar blocking temperature of hornblende. This age of metamorphism is older than the $\approx$ 94 Ma inferred age of metamorphism (Crawford et al, 1987) to the northwest of the Ecstall pluton, and older yet than the 90 Ma inferred age of metamorphism (Sutter and Crawford, 1985) west of the Prince Rupert shear zone. These dates define an apparent westward younging trend in age of last regional metamorphism across the western belt of the Coast Plutonic Complex.

West of the Prince Rupert shear zone, approximately 90 Ma old metamorphism is interpreted by Crawford et al. (1987) as resulting from superimposition of high-pressure, high-temperature schists and gneisses east of the moderately easterly dipping Prince Rupert shear zone over lower-grade rocks to the west. Crawford et al. inferred the mechanism of superimposition of the two rock packages to be crustal thickening accomplished by westward and northwestward thrusting of rock packages separated by shear zones (Figure 5-1).

One could speculate that deformation and metamorphism related to crustal thickening may have also affected the Scotia-Quaal metamorphic belt. The effect of this deformation could have been to bring a hypothetical package comprising the Scotia-Quaal belt to a depth

Figure 5-1: Sequence of schematic cross-sections after Crawford et al. (1987) showing a possible scenario for the evolution of the Scotia-Quaal belt in the context of the interpretation of Crawford et al. (1987) of westward thrusting of at least three rock packages during crustal thickening. (A) Within the framework of this interpretation, at the time of westward thrusting, a fault zone could have bounded the Scotia-Quaal rock package at a location coincident with the Eocene Work Channel structural zone. Rocks that overlay the presently exposed rocks of the Scotia-Quaal belt would have been thrust to the west. Movement of the rock package comprising the Scotia-Quaal belt could have occurred prior to 110 Ma ago, between 110 and 94 Ma ago or around the time of Ecstall emplacement 94 Ma ago. Movement on the fault located along the western margin of the Ecstall pluton was interpreted by Crawford et al. (1987) to have continued until the time of intrusion of the Ecstall pluton 94 Ma ago. That fault could (but does not have to) form the western boundary of the rock package comprising the Scotia-Quaal belt. (B) According to Crawford et al. (1987), movement on the Prince Rupert shear zone continued until approximately 90-85 Ma ago. (C) The Central Gneiss Complex was uplifted between 65 and 50 Ma ago by movement along the Work Channel structural zone which is located within the Quottoon pluton, probably near its western boundary. Features east of the Quottoon pluton are taken from Crawford et al. (1987) and their evaluation are beyond the scope of this study.

of approximately 30 km (based on metamorphic pressure estimates in the Scotia-Quaal area), where it stayed long enough to allow complete mineral equilibration before rapid uplift of the package to lower depth at a later time. If this is true, then a mechanism must be found to explain later uplift of the package. Continued deformation related to crustal thickening could have provided a means for uplift of the package to approximately 20 km (based on pressure estimates at the eastern margin of the Ecstall pluton, using Johnson and Rutherford's (1989) calibration of the Al-in-hornblende barometer) if this uplift occurred prior to the intrusion of the Late Cretaceous Ecstall pluton. There is no evidence in the Scotia-Quaal area for post-early Late Cretaceous / pre-Late Paleocene deformation during which the package could have been uplifted.

Alternatively, deformation related to crustal thickening could have resulted in rapid uplift of the package comprising the Scotia-Quaal area from 30 to 20 km depth (based on pressure estimates at the eastern margin of the Ecstall pluton, using Johnson and Rutherford's (1989) calibration of the Al-in-hornblende barometer). This could have been achieved through westward movement (Figure 5-1), along thrusts as yet unrecognized, of rocks that at the time overlay the presently exposed rocks of the Scotia-Quaal area. A candidate location for the eastern boundary of the hypothetical rock package comprising the Scotia-Quaal belt could be the site of the Late Paleocene-Early Eocene steeply easterly-dipping Work Channel structural zone (Figure 5-1).

If the Scotia-Quaal belt participated in the deformational event responsible for westward and northwestward stacking of rock packages and if it was uplifted through upward and westward movement, then it is possible that the Work Channel structural zone coincides with a steep segment at depth of the fault zone along which pre- or syn-94 Ma westward thrusting occurred.

A southern extension of the Work Channel lineament, herein called the Work Channel structural zone, does not traverse the Scotia-Quaal metamorphic belt, but is located within the Quottoon pluton, probably near its western margin. Steep units and fabrics in the Scotia-Quaal metamorphic belt do not result from Late Paleocene-Early Eocene deformation, but were in their present configuration prior to early Late Cretaceous time. Post-early Late Cretaceous deformation associated with the Work Channel structural zone is restricted to the easternmost 1.5 km of the Scotia-Quaal belt and results in fabrics parallel to the older regional fabric. Consistent pressure estimates throughout the Scotia-Quaal metamorphic belt indicate that no significant differential vertical movement occurred within the Scotia-Quaal belt during Late Paleocene-Early Eocene deformation. This observation may also apply north of the Skeena River, along Work Channel, where steep fabrics in metamorphic rocks were previously interpreted (Crawford and Hollister, 1982) as resulting from Tertiary deformation, but could also result from the same pre-early Late Cretaceous deformation as that responsible for steep fabrics in the Scotia-Quaal area.

As was previously mentioned by many authors (for most recent summaries, see Crawford et al., 1987 and van der Heyden, 1989), the Work Channel structural zone does separate rocks with contrasting metamorphic and cooling histories. At least at the latitude of the Scotia-Quaal belt, it is a major crustal break along which Paleocene to Eocene uplift of the Central Gneiss Complex occurred, possibly through reactivation of an older fault. No evidence is observed within the Scotia-Quaal metamorphic belt in support or against the hypothesis that the Work Channel structural zone may mark the western boundary of an Eocene metamorphic core complex, as suggested by van der Heyden (1989) and Heah (1990 and 1991). The main arguments in favor of this postulate are the contrasting cooling dates on either side of the Work Channel structural zone and the extensional structural data gathered by Heah (1990, 1991) on the eastern side of the Central Gneiss Complex.

Detailed structural work in the Quottoon pluton is necessary to resolve the question of the role of the Work Channel structural zone with respect to a proposed (van der Heyden, 1989 and Heah, 1990 and 1991) metamorphic core complex.

Finally, the Work Channel structural zone does not mark the boundary, at the latitude of the study area, between Alexander/Wrangellia superterrane on the west and Stikine terrane on the east as previously suggested (Crawford and Crawford, 1990). If it marked a terrane boundary at all, it could be a pre-Early Jurassic boundary between the "Nisling-like" Scotia-Quaal package and Stikine terrane. Additional mapping and isotopic work in the Central Gneiss Complex is necessary to evaluate this hypothesis.

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APPENDIX 1 MAPS AND CROSS-SECTIONAL SKETCHES

Appendix 1 is located in the back pocket

This appendix comprises:

Part A: Geological maps of the Scotia-Quaal metamorphic belt

**Map 1 of 4 : Kitkiata Inlet (103 H/11)
Map 2 of 4 : Foch Lagoon (103 H/14)
Map 3 of 4 : Kumealon Lake (103 H/13)
Map 4 of 4 : Port Essington (103 I/4)**

Part B: Station location map

**Map 1 of 4 : Kitkiata Inlet (103 H/11)
Map 2 of 4 : Foch Lagoon (103 H/14)
Map 3 of 4 : Kumealon Lake (103 H/13)
Map 4 of 4 : Port Essington (103 I/4)**

Part C: Cross-sectional sketches

**APPENDIX 2
UNIVERSAL TRANSVERSE MERCATOR COORDINATES**

Grid Zone Designation 9U

**Map sheets: Foch Lagoon (103 H/14)
Kitkiata Inlet (103 H/11)
Kumealon Lake (103 H/13)
Port Essington (103 I/4)
Port Edward (103 J/1)**

Mafic volcanic samples:

87-203-3	5964 725 N / 464 450 E
87-84-2	5965 425 N / 465 225 E
87-175-1	5972 875 N / 464 075 E
88-73-3	5971 975 N / 466 025 E
86-11A-7	5969 525 N / 466 350 E
86-5B-2	5971 850 N / 466 450 E
87-182-1	5976 750 N / 465 900 E
88-84-3	5972 000 N / 470 300 E
87-145-2	5972 700 N / 470 950 E

Garnet-bearing samples used for geothermobarometry:

89-137-2	5934 675 N / 494 500 E
88-54-1	5950 525 N / 491 675 E
88-104-1	5958 800 N / 481 225 E
87-237-1	5962 450 N / 474 150 E
87-195-3	5966 500 N / 471 200 E
87-150-7	5974 800 N / 469 750 E
87-46-1	5990 600 N / 459 675 E
89-69-2	5998 625 N / 462 875 E
89-106-3	5960 425 N / 476 175 E
86-4A-2	5972 225 N / 467 450 E
87-124-1	5972 200 N / 465 800 E
87-111-2	5972 575 N / 461 550 E

Samples from the Ecstall pluton used for Al-in-hornblende geobarometry:

87-19-1	6009 825 N / 432 925 E
87-107-1	5972 850 N / 460 750 E
87-96-1	5966 375 N / 461 575 E
89-139	5934 100 N / 494 325 E

Appendix 2 (end)

U-Pb samples:

87-172-2	5976 875 N / 464 800 E
88-140-2	5985 850 N / 465 075 E
87-139-5	5972 250 N / 470 575 E
87-218-2	5976 025 N / 468 400 E
88-108-2	5956 750 N / 479 600 E
87-140-2	5972 350 N / 470 650 E
87-246-1	5979 375 N / 474 500 E

K-Ar samples:

88-147-1	5961 850 N / 465 000 E
88-80-2	5972 125 N / 464 800 E
88-73-2	5971 975 N / 466 025 E
88-67-2	5972 825 N / 460 950 E
88-84-2	5972 000 N / 470 300 E

Rb-Sr and Sm-Nd samples:

89-133-2	5972 000 N / 463 525 E
89-95-3	5974 600 N / 470 475 E
89-98-4	5959 850 N / 465 175 E
89-68-3	5998 800 N / 462 475 E

APPENDIX 3
DEFINITION OF ABBREVIATIONS

Ab	Albite
Act	Actinolite
Alm	Almandine
And	Andesine
Apa	Apatite
Bt	Biotite
Carb	Carbonate
Cc	Calcite
Chl	Chlorite
Cpx	Clinopyroxene
Cpy	Chalcopyrite
Epi	Epidote
Fb	Fibrolite
Fe Ox	Iron Oxide
Ged	Gedrite
Gn	Garnet
Gr	Grossularite
Hb	Hornblende
Ilm	Ilmenite
Kfs	Potassium feldspar
Ky	Kyanite
Ms	Muscovite
Olig	Oligoclase
Op	Opaque
Plag	Plagioclase
Preh	Prehnite
Px	Pyroxene
Py	Pyrite

Appendix 3 (end)

Rut	Rutile
Qtz	Quartz
Sil	Sillimanite
Ser	Sericite
St	Staurolite
Sx	Sulphide
Tit	Titanite
Tr	Tremolite
WM	White Mica

APPENDIX 4
MINERAL ASSEMBLAGES IN METAPELITIC AND METABASIC
SAMPLES
OF THE SCOTIA-QUAAL METAMORPHIC BELT

Appendix 4A is a table of mineral assemblages in metapelitic samples and Appendix 4B, of mineral assemblages in metabasic samples. Refer to Appendix 1B for sample locations. Key to abbreviated mineral names is presented in Appendix 3. X indicate the presence of the mineral, R is used to indicate that the mineral formed during retrogressive metamorphism and T means that the mineral occurs only in trace amounts. The two- or three-letter code in left-hand side column, beside the sample number, refers to location of sample: "S" stands for south, "N" for north, "C" for center, "W" for west and "E" for east. For example, SW means south-western part of the Scotia-Quaal metamorphic belt. CW refers to a sample location on the western side of the central region, whereas NC refers to a sample location in the center of the northern region. NNE refers to samples north of the Skeena river. CSW refers to samples close to the boundary between the central and southern regions, on the west side of the belt. Unit numbers refer to units described in chapter 1 and in the map legends (Appendix 1A): 1 is for the layered gneiss unit, 2 is for the quartzite unit, 3 is for the metasedimentary clastic unit, 4 is for the metavolcanic unit and 5 refers to the Big Falls orthogneiss.

Sample #	Rock Type	Unit #	Qtz	Plag	Chl	Bt	Ms	Gn	St	Fb	Sil	Ky	Kfs	Apa	Op	Other
SC 89-15-3	Ms schist	4	X	X		X	X							X	X	Carb, Epi
SCE 88-99	Ms schist	3	X	X		X	X								X	Carb
SW 89-162-3	Gn-bt semi-schist	3	X	X		X										
CSE 89-111-7	Ms schist	4	X	X	X		X	T-R						X		Carb, Epi
CSE 89-112-1	Bt-plag gneiss	4	X	X			X									
CSW 89-98-1	Ky-gn schist	2	X	X	R	X	X	X	?	?	X					
CSW 89-102-2	Ms-fb schist	2	X	X	T-R	X	X									
CSE 87-237-1	Mica-gn schist	2	X	X		X	X	X							X	
CW 88-146-3	Ky schist	4	X	X		X	X	X				X			X	
CC 87-199-2	Ky-fb-ms semi-schist	2	X	X		X	X	X				X			X	
CE 87-192-1	Ky-fb schist	2	X	And		X	X	X				X			X	
CE 86-8A1	Fb-ms-bt schist	2	X	And	T-R	X	X	X				X			X	
CE 86-8A4	Kfs-sil schist	2	X	Olig-And		X	X	X				X			X	
CE 87-188-4	Gn-sil metapelite	2	X	X		X	X	X				X			X	
CW 87-59-2	Ms schist	4	X	X	X		X	X						X	X	Carb
CC 87-60-1	Pyritic phyllite	4	X	X	X		X	X							X	Py
CC 87-219-1	Ky-ms schist	4	X	X			X			X		X			X	
CC 87-124-1	Gn schist	4	X	Ab	R	X	X	X							X	
CC 87-125-2	Metagillite	4	X	X	R	X	X	X							X	
CC 86-5B1	Metagillite	4	X	X	X	X	X	X							X	
CC 88-87-2	Gn-bt metasedimentary rock	4	X	Olig	X	X	X	X			?				X	
CE 87-146-2	Sil schist	2	X	X	R	X	X	X			X				X	
CC 87-169-4	Metagillite	4	X	X	X	X	X	X							X	
CC 87-177-1	St-Fb-Ky semi-schist	2	X	X	R	X	X	X				X			X	
CC 87-176-2	Silvery phyllite	2	X	X			X									
CE 87-216-3	Bt-gn-fb schist	2	X	X	R	X	X	X				X			X	
CE 87-149-1	Bt semi-schist	2	X	X	T-R	X	T	X				X			Rut	
CE 87-150-4A	Sil schist	2	X	And		X	X								X	
CE 87-150-7	Ky semi-schist	2	X	Ab	R	X	X	X								
CE 87-153-1	Fb schist	2	X	And	R	X	X	X			X				X	
CE 87-154-1	Sil-gn metapelite	2	X	X	R	X		X	?					X	X	
CE 87-154-2	Sil-gn metapelite	2	X	X	R	X		X			X			X	X	
CE 87-154-3	Sil schist	2	X	X	R	X		X			X			X	X	
CE 87-156-1	Gn-sil schist	2	X	X	R	X		X			X			X	X	
NW 87-46-3	Ms-bt-gn semi-schist	4	X	Olig-And		X	X	X						X	X	
NW 87-46-5	Ms-bt-gn gneiss	4	X	X		X	X	X						X	X	
NNE 89-69-1	Ms-ky-sil schist	2	X	And		X	X	X						X	X	
NNE 89-69-2	Sil-ms schist	2	X	And	X	X	X	X							X	
NNE 89-77-2	Semi-pelite gneiss	2	X	And	R	X	X	X						X	X	

Sample #	Rock Type	Unit #	Qtz	Plag	Chl	Tr	Hb	Pz	Epi	Carb	Bt	WM	Tit	Ilm	Rut	Apa	Sx	Gn	Other
SW 89-13-2	Bt-hb schist	4	X	And	R-T		X		X		X								Op
SC 89-15-2	Hb-chl schist	4	X	X	X		X		X	R	X								Op
SC 89-16	Tr-hb-mica schist	4	X	Olig	X	X			X		X								Op
SC 89-17	Chl schist	4	X	X	X				X		X								Op
SC 89-30-3	Gn-chl-ms schist	4	X	?	X				X							X?		X	Op
SC 89-30-4	Chlorite schist	4	X	X	X				X									X	Op
SC 89-2	Mica schist	4	X	X					X		X								Op
SC 89-153	Chl. schist	4	X		X				X		X								Op, Gr
SW 88-162-2	Bt-chl schist	4	X	X	X				X		X						Py	X	Op
SE 88-182	Gn-hb-bt gneiss	1	X	X			X		X		X				X?			X	Op
SE 87-229-2	Gn-hb gneiss	1	X	And	R		X		X		X	R-Ser	X					X	Op
CW 87-203	Hb semi-schist	4	X	X	X		X		X		X	T							Op
CW 87-213-1	Chl-bt schist	4	X?	X	X				X		X	R-Ser						X	Op
CW 87-213-2	Hb semi-schist	4	X	X	R		X?				X								Op
CW 87-213-3	Layered metavolcanic	4	X	X	X		X				X								Op
CW 87-84	Hb-chl schist	4	X	Olig	X		X		T		X				X				Op
CE 87-197-1	Gn-hb gneiss	2	X	Olig-And			X		X		X							X	Op
CE 87-189-1	Hb gneiss	2	X	And			X		X		X								Op
CW 87-107	Amphibolite	2	X	Ab?	R?		X		T		X	R-Ser			X?				Op
CW 88-69-1	Bt-hb gneiss	4	X	X			X		X		X								Op
CW 87-115-1	Amphibolite	5	X	?	X		X		X		X				X?				Op
CW 87-119-1	Chl semi-schist	4	X	Olig	X		X		X		T				X?				Op
CW 88-80-3	Hb semi-schist	4	X	X	T		X		X		X								Op
CW 88-73-3	Chl schist	4	X	And	X		X		X		X							X	T-Op
CC 86-11A5	Hb-chl schist	4	X	X	X		X		X		X						Py		Op
CC 86-11A7	Sericite schist	4	X	Celsian			X		X	R	X						Py/Cpy		Op
CC 86-5B2	Hb-carb-chl schist	4	X	Olig	X		X		X	X					T		Py/Cpy		Op
CC 86-5A1	Gn-hb schist	4	X		X		X		X		X							X	Op
CC 87-128-4	Amphibolite	4	X	And			X		T		X								T-Op
CE 88-84-3	Cpx-hb gneiss	3	X	And			X		X		X								Op
CE 87-145-2	Gn-hb gneiss	2	X	And			X		X		X							X	Op
CW 87-175-1	Clastic hb-chl schist	4	X	Olig	R		X		X		X								Op
CW 87-175-2	Hb-chl semi-schist	4	X	X	R		X		X		X								Op
CW 87-175-3	Hb metabasite	4	X	X	X		X		X		X								Op
CW 87-170-3	Chlorite schist	4	X	X	X		X		X		X								Op
CC 87-182-1	Chl-bt semi-schist	4	X	Ab-And	X		X		X		X								Op
NW 89-46-5	Gn-hb gneiss	4	X	Olig	R		X		X		X	R-Ser						X	Op
NW 87-46-1	Gn-hb-bt gneiss	4	X	X	R-T		X		X		X							X	Op
NW 87-45-1	Hb-bt migmatite gneiss	4	X	X	T		X		X		X								Op
NC 87-41-2	Cpx-hb gneiss	4	X	Olig-And	R		X		X		X								X

APPENDIX 5 ELECTRON MICROPROBE ANALYTICAL PROCEDURE

Electron microprobe analyses were obtained in the Microprobe Laboratory of Carleton University by energy dispersive spectrometry (EDS) using a Cambridge Microscan 5 instrument. Operating voltage was 20 kV and the specimen current was set at 9.0 nanoamperes measured on an amphibole standard (Kakanui hornblende, U.S.N.M. Standard 143965). The spectrum collection time was 100 seconds (live detector time).

The data was reduced on a personal computer using program EDDI (Pringle, 1989). In this program, all iron is calculated as FeO.

For the study of mafic metavolcanic rocks, mineral formulae were also calculated based on cation distribution in order to estimate the Fe₂O₃ content of the minerals. This was done using the calculation technique described by Laird and Albee (1981).

Amphiboles, $A_{0.1}^{VIII-XII}M_4^{VI-VIII}(M_{1,2,3})_5^{VI}T_8^{IV}O_{22}(OH,O,F,CL)_2$ structural formulae were calculated as follows:

Total cations less (Ca+Na+K) normalized to 13

(M4 site assumed free of Fe²⁺, Mg and Mn)

$Al^{IV} = 8 - Si$

$Al^{VI} = Al_{Total} - Al^{IV}$

$Fe^{3+} = 46 - \text{total cation charge assuming all ferrous iron}$

$Fe^{2+} = Fe_{Total} - Fe^{3+}$

$Na^{M4} = 7 - (Ca + Fe_{Total} + Mg + Mn + Al^{VI} + Ti + Cr)$

$Na^A = Na_{Total} - Na^{M4}$

Chlorite analyses were normalized to 10 cations based on the formula $Y_6^{VI}Z_4^{IV}O_{10}(OH,O,F,CL)_8$ and on the following assumptions:

$$Al^{IV} = 4 - Si$$

$$Al^{VI} = Al_{Total} - Al^{IV}$$

$$Fe^{3+} = Al^{IV} - Al^{VI} - Cr - 2Ti$$

$$Fe^{2+} = Fe_{Total} - Fe^{3+}$$

Plagioclase is normalized to 5 cations and all iron is assumed ferrous.

Epidote group minerals $[X_2^{VIII}Y_3^{VI}Z_3^{IV}O_{12}(OH,F)]$, and garnet $[X_3^{VIII}Y_2^{VI}Z_3^{IV}O_{12}]$ are both normalized to 8 cations and based on the following assumptions:

$$Al^{IV} = 3 - Si$$

$$Al^{VI} = Al_{Total} - Al^{IV}$$

$$\text{Epidote: } Fe^{3+} = 3 - Al^{VI} - Ti \text{ (assuming all Mn divalent)}$$

$$\text{Garnet: } Fe^{3+} = 2 - Al^{VI} - Ti - Cr \text{ (assuming all Mn divalent)}$$

$$Fe^{2+} = Fe_{Total} - Fe^{3+}$$

Pyroxene analyses were normalized to 4 cations in accordance with the formula $M_2^{VI-VIII}M_1^{VI}T_2^{IV}O_6$, based on the following assumptions:

$$Al^{IV} = 2 - Si$$

$$Al^{VI} = Al_{Total} - Al^{IV}$$

$$Fe^{3+} = 12 - \text{total cation charge assuming all ferrous iron}$$

$$Fe^{2+} = Fe_{Total} - Fe^{3+}$$

Precision

Repeated analysis (by energy dispersive spectrometry) of the amphibole standard "Kakanui hornblende" reveals that all elements except Mn, Cr and Na are measured within the 3 to 5% error limit used for error propagation in geothermobarometry. Proportions of Mn and Cr in Kakanui hornblende close to or below the detection limit of the instrument are responsible for the poor precision obtained for these two elements. The high Na error is thought to be due to low Na- content in amphibole. Repeated measurements of Na in albitic plagioclase gave results within a 5% error range. Average compositions of Kakanui hornblende, as obtained by energy dispersive spectrometry using the Cambridge Microscan 5 instrument are shown in Table A5-1. Each set of values corresponds to the average of analyses performed during one day. Generally, between 6 and 10 analyses were performed on a spot before moving the beam to a new location on the standard. The averages and standard deviations compare well with values obtained in other laboratories for the same standard (refer to Jarosewich et al., 1979). The averages differ no more from the accepted composition of the standard (chemical analysis; Jarosewich et al., 1979) than averages from other laboratories do.

Table A5-1: Analyses of Kakanui hornblende using Kakanui hornblende as reference sample.

	Accepted values	Mean (1) (N=61)	σ	Mean (2) (N=60)	σ
SiO ₂	40.37	40.57	0.19	40.05	0.57
Al ₂ O ₃	14.90	14.91	0.16	14.82	0.30
TiO ₂	4.38	4.69	0.05	4.70	0.12
FeO	10.92	10.87	0.11	10.81	0.16
MnO	0.09	0.06	0.04	0.06	0.04
Cr ₂ O ₃	-	0.02	0.02	0.01	0.02
MgO	12.80	12.95	0.14	12.78	0.32
CaO	10.30	10.25	0.09	10.20	0.15
K ₂ O	2.05	2.07	0.04	2.04	0.04
Na ₂ O	2.50	2.95	0.26	2.58	0.25

APPENDIX 6
ELECTRON MICROPROBE ANALYSES OF MINERALS
FROM MAFIC METAVOLCANIC ROCKS
OF THE CENTRAL REGION
SCOTIA-QUAAL METAMORPHIC BELT

This appendix gives the composition of minerals used for geothermobarometry. Refer to Chapter 2, Section 3 for discussion of results, to Table 2-1 for mineral assemblages in each sample, to Appendix 1B for sample locations and to Appendix 2 for UTM coordinates. Analyses are presented in the following order: hornblende for all samples in the order given in Table 2-2, chlorite for all samples in the order given in Table 2-3, plagioclase, epidote, garnet and pyroxene. The analytical procedure for electron microprobe analysis and the technique for calculation of Fe^{3+} content are presented in Appendix 5.

Sample number	Mineral analysed				Figure to which analysis refers
Sample 88-84-3	Amphibole compositions				Table 2-2
	84-3.1C	84-3.1E	84-3.2G	84-3.2H	average
SiO ₂	48.01	47.75	46.62	45.16	46.910
Al ₂ O ₃	8.93	8.48	10.7	11.76	9.970
TiO ₂	0.44	0.45	0.65	0.58	0.530
MgO	14.63	14.3	13.72	13.33	13.990
FeO	11.67	11.85	12.47	12.82	12.200
MnO	0.25	0.18	0.26	0.25	0.240
Cr ₂ O ₃	0.49	0.49	0.08	0.47	0.380
Na ₂ O	0.72	0.52	1.02	0.87	0.780
CaO	12.61	12.53	12.41	12.42	
K ₂ O	0.67	0.57	0.85	0.91	
TOTAL	98.42	97.12	98.78	98.67	
23 oxygens					
Si	6.925	6.977	6.737	6.577	
Al	1.075	1.023	1.263		
	8	8	8		
Al	0.443	0.437			
Ti	0.048	0.049			
Mg	3.145	2.956			
Fe	1.507				
Mn					

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PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

Sample 87-203-3		Amphibole compositions										Table 2-2	
		203-3.1A	203-3.1B	203-3.97	203-3.2A	203-3.98	203-3.99	203-3.10	203-3.3A	average			
SiO ₂		49.92	48.87	49.99	47.50	49.40	48.73	49.60	49.14	49.140			
Al ₂ O ₃		7.60	8.94	7.34	9.56	8.52	8.85	7.76	8.63	8.400			
TiO ₂		0.25	0.45	0.29	0.32	0.35	0.37	0.41	0.39	0.350			
MgO		17.39	16.49	17.25	15.92	16.99	16.75	17.27	16.81	16.860			
FeO		8.47	8.94	8.27	8.85	8.66	8.89	8.27	8.86	8.650			
MnO		0.25	0.26	0.28	0.28	0.27	0.29	0.34	0.34	0.290			
Cr ₂ O ₃		0.55	0.66	0.56	1.63	0.64	0.76	0.72	0.54	0.760			
Na ₂ O		0.57	0.68	0.56	0.76	0.77	1.03	0.48	1.03	0.730			
CaO		12.50	12.06	12.60	12.33	12.64	12.06	12.51	12.33	12.380			
K ₂ O		0.20	0.27	0.24	0.28	0.47	0.26	0.22	0.34	0.280			
TOTAL		97.70	97.62	97.38	97.43	98.71	97.99	97.58	98.41	97.840			
23 oxygens													
Si		7.106	6.979	7.136	6.837	6.990	6.949	7.070	6.979	7.0060			
Al		0.894	1.021	0.864	1.163	1.010	1.051	0.930	1.021	0.9940			
		8	8	8	8	8	8	8	8	8			
Al		0.380	0.484	0.371	0.458	0.412	0.436	0.375	0.423	0.4170			
Ti		0.026	0.048	0.031	0.035	0.038	0.040	0.044	0.042	0.0380			
Mg		3.689	3.511	3.670	3.415	3.584	3.560	3.670	3.560	3.5830			
Fe		1.008	1.068	0.987	1.065	1.024	1.061	0.985	1.053	1.0310			
Mn		0.031	0.032	0.034	0.035	0.032	0.035	0.041	0.041	0.0350			
Cr		0.062	0.074	0.064	0.186	0.071	0.086	0.081	0.060	0.0850			
		5.196	5.217	5.157	5.194	5.161	5.218	5.196	5.179	5.1890			
Na		0.157	0.189	0.154	0.211	0.212	0.285	0.134	0.283	0.2030			
Ca		1.907	1.846	1.928	1.902	1.916	1.843	1.910	1.877	1.8910			
K		0.036	0.048	0.044	0.051	0.085	0.047	0.040	0.061	0.0520			
		2.100	2.083	2.126	2.164	2.213	2.175	2.084	2.221	2.1460			
Fe/Mg		0.2732	0.3042	0.2689	0.3119	0.2857	0.2980	0.2684	0.2958	0.28775			
Mg/Mg+Fe		0.7854	0.7668	0.7881	0.7623	0.7778	0.7704	0.7884	0.7717	0.77655			

Sample 87-84-2		Amphibole compositions							Table 2-2	
		84-2.1G	84-2.142	84-2.144	84-2.1F	average	84-2.141	84-2.143	average	
SiO ₂		43.33	43.75	44.45	43.49	43.760	47.60	47.68	47.640	
Al ₂ O ₃		15.14	15.16	13.49	14.79	14.650	9.64	9.38	9.510	
TiO ₂		0.51	0.51	0.56	0.49	0.520	0.40	0.40	0.400	
MgO		11.27	12.10	11.99	11.82	11.790	14.65	14.62	14.640	
FeO		12.88	11.83	13.01	12.23	12.490	11.37	11.18	11.280	
MnO		0.38	0.24	0.31	0.22	0.290	0.24	0.30	0.270	
Cr ₂ O ₃		0.12	0.07	0.19	0.03	0.100	0.11	0.17	0.140	
Na ₂ O		2.02	1.59	1.54	1.53	1.670	1.23	1.16	1.200	
CaO		10.82	11.28	11.47	11.68	11.310	11.75	11.54	11.640	
K ₂ O		0.24	0.20	0.25	0.27	0.240	0.19	0.17	0.180	
TOTAL		96.71	96.73	97.26	96.55	96.820	97.18	96.60	96.900	
23 oxygens										
Si		6.391	6.408	6.52	6.407	6.4320	6.91	6.952	6.9310	
Al		1.609	1.592	1.48	1.593	1.5680	1.09	1.048	1.0690	
		8	8	8	8	8	8	8	8	
Al		1.023	1.025	0.853	0.976	0.9700	0.559	0.564	0.5620	
Ti		0.057	0.056	0.062	0.054	0.0570	0.044	0.044	0.0440	
Mg		2.478	2.641	2.621	2.596	2.5840	3.171	3.178	3.1740	
Fe		1.588	1.449	1.596	1.506	1.5350	1.381	1.364	1.3720	
Mn		0.047	0.03	0.039	0.028	0.0360	0.03	0.037	0.0330	
Cr		0.014	0.008	0.023	0.004	0.0120	0.012	0.02	0.0160	
		5.207	5.209	5.194	5.164	5.1940	5.197	5.207	5.2010	
Na		0.577	0.451	0.439	0.437	0.4760	0.347	0.328	0.3380	
Ca		1.71	1.77	1.803	1.844	1.7820	1.828	1.803	1.8150	
K		0.046	0.037	0.047	0.05	0.0450	0.035	0.031	0.0330	
		2.333	2.258	2.289	2.331	2.3030	2.21	2.162	2.1860	
Fe/Mg		0.6408	0.5487	0.6089	0.5801	0.59404	0.4355	0.4292	0.43226	
Mg/Mg+Fe		0.6094	0.6457	0.6215	0.6329	0.62734	0.6966	0.6997	0.69820	

Sample 87-175-1		Amphibole compositions						Table 2-2	
		175-1.C	175-1.1E	175-1.1H	175-1.18	175-1.19	average		
SiO ₂		42.32	42.43	41.63	43.25	44.25	42.776		
Al ₂ O ₃		13.18	16.04	16.35	14.44	13.68	14.738		
TiO ₂		0.3	0.57	0.63	0.4	0.37	0.454		
MgO		10.45	9.64	9.22	9.83	11.02	10.032		
FeO		15.01	16.25	15.99	15.77	14.99	15.602		
MnO		0.38	0.33	0.43	0.31	0.38	0.366		
Cr ₂ O ₃		0.13	0.12	0.03	0.1	0.12	0.100		
Na ₂ O		1.34	1.37	1.46	1.2	1.19	1.312		
CaO		11.27	11.37	11.8	11.85	11.61	11.580		
K ₂ O		0.24	0.7	0.32	0.25	0.21	0.344		
TOTAL		94.62	98.82	97.86	97.4	97.83	97.306		
23 oxygens									
Si		6.466	6.239	6.181	6.423	6.508	6.3634		
Al		1.534	1.761	1.819	1.577	1.492	1.6366		
		8	8	8	8	8	8		
Al		0.840	1.018	1.043	0.951	0.88	0.9464		
Ti		0.035	0.063	0.071	0.044	0.041	0.0508		
Mg		2.381	2.113	2.04	2.175	2.415	2.2248		
Fe		1.917	1.999	1.986	1.96	1.844	1.9412		
Mn		0.049	0.041	0.055	0.039	0.047	0.0462		
Cr		0.016	0.013	0.004	0.012	0.014	0.0118		
		5.238	5.247	5.199	5.181	5.241	5.2212		
Na		0.396	0.392	0.421	0.345	0.039	0.3186		
Ca		1.845	1.792	1.877	1.886	1.829	1.8458		
K		0.047	0.132	0.06	0.047	0.039	0.0650		
		2.288	2.316	2.358	2.278	2.207	2.2894		
Fe/Mg		0.8051	0.9460	0.9735	0.9011	0.7636	0.87788		
Mg/Mg+Fe		0.5540	0.5139	0.5067	0.5260	0.5670	0.53352		

Sample 87-73-3		Amphibole compositions												Table 2-2	
		73-3.104	73-3.105	73-3.1F	73-3.16	73-3.2C	73-3.106	73-3.107	73-3.108	73-3.109	73-3.110	73-3.111	73-3.112	average	
SiO2		39.90	40.78	40.38	40.14	40.54	41.19	40.98	40.88	40.05	40.39	40.57	40.86	40.560	
Al2O3		18.04	18.05	18.45	18.33	17.95	17.28	17.36	17.20	17.94	17.91	17.59	18.46	17.880	
TiO2		0.30	0.37	0.37	0.37	0.37	0.45	0.36	0.36	0.28	0.40	0.38	0.35	0.360	
MgO		4.74	5.51	5.46	5.11	5.82	5.92	6.06	5.57	5.07	5.31	5.34	5.81	5.480	
FeO		20.54	20.34	20.27	20.58	20.57	20.06	20.73	20.55	20.70	21.04	20.25	20.12	20.480	
MnO		0.12	0.13	0.14	0.11	0.08	0.13	0.15	0.20	0.27	0.17	0.28	0.06	0.150	
Cr2O3		0.11	0.15	0.09	0.08	0.05	0.09	0.06	0.08	0.06	0.08	0.03	0.10	0.080	
Na2O		1.36	1.71	1.47	1.40	1.73	1.08	1.47	1.31	1.16	1.84	1.54	2.16	1.520	
CaO		10.92	10.99	11.14	10.99	11.02	11.10	11.06	11.63	11.46	11.12	11.49	11.05	11.160	
K2O		0.35	0.39	0.36	0.37	0.46	0.38	0.38	0.48	0.46	0.44	0.40	0.46	0.410	
TOTAL		96.38	98.42	98.13	97.48	98.59	97.68	98.61	98.26	97.45	98.70	97.87	99.43	98.080	
23 oxygens															
Si		6.123	6.121	6.076	6.089	6.088	6.208	6.149	6.166	6.095	6.080	6.137	6.072	6.1170	
Al		1.877	1.879	1.924	1.911	1.912	1.792	1.851	1.834	1.905	1.920	1.863	1.928	1.8830	
		8	8	8	8	8	8	8	8	8	8	8	8	8	
Al		1.386	1.315	1.349	1.366	1.266	1.278	1.220	1.224	1.313	1.258	1.273	1.305	1.2960	
Ti		0.035	0.042	0.041	0.043	0.042	0.051	0.040	0.040	0.033	0.045	0.044	0.039	0.0410	
Mg		1.085	1.234	1.225	1.155	1.302	1.329	1.356	1.252	1.151	1.192	1.204	1.288	1.2310	
Fe		2.637	2.553	2.550	2.611	2.584	2.529	2.601	2.592	2.634	2.650	2.562	2.501	2.5830	
Mn		0.015	0.016	0.018	0.015	0.010	0.017	0.019	0.025	0.035	0.021	0.036	0.008	0.0200	
Cr		0.014	0.018	0.011	0.009	0.006	0.010	0.007	0.010	0.007	0.010	0.003	0.012	0.0100	
		5.172	5.178	5.194	5.199	5.210	5.214	5.243	5.143	5.173	5.176	5.122	5.153	5.1810	
Na		0.405	0.498	0.428	0.411	0.503	0.316	0.427	0.383	0.344	0.538	0.452	0.623	0.4440	
Ca		1.795	1.767	1.796	1.786	1.773	1.792	1.778	1.879	1.869	1.794	1.863	1.759	1.8040	
K		0.069	0.075	0.069	0.072	0.089	0.073	0.072	0.092	0.089	0.084	0.077	0.088	0.0790	
		2.269	2.340	2.293	2.269	2.365	2.181	2.277	2.354	2.302	2.416	2.392	2.470	2.3270	
Fe/Mg		2.4304	2.0689	2.0816	2.2606	1.9846	1.9029	1.9181	2.0703	2.2884	2.2232	2.1279	1.9418	2.09829	
Mg/Mg+Fe		0.2915	0.3259	0.3245	0.3067	0.3350	0.3445	0.3427	0.3257	0.3041	0.3103	0.3197	0.3399	0.32276	

Sample 86-5B-2	Amphibole compositions							Table 2-2	
	5B-2.5A	5B-2.5B	5B-2.4A	5B-2.4B	5B-2.2B	5B-2.3A			
SiO ₂	45.16	44.27	43.98	45.33	45.84	44.91			
Al ₂ O ₃	12.31	12.74	13.00	11.49	9.93	11.50			
TiO ₂	0.22	0.14	2.03	0.28	0.33	0.15			
MgO	12.66	12.57	12.29	13.32	13.74	12.66			
FeO	13.42	13.52	13.73	12.72	12.34	12.10			
MnO	0.33	0.40	0.18	0.32	0.17	0.30			
Cr ₂ O ₃	0.08	0.20	0.00	0.17	0.18	0.27			
Na ₂ O	1.37	1.47	1.44	1.72	1.28	1.68			
CaO	12.00	11.70	12.04	11.90	11.86	11.93			
K ₂ O	0.16	0.22	0.14	0.17	0.10	0.17			
TOTAL	97.71	97.23	98.83	97.42	95.77	95.67			
23 oxygens									
Si	6.609	6.527	6.496	6.645	6.806	6.688			
Al	1.391	1.473	1.504	1.355	1.194	1.312			
	8	8	8	8	8	8			
Al	0.732	0.741	0.759	0.631	0.543	0.706			
Ti	0.024	0.016	0.033	0.031	0.037	0.017			
Mg	2.762	2.762	2.706	2.910	3.041	2.810			
Fe	1.643	1.667	1.696	1.560	1.532	1.507			
Mn	0.041	0.050	0.022	0.040	0.021	0.038			
Cr	0.010	0.024	0.000	0.020	0.021	0.032			
	5.212	5.260	5.216	5.192	5.195	5.110			
Na	0.387	0.420	0.412	0.489	0.370	0.484			
Ca	1.881	1.849	1.906	1.869	1.887	1.904			
K	0.030	0.041	0.027	0.032	0.020	0.032			
	2.298	2.310	2.345	2.390	2.277	2.420			
Fe/Mg	0.5949	0.6035	0.6268	0.5361	0.5038	0.5363			
Mg/Mg+Fe	0.6270	0.6236	0.6147	0.6510	0.6650	0.6509			

Sample 86-11A-7		Amphibole compositions					Table 2-2
		11A-7.1C	11A-7.1D	11A-7.92	11A-7.93	average	
SiO ₂		52.83	53.15	51.42	53.32	52.680	
Al ₂ O ₃		7.99	6.48	8.56	6.23	7.320	
TiO ₂		0.34	0.34	1.05	0.32	0.510	
MgO		19.49	20.40	19.16	20.98	20.010	
FeO		3.43	2.42	2.97	2.58	2.850	
MnO		0.67	0.68	0.70	0.63	0.670	
Cr ₂ O ₃		0.17	0.19	0.23	0.22	0.200	
Na ₂ O		0.87	0.21	0.75	0.13	0.490	
CaO		13.50	13.34	2.79	13.47	13.270	
K ₂ O		0.10	0.10	0.17	0.12	0.120	
TOTAL		99.39	97.31	97.80	98.00	98.120	
23 oxygens							
Si		7.217	7.361	7.124	7.343	7.2610	
Al		0.783	0.639	0.876	0.657	0.7390	
		8	8	8	8	8	
Al		0.503	0.420	0.522	0.354	0.4500	
Ti		0.035	0.035	0.109	0.033	0.0530	
Mg		3.969	4.211	3.958	4.308	4.1120	
Fe		0.392	0.280	0.344	0.297	0.3280	
Mn		0.078	0.080	0.082	0.073	0.0780	
Cr		0.018	0.210	0.025	0.024	0.0220	
		4.995	5.047	5.040	5.089	5.0430	
Na		0.231	0.056	0.200	0.034	0.1310	
Ca		1.976	1.979	1.899	1.988	1.9610	
K		0.017	0.017	0.031	0.021	0.0210	
		2.224	2.052	2.130	2.043	2.1130	
Fe/Mg		0.0988	0.0665	0.0869	0.0689	0.07977	
Mg/Mg+Fe		0.9101	0.9377	0.9200	0.9355	0.92613	

Sample 87-182-1		Amphibole compositions					Table 2-2	
	182-1.13	182-1.14	182-1.2	182-1.15	182-1.16			
SiO2	51.54	45.16	46.89	50.98	50.77			
Al2O3	5.2	11.49	9.62	5.75	5.36			
TiO2	0.41	0.38	0.31	0.4	0.44			
MgO	16.98	13.13	14.36	16.54	16.62			
FeO	10.81	13.82	12.53	11.09	10.95			
MnO	0.39	0.35	0.25	0.42	0.37			
Cr2O3	0.16	0.19	0.14	0.28	0.09			
Na2O	0.73	1.09	1.35	1.07	0.39			
CaO	12.05	11.46	11.52	11.55	11.66			
K2O	0.1	0.21	0.2	0.11	0.06			
TOTAL	98.37	97.28	97.17	98.19	96.71			
23 oxygens								
Si	7.342	6.644	6.856	7.292	7.346			
Al	0.658	1.356	1.144	0.708	0.654			
	8	8	8	8	8			
Al	0.215	0.637	0.514	0.261	0.26			
Ti	0.044	0.042	0.034	0.043	0.048			
Mg	3.606	2.879	3.129	3.526	3.585			
Fe	1.288	1.7	1.533	1.326	1.325			
Mn	0.047	0.043	0.031	0.051	0.046			
Cr	0.018	0.022	0.017	0.032	0.011			
	5.218	5.323	5.258	5.239	5.275			
Na	0.202	0.31	0.384	0.296	0.109			
Ca	1.839	1.806	1.804	1.77	1.808			
K	0.018	0.04	0.037	0.019	0.012			
	2.059	2.156	2.225	2.085	1.929			
Fe/Mg	0.3572	0.5905	0.4899	0.3761	0.3696			
Mg/Mg+Fe	0.7368	0.6287	0.6712	0.7267	0.7301			

Sample 88-84-3		Amphibole compositions					Table 2-2	
	84-3.1C	84-3.1E	84-3.2G	84-3.2H	average			
SiO2	48.01	47.75	46.62	45.26	46.910			
Al2O3	8.93	8.48	10.7	11.76	9.970			
TiO2	0.44	0.45	0.65	0.58	0.530			
MgO	14.63	14.3	13.72	13.33	13.990			
FeO	11.67	11.85	12.47	12.82	12.200			
MnO	0.25	0.18	0.26	0.25	0.240			
Cr2O3	0.49	0.49	0.08	0.47	0.380			
Na2O	0.72	0.52	1.02	0.87	0.780			
CaO	12.61	12.53	12.41	12.42	12.490			
K2O	0.67	0.57	0.85	0.91	0.750			
TOTAL	98.42	97.12	98.78	98.67	98.240			
23 oxygens								
Si	6.925	6.977	6.737	6.577	6.8040			
Al	1.075	1.023	1.263	1.423	1.1960			
	8	8	8	8	8			
Al	0.443	0.437	0.56	0.591	0.5080			
Ti	0.048	0.049	0.07	0.064	0.0580			
Mg	3.145	3.114	2.956	2.886	3.0260			
Fe	1.407	1.448	1.507	1.558	1.4800			
Mn	0.031	0.023	0.032	0.031	0.0290			
Cr	0.056	0.057	0.009	0.054	0.0440			
	5.130	5.128	5.134	5.184	5.1450			
Na	0.202	0.146	0.285	0.246	0.2200			
Ca	1.948	1.961	1.921	1.934	1.9410			
K	0.122	0.106	0.157	0.168	0.1380			
	2.272	2.213	2.363	2.348	2.2990			
Fe/Mg	0.4474	0.4650	0.5098	0.5398	0.48909			
Mg/Mg+Fe	0.6909	0.6826	0.6623	0.6494	0.67155			

Sample 87-145-2		Amphibole compositions						Table 2-2	
		145-2.11	145-2.1H	145-2.11	145-2.11	145-2.2B	average		
SiO ₂		41.11	41.12	40.58	12.37	40.82	41.190		
Al ₂ O ₃		12.96	12.99	12.60	1.40	12.87	17.280		
TiO ₂		0.94	1.56	1.48	6.73	1.58	0.450		
MgO		5.79	6.69	6.59	21.09	6.70	5.920		
FeO		23.43	21.72	21.35	0.24	21.27	20.060		
MnO		0.43	0.38	0.35	0.01	0.27	0.130		
Cr ₂ O ₃		0.08	0.13	0.10	1.37	0.09	0.090		
Na ₂ O		1.26	1.41	1.36	11.26	1.41	1.080		
CaO		11.30	11.43	11.16	1.06	11.72	11.100		
K ₂ O		1.06	1.28	1.26	0.37	1.24	0.380		
TOTAL		98.36	98.71	96.83	55.90	97.97	97.680		
23 oxygens									
Si		6.336	6.28	6.314	6.395	6.275	6.3200		
Al		1.664	1.72	1.686	1.605	1.725	1.6800		
		8	8	8	8	8	8		
Al		0.690	0.619	0.624	0.653	0.608	0.6390		
Ti		0.109	0.179	0.173	0.163	0.182	0.1610		
Mg		1.331	1.523	1.528	1.553	1.537	1.4940		
Fe		3.020	2.774	2.777	2.731	2.735	2.8080		
Mn		0.056	0.050	0.046	0.032	0.035	0.0440		
Cr		0.010	0.016	0.013	0.002	0.011	0.0100		
		5.216	5.161	5.161	5.134	5.108	5.1560		
Na		0.375	0.416	0.410	0.412	0.420	0.4070		
Ca		1.866	1.870	1.860	1.869	1.931	1.8790		
K		0.208	0.249	0.250	0.210	0.243	0.2320		
		2.449	2.535	2.520	2.491	2.594	2.5180		
Fe/Mg		2.2690	1.8214	1.8174	1.7585	1.7794	1.87952		
Mg/Mg+Fe		0.3059	0.3544	0.3549	0.3625	0.3598	0.34728		

Sample 87-203-3				Chlorite compositions														Table 2-3			
203-3-2D 203-3-10 average				84-2-1D 84-2-148 84-2-149 84-2-150 84-2-151C 84-2-151 84-2-152 84-2-153 84-2-154 average																	
SiO2	27.62	27.86	27.740	26.71	27.01	26.77	27.12	27.63	26.90	26.47	31.49	27.00	27.460								
Al2O3	21.68	21.36	21.520	23.41	22.29	22.34	22.16	21.53	22.25	22.41	20.08	21.69	22.020								
TiO2	0.14	0.13	0.140	0.13	0.17	0.12	0.12	0.29	0.13	0.20	0.07	0.13	0.150								
FeO	14.09	14.2	14.140	14.74	15.56	15.08	14.93	15.55	14.75	15.26	14.72	15.18	15.090								
MnO	0.34	0.36	0.350	0.23	0.25	0.29	0.24	0.24	0.17	0.26	0.12	0.22	0.220								
MgO	24.28	24.94	24.610	23.93	23.48	23.52	24.02	23.23	24.26	23.70	22.09	24.27	23.610								
CR2O3	0.91	0.72	0.820	0.02	0.06	0.03	0.04	0.30	0.03	0.03	0.01	0.04	0.060								
K2O	0.11	0.09	0.100	0.07	0.09	0.03	0.08	0.09	0.06	0.05	0.06	0.07	0.070								
CAO	0.17	0.14	0.160	89.24	88.91	88.18	88.71	88.86	88.55	88.38	88.64	88.60	88.680								
TOTAL	89.34	89.8	89.580											88.60	88.680						
28 oxygens																					
SI	5.393	5.414	5.4040	5.219	5.324	5.309	5.34	5.452	5.302	5.248	6.123	5.335	5.407								
AL	2.607	2.586	2.5960	2.781	2.676	2.691	2.66	2.548	2.698	2.752	1.877	2.665	2.593								
	8	8	8	8	8	8	8	8	8	8	8	8	8								
AL	2.384	2.305	2.3450	2.611	2.504	2.531	2.483	2.460	2.470	2.484	2.726	2.386	2.5180								
TI	0.021	0.02	0.0200	0.019	0.024	0.018	0.018	0.043	0.020	0.029	0.010	0.020	0.0220								
FE	2.301	2.307	2.3040	2.410	2.565	2.501	2.459	2.567	2.431	2.531	2.394	2.509	2.4850								
MN	0.056	0.059	0.0570	0.038	0.042	0.049	0.040	0.040	0.028	0.044	0.020	0.037	0.0370								
MG	7.068	7.224	7.1460	6.970	6.899	6.954	7.049	6.835	7.129	7.005	6.402	7.150	6.9320								
CR	0.141	0.111	0.1260	0.006	0.014	0.008	0.010	0.075	0.008	0.006	0.003	0.009	0.0150								
K	0.027	0.022	0.0240	0.014	0.020	0.006	0.017	0.018	0.013	0.010	0.013	0.014	0.0140								
CA	0.036	0.029	0.0330	12.068	12.068	12.067	12.076	12.038	12.099	12.109	11.568	12.125	12.0230								
	12.034	12.077	12.0550	0.3458	0.3718	0.3596	0.3488	0.3756	0.3410	0.3613	0.3739	0.3509	0.35848								
FE/MG	0.3256	0.3194	0.32242	0.7431	0.7290	0.7355	0.7414	0.7270	0.7457	0.7346	0.7278	0.7402	0.73612								
MG/MG+FE	0.7544	0.7579	0.75619											88.60	88.680						

Sample 87-175-1		Chlorite compositions										Table 2-3	
		175-1.01	175-1.02	175-1.03	175-1.2C	175-1.04	175-1.05	175-1.06	175-1.11	average			
SiO ₂		25.73	26.08	26.23	26.22	26.19	26.62	25.98	25.77	26.100			
Al ₂ O ₃		23.25	23.62	22.83	22.60	22.92	22.31	22.33	22.89	22.840			
TiO ₂		0.10	0.13	0.08	0.13	0.16	0.15	0.28	0.10	0.140			
FeO		18.18	18.77	18.98	18.86	18.71	18.52	18.83	19.47	18.790			
MnO		0.22	0.22	0.27	0.27	0.28	0.29	0.20	0.21	0.250			
MgO		21.13	22.04	22.21	22.09	21.94	22.27	20.91	21.58	21.770			
K ₂ O		0.08	0.05	0.04	0.03	0.03	0.06	0.36	0.00	0.080			
CaO		0.09	0.07	0.02	0.04	0.07	0.06	0.07	0.04	0.060			
TOTAL		88.78	90.98	90.66	90.24	90.30	90.28	88.96	90.06	90.030			
28 oxygens													
Si		5.155	5.107	5.164	5.185	5.171	5.251	5.224	5.124	5.1730			
Al		2.845	2.893	2.836	2.815	2.829	2.749	2.776	2.876	2.8270			
		8	8	8	8	8	8	8	8	8			
Al		2.646	2.560	2.463	2.453	2.504	2.439	2.516	2.488	2.5090			
Ti		0.015	0.020	0.011	0.020	0.024	0.022	0.042	0.015	0.0210			
Fe		3.046	3.075	3.125	3.148	3.090	3.056	3.166	3.238	3.1140			
Mn		0.037	0.037	0.045	0.045	0.046	0.049	0.035	0.035	0.0410			
Mg		6.310	6.434	6.520	6.511	6.457	6.549	6.267	6.396	6.4310			
K		0.020	0.014	0.010	0.008	0.007	0.015	0.091	0.000	0.0200			
Ca		0.019	0.014	0.005	0.009	0.014	0.012	0.016	0.008	0.0120			
		12.093	12.154	12.179	12.164	12.142	12.142	12.133	12.180	12.1480			
Fe/Mg		0.4827	0.4779	0.4793	0.4835	0.4786	0.4666	0.5052	0.5063	0.48422			
Mg/Mg+Fe		0.6744	0.6766	0.6760	0.6741	0.6763	0.6818	0.6644	0.6639	0.67376			

Sample 86-5B-2		Chlorite compositions					Table 2-3
		5B-2.5C	5B-2.4C	5B-2.2C	5B-2.1B	5B-2.3B	
SiO ₂		26.15	26.72	25.93	26.28	25.220	
Al ₂ O ₃		21.14	21.48	21.01	21.26	21.690	
TiO ₂		0.01	0.03	0.00	0.03	0.120	
FeO		14.37	13.76	13.88	13.76	24.220	
MnO		0.24	0.15	0.35	0.29	0.080	
Cr ₂ O ₃		0.03	0.00	0.34	0.27	0.000	
MgO		23.20	23.56	23.20	23.65	17.300	
K ₂ O		0.00	0.00	0.00	0.01	0.010	
CaO		0.00	0.01	0.01	0.00	0.000	
TOTAL		85.14	85.71	84.72	85.55	88.640	
28 oxygens							
Si		5.363	5.413	5.342	5.35	5.2280	
Al		2.637	2.587	2.658	2.65	2.7720	8
		8	8	8	8	8	
Al		2.473	2.542	2.444	2.452	2.5280	
Ti		0.002	0.004	0.000	0.004	0.0180	
Fe		2.465	2.331	2.391	2.342	4.1980	
Mn		0.041	0.026	0.060	0.050	0.0140	
R		0.005	0.000	0.055	0.044	0.0000	
Mg		7.091	7.114	7.124	7.179	5.3440	
K		0.000	0.000	0.000	0.003	0.0020	
Ca		0.000	0.002	0.001	0.000	0.0000	
		12.077	12.019	12.075	12.074	12.1040	
FE/MG		0.3476	0.3476	0.3476	0.3476	0.3476	0.34762
MG/MG+FE		0.7420	0.7420	0.7420	0.7420	0.7420	0.74205

Sample 87-73-3		Chlorite compositions							Table 2-3	
		73-3.116	73-3.11	73-3.1J	73-3.2E	73-3.2G	73-3.2H	average		
SiO2		25.04	24.87	24.37	25.19	25.88	24.25	24.940		
Al2O3		21.96	22.96	22.62	21.94	22.21	22.81	22.420		
TiO2		0.17	0.14	0.12	0.16	0.25	0.16	0.160		
FeO		27.31	27.30	27.76	27.07	26.84	27.17	27.240		
MnO		0.19	0.15	0.37	0.26	0.25	0.27	0.250		
MgO		14.67	14.04	14.25	15.10	14.52	13.99	14.430		
K2O		0.05	0.41	0.06	0.06	0.50	0.07	0.200		
CaO		0.06	0.00	0.05	0.07	0.06	0.15	0.060		
TOTAL		89.45	89.87	89.60	89.85	90.51	88.87	89.700		
28 oxygens										
Si		5.228	5.17	5.101	5.229	5.324	5.102	5.193		
Al		2.772	2.83	2.899	2.771	2.676	2.898	2.807		
		8	8	8	8	8	8	8		
Al		2.632	2.795	2.681	2.597	2.710	2.759	2.6960		
Ti		0.026	0.021	0.018	0.025	0.038	0.026	0.0260		
Fe		4.768	4.747	4.859	4.700	4.619	4.780	4.7450		
Mn		0.034	0.026	0.065	0.045	0.043	0.049	0.0440		
Mg		4.565	4.351	4.446	4.672	4.454	4.387	4.4790		
K		0.014	0.110	0.017	0.016	0.132	0.020	0.0520		
Ca		0.012	0.000	0.012	0.014	0.013	0.033	0.0140		
		12.051	12.050	12.098	12.069	12.009	12.054	12.0560		
FE/MG		1.0445	1.0910	1.0929	1.0060	1.0370	1.0896	1.05939		
MG/MG+FE		0.4891	0.4782	0.4778	0.4985	0.4909	0.4786	0.48558		

Sample 87-182-1		Chlorite compositions							Table 2-3	
		182-1.2E	182-1.07	182-1.08	182-1.09	182-1.10	182-1.11	average		
SiO2		27.29	26.99	26.88	27.65	27.18	27.68	27.280		
Al2O3		21.18	20.94	22.10	21.33	21.44	21.10	21.350		
TiO2		0.14	0.14	0.19	0.18	0.19	0.18	0.170		
FeO		18.68	17.55	18.14	17.47	18.65	17.95	18.080		
MNO		0.19	0.19	0.18	0.17	0.21	0.17	0.180		
MGO		22.99	23.59	22.52	23.92	22.39	22.80	23.030		
K2O		0.16	0.06	0.06	0.11	0.32	0.08	0.130		
CAO		0.02	0.07	0.06	0.08	0.07	0.11	0.070		
TOTAL		90.65	89.53	90.13	90.91	90.45	90.07	90.290		
28 oxygens										
SI		5.365	5.347	5.296	5.382	5.361	5.449	5.3670		
AL		2.635	2.653	2.704	2.618	2.639	2.551	2.6330		
		8	8	8	8	8	8	8		
AL		2.274	2.238	2.428	2.275	2.344	2.344	2.3170		
TI		0.021	0.021	0.028	0.026	0.028	0.026	0.0250		
FE		3.072	2.908	2.989	2.844	3.076	2.956	2.9740		
MN		0.031	0.031	0.031	0.029	0.034	0.028	0.0310		
MG		6.737	6.968	6.614	6.940	6.582	6.690	6.7550		
K		0.041	0.014	0.014	0.026	0.081	0.019	0.0330		
CA		0.004	0.014	0.012	0.017	0.015	0.023	0.0140		
		12.180	12.194	12.116	12.157	12.160	12.086	12.1490		
FE/MG		0.4560	0.4173	0.4519	0.4098	0.4673	0.4419	0.44027		
MG/MG+FE		0.6868	0.7055	0.6887	0.7093	0.6815	0.6936	0.69432		

Sample 87-84-2		Plagioclase compositions					Sample 87-175-1		Plagioclase compositions		
		84-2.1K	84-2.1O	84-2.1P	84-2.1Q	84-2.1R	average		175-1.24	175-1.2A	average
SiO ₂		59.05	62.74	65.48	63.66	59.08	62.000	SiO ₂	62.61	62.51	62.560
Al ₂ O ₃		26.12	24.33	22.59	23.52	26.49	24.610	Al ₂ O ₃	24.11	24.40	24.260
Na ₂ O		7.58	8.71	10.29	9.19	6.88	8.530	Na ₂ O	8.36	7.97	8.170
CaO		7.78	5.34	3.21	4.51	8.01	5.770	CaO	5.03	5.46	5.240
K ₂ O		0.19	0.19	0.26	0.24	0.18	0.210	K ₂ O	0.25	0.21	0.230
FeO		0.09	0.05	0.18	0.16	0.16	0.130	FeO	0.12	0.14	0.130
TOTAL		100.81	101.36	102.01	101.28	100.8	101.250	TOTAL	100.48	100.69	100.590
32 oxygens								32 oxygens			
Si		10.489	10.981	11.350	11.136	10.475	10.8890	Si	11.033	10.991	11.0120
Al		5.469	5.019	4.615	4.850	5.535	5.0940	Al	5.008	5.058	5.0330
		15.958	16.000	15.965	15.986	16.010	15.9930		16.041	16.049	16.0450
Na		2.609	2.956	3.458	3.117	2.366	2.9050	Na	2.858	2.716	2.7870
Ca		1.480	1.002	0.596	0.845	1.522	1.0860	Ca	0.949	1.029	0.9890
K		0.043	0.043	0.057	0.053	0.041	0.0470	K	0.055	0.046	0.0510
		4.132	4.001	4.111	4.015	3.929	4.0380		3.862	3.791	3.8270
Fe		0.013	0.007	0.026	0.024	0.024	0.0190	Fe	0.017	0.021	0.0190
An		0.36	0.25	0.14	0.21	0.39	0.27	An	0.25	0.27	0.26

Sample 86-5B-2		Plagioclase compositions									
		5B-2.1A	5B-2.3A	84-1.1I	84-3.2A	84-3.2B	84-3.2C	84-3.2D	84-3.2O	84-3.2N	average
SiO ₂		60.822	60.670	59.35	57.62	58.01	57.92	57.45	57.34	56.87	57.82
Al ₂ O ₃		23.690	23.588	26.24	27.38	27.28	27.16	27.37	27.31	27.62	27.2
Na ₂ O		8.775	8.979	6.89	6.27	6.71	6.35	6.18	5.9	5.64	6.33
CaO		5.300	5.267	7.71	8.98	8.44	8.42	9.07	9.31	9.24	8.7
K ₂ O		0.087	0.023	0.35	0.26	0.28	0.31	0.29	0.29	0.21	0.28
FeO		0.026	0.000	0.09	0.15	0.13	0.12	0.13	0.27	0.14	0.15
TOTAL		98.700	98.527	100.63	100.66	100.85	100.28	100.49	100.42	99.72	100.48
32 oxygens											
Si		10.944	10.936	10.532	10.264	10.308	10.335	10.253	10.246	10.212	10.308
Al		5.024	5.012	5.487	5.749	5.713	5.713	5.758	5.754	5.846	5.716
		15.968	15.948	16.019	16.013	16.021	16.048	16.011	16	16.058	16.024
Na		3.060	3.140	2.37	2.166	2.311	2.196	2.14	2.043	1.965	2.188
Ca		1.020	1.016	1.467	1.713	1.607	1.609	1.735	1.782	1.779	1.662
K		0.020	0.004	0.079	0.058	0.064	0.071	0.065	0.066	0.048	0.064
		4.100	4.160	3.916	3.937	3.982	3.876	3.94	3.891	3.792	3.914
Fe		0.004	0.000	0.014	0.023	0.02	0.017	0.019	0.04	0.021	0.022
An		0.249	0.244	0.375	0.435	0.404	0.415	0.440	0.458	0.469	0.425

Sample 88-84-3		Plagioclase compositions									
		84-1.1I	84-3.2A	84-3.2B	84-3.2C	84-3.2D	84-3.2O	84-3.2N	average		
SiO ₂		59.35	57.62	58.01	57.92	57.45	57.34	56.87	57.82		
Al ₂ O ₃		26.24	27.38	27.28	27.16	27.37	27.31	27.62	27.2		
Na ₂ O		6.89	6.27	6.71	6.35	6.18	5.9	5.64	6.33		
CaO		7.71	8.98	8.44	8.42	9.07	9.31	9.24	8.7		
K ₂ O		0.35	0.26	0.28	0.31	0.29	0.29	0.21	0.28		
FeO		0.09	0.15	0.13	0.12	0.13	0.27	0.14	0.15		
TOTAL		100.63	100.66	100.85	100.28	100.49	100.42	99.72	100.48		
32 oxygens											
Si		10.532	10.264	10.308	10.335	10.253	10.246	10.212	10.308		
Al		5.487	5.749	5.713	5.713	5.758	5.754	5.846	5.716		
		16.019	16.013	16.021	16.048	16.011	16	16.058	16.024		
Na		2.37	2.166	2.311	2.196	2.14	2.043	1.965	2.188		
Ca		1.467	1.713	1.607	1.609	1.735	1.782	1.779	1.662		
K		0.079	0.058	0.064	0.071	0.065	0.066	0.048	0.064		
		3.916	3.937	3.982	3.876	3.94	3.891	3.792	3.914		
Fe		0.014	0.023	0.02	0.017	0.019	0.04	0.021	0.022		
An		0.375	0.435	0.404	0.415	0.440	0.458	0.469	0.425		

Sample 87-182-1		Plagioclase composition									
	Albite	Albite					Andesine				
		182-1.1P	182-1.1A	182-1.1S	182-1.2P	average	182-1.2L	182-1.2Q	average		
SiO2		67.64	67.54	67.77	67.83	67.695	59.64	58.18	58.910		
Al2O3		20.52	20.45	20.13	20.22	20.33	25.61	26.67	26.140		
Na2O		11.69	11.74	11.38	11.36	11.5425	7.85	6.97	7.410		
CaO		0.79	0.79	0.54	0.64	0.69	6.62	7.77	7.195		
K2O		0.25	0.25	0.27	0.27	0.26	0.17	0.15	0.160		
FeO		0.13	0.13	0.25	0.12	0.1575	0.12	0.2	0.160		
TOTAL		101.02	100.9	100.34	100.44	100.675	100.01	99.94	99.975		
32 oxygens											
Si		11.763	11.763	11.154	11.836	11.6290	10.634	10.41	10.5220		
Al		4.205	4.197	4.839	4.159	4.3500	5.382	5.624	5.5030		
		15.968	15.96	15.993	15.995	15.9790	16.016	16.034	16.0250		
Na		3.943	3.964	3.855	3.844	3.9015	2.712	2.418	2.5650		
Ca		0.148	0.148	0.101	0.119	0.1290	1.264	1.489	1.3765		
K		0.055	0.056	0.061	0.059	0.0578	0.039	0.034	0.0365		
		4.146	4.168	4.017	4.022	4.0883	4.015	3.941	3.9780		
Fe		0.018	0.019	0.026	0.018	0.0203	0.018	0.03	0.0240		
An		0.04	0.04	0.03	0.03	0.03	0.31	0.38	0.35		

Sample 87-182-1		Plagioclase compositions (end)									
	Oligoclase	182-1.1N	182-1.1O	182-1.Q	182-1.1R	182-1.2K	182-1.2N	182-1.2O	182-1.2R	average	
SiO2		61.88	61.49	62.51	63.28	63.33	63.48	63.34	61.46	62.596	
Al2O3		23.52	22.96	23.67	23.83	23.31	22.77	23.07	24.31	23.430	
Na2O		8.97	8.65	9.08	9.40	9.30	9.43	9.46	8.83	9.140	
CaO		4.56	4.13	4.53	4.21	4.19	3.53	4.10	5.11	4.295	
K2O		0.25	0.69	0.18	0.24	0.25	0.23	0.17	0.17	0.273	
FeO		0.37	0.96	0.24	0.21	0.18	0.13	0.15	0.20	0.305	
TOTAL		99.55	98.88	100.21	101.17	100.56	99.57	100.29	100.08	100.039	
32 oxygens											
Si		11.037	11.078	11.061	11.086	11.154	11.261	11.181	10.913	11.0964	
Al		4.945	4.875	4.936	4.922	4.839	4.760	4.800	5.088	4.8956	
		15.982	15.953	15.997	16.008	15.993	16.021	15.981	16.001	15.9920	
Na		3.103	3.022	3.114	3.193	3.176	3.243	3.239	3.039	3.1411	
Ca		0.872	0.796	0.859	0.791	0.791	0.670	0.776	0.973	0.8160	
K		0.057	0.159	0.042	0.053	0.056	0.052	0.039	0.039	0.0621	
		4.032	3.977	4.015	4.037	4.023	3.965	4.054	4.051	4.0193	
Fe		0.055	0.144	0.036	0.030	0.026	0.019	0.022	0.030	0.0453	
An		0.22	0.20	0.21	0.20	0.20	0.17	0.19	0.24	0.20	

Sample 87-145-2		Plagioclase compositions				
		145-2.1F	145-2.2D	145-2.2E	145-2.2F	average
SiO ₂		60.13	58.11	60.30	60.35	59.720
Al ₂ O ₃		25.21	25.01	25.60	24.95	25.190
Na ₂ O		7.41	7.30	7.29	7.60	7.400
CaO		6.37	6.47	6.66	6.18	6.420
K ₂ O		0.38	0.25	0.29	0.33	0.310
FeO		0.21	0.35	0.17	0.15	0.220
TOTAL		99.71	97.49	100.31	99.56	99.260
32 oxygens						
Si		10.734	10.632	10.697	10.780	10.7110
Al		5.305	5.394	5.353	5.253	5.3260
		16.039	16.026	16.050	16.033	16.0370
Na		2.564	2.590	2.508	2.633	2.5740
Ca		1.219	1.269	1.266	1.183	1.2340
K		0.086	0.058	0.065	0.076	0.0710
		3.869	3.917	3.839	3.892	3.8790
Fe		0.031	0.053	0.025	0.023	0.0330
An		0.32	0.32	0.33	0.30	0.32

Sample 87-84-2		Sample 87-175-1 Epidote compositions				
	84-2.2B		175-1.2E	175-1.2F	175-1.2G	average
SiO ₂	38.17		39.16	38.84	39.07	39.020
Al ₂ O ₃	25.97		27.18	27.58	28.57	27.780
MgO	0.00		0.00	0.00	0.00	0.000
FeO	8.92		7.93	7.19	5.74	6.950
TiO ₂	0.14		0.09	0.00	0.06	0.050
MnO	0.20		0.24	0.14	0.17	0.180
V ₂ O ₃	0.10		0.09	0.15	0.29	0.170
Cr ₂ O ₃	0.02		0.10	0.11	0.08	0.100
CaO	23.24		23.23	23.80	23.68	23.570
TOTAL	96.76		98.02	97.81	97.66	97.820
25 oxygens						
Si	6.151		6.179	6.131	6.123	6.1440
Al	4.932		5.054	5.132	5.278	5.1550
Mg	0.000		0.000	0.000	0.000	0.0000
Fe	1.203		1.046	0.949	0.752	0.9150
Ti	0.016		0.011	0.000	0.007	0.0060
Mn	0.028		0.032	0.019	0.023	0.0240
V	0.013		0.011	0.019	0.036	0.0220
Cr	0.002		0.012	0.014	0.010	0.0120
Ca	4.013		3.928	4.025	3.978	3.9770
	16.358		16.273	16.289	16.207	16.2550

Sample 87-73-3		Epidote compositions							
	73-3.1D	73-3.1E	73-3.129	73-3.1I	73-3.130	73-3.131	average		
SiO ₂	38.54	38.40	38.69	38.06	38.48	38.33	38.420		
Al ₂ O ₃	26.45	27.11	27.21	26.87	26.07	26.75	26.740		
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.000		
FeO	8.05	8.47	8.69	8.36	9.41	8.34	8.550		
TiO ₂	0.00	0.03	0.07	0.11	0.04	0.07	0.050		
MnO	0.41	0.10	0.17	0.08	0.15	0.08	0.170		
V ₂ O ₃	0.10	0.09	0.10	0.04	0.05	0.03	0.070		
Cr ₂ O ₃	0.07	0.12	0.09	0.06	0.14	0.06	0.090		
CaO	23.37	22.93	22.94	22.87	23.11	22.87	23.010		
TOTAL	96.99	97.25	97.96	96.45	97.45	96.53	97.100		
25 oxygens									
Si	6.169	6.124	6.129	6.121	6.163	6.154	6.1430		
Al	4.990	5.095	5.081	5.092	4.921	5.061	5.0400		
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.0000		
Fe	1.078	1.129	1.152	1.124	1.260	1.121	1.1440		
Ti	0.000	0.004	0.008	0.013	0.005	0.008	0.0060		
Mn	0.056	0.013	0.022	0.011	0.021	0.011	0.0220		
V	0.013	0.012	0.012	0.005	0.006	0.004	0.0090		
Cr	0.009	0.015	0.012	0.007	0.018	0.008	0.0120		
Ca	4.009	3.918	3.894	3.940	3.965	3.934	3.9430		
	16.324	16.310	16.310	16.313	16.359	16.301	16.3190		

Sample 86-11A-7		Epidote	
	77A7.1E	11A7.1F	average
SiO2	38.00	38.59	38.290
Al2O3	28.77	29.34	29.060
MgO	0.00	0.00	0.000
FeO	4.71	4.72	4.720
TiO2	0.07	0.06	0.060
MnO	0.60	0.67	0.640
V2O3	0.01	0.04	0.020
Cr2O3	0.04	0.06	0.050
CaO	23.42	23.35	23.390
TOTAL	95.62	96.83	96.230
25 oxygens			
Si	6.067	6.075	6.0710
Al	5.415	5.445	5.4300
Mg	0.000	0.000	0.0000
Fe	0.630	0.622	0.6260
Ti	0.009	0.007	0.0080
Mn	0.081	0.090	0.0860
V	0.001	0.005	0.0030
Cr	0.005	0.008	0.0060
Ca	4.007	3.939	3.9730
	16.215	16.191	16.2030

Sample 87-182-1		Epidote compositions										average
182-1.73	182-1.74	182-1.75	182-1.1F	182-1.76	182-1.77	182-1.78	182-1.79	182-1.80	182-1.1B			
37.55	37.90	39.38	36.99	37.90	38.08	38.28	37.73	37.57	38.36	37.970		
22.79	24.35	24.08	22.01	23.11	22.41	21.95	22.27	23.88	24.33	23.120		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000		
12.81	11.35	11.27	14.17	13.30	13.34	14.14	13.14	11.57	11.73	12.680		
0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.04	0.030		
0.19	0.25	0.22	0.18	0.85	0.20	0.24	0.21	0.27	0.18	0.280		
0.06	0.06	0.00	0.00	0.01	0.00	0.00	0.05	0.07	0.00	0.020		
0.16	0.18	0.05	0.03	0.00	0.02	0.00	0.06	0.14	0.12	0.080		
22.84	22.83	22.42	22.78	22.36	23.00	23.21	22.99	22.80	23.24	22.850		
96.40	97.08	97.42	96.16	97.53	97.05	97.82	96.45	96.38	98.00	97.030		
6.216	6.170	6.350	6.192	6.214	6.272	6.285	6.256	6.177	6.195	6.2330		
4.448	4.674	4.577	4.342	4.466	4.352	4.248	4.353	4.628	4.631	4.4730		
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000		
1.774	1.546	1.520	1.984	1.824	1.837	1.942	1.823	1.590	1.584	1.7410		
0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.005	0.0040		
0.026	0.034	0.030	0.025	0.118	0.028	0.034	0.030	0.038	0.025	0.0390		
0.008	0.008	0.000	0.000	0.002	0.000	0.000	0.006	0.009	0.000	0.0030		
0.021	0.023	0.007	0.005	0.000	0.003	0.000	0.008	0.018	0.015	0.0100		
4.052	3.983	3.873	4.086	3.928	4.059	4.082	4.084	4.016	4.021	4.0180		
16.545	16.458	16.357	16.634	16.552	16.551	16.591	16.560	16.486	16.476	16.5210		

Sample 87-73-3 Garnet compositions														Sample 87-145-2 Garnet compositions			
	73-3.1B	73-3.124	73-3.125	73-3.1C	73-3.2A	73-3.126	73-3.127	73-3.2B	average		145-2.1A	145-2.1B	145-2.1C	average			
SiO2	36.99	37.54	37.38	37.43	37.01	37.39	37.63	37.61	37.370	SiO2	37.18	37.85	37.93	37.650	SiO2		
Al2O3	21.01	21.31	20.90	20.65	21.43	21.24	21.05	21.02	21.070	Al2O3	20.64	21.24	21.16	21.010	Al2O3		
CaO	4.52	6.39	7.85	7.82	5.42	6.92	6.88	5.13	6.370	CaO	9.73	9.85	9.99	9.850	CaO		
TiO2	0.07	0.10	0.17	0.30	0.01	0.16	0.10	0.03	0.120	TiO2	0.18	0.11	0.12	0.140	TiO2		
MgO	1.97	1.44	0.55	0.51	1.95	1.36	1.11	2.18	1.380	MgO	1.36	1.63	1.69	1.560	MgO		
MnO	1.51	3.89	7.53	9.20	1.46	4.50	5.01	1.46	4.320	MnO	3.42	2.22	2.97	2.870	MnO		
FeO	34.86	31.01	26.34	25.07	33.74	30.17	29.75	34.21	30.640	FeO	27.15	28.23	27.77	27.720	FeO		
TOTAL	100.93	101.68	100.72	100.98	101.02	101.74	101.53	101.64	101.270	TOTAL	99.66	101.13	101.63	100.800	TOTAL		
24 oxygens										24 oxygens					24 oxygens		
Si	5.940	5.961	5.996	6.001	5.918	5.940	5.989	5.977	5.9650	Si	5.982	5.981	5.972	5.9780	Si		
Al	0.060	0.039	0.004	0.000	0.082	0.060	0.011	0.023	0.0350	Al	0.018	0.019	0.028	0.0220	Al		
	6	6	6	6.001	6	6	6	6	6		6	6	6	6			
Al	3.917	3.950	3.948	3.901	3.956	3.917	3.938	3.914	3.9300	Al	3.895	3.937	3.900	3.9110	Al		
Ca	0.083	0.050	0.052	0.099	0.044	0.083	0.062	0.086	0.0700	Ca	0.105	0.063	0.100	0.0890	Ca		
Ti	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	Ti	0.000	0.000	0.000	0.0000	Ti		
	4	4	4	4	4	4	4	4	4		4	4	4	4			
Ca	0.694	1.037	1.297	1.245	0.884	1.095	1.112	0.788	1.0190	Ca	1.573	1.604	1.585	1.5870	Ca		
Ti	0.009	0.012	0.021	0.036	0.002	0.020	0.012	0.004	0.0140	Ti	0.022	0.013	0.014	0.0160	Ti		
Mg	0.472	0.340	0.132	0.122	0.465	0.322	0.264	0.515	0.3290	Mg	0.327	0.383	0.396	0.3690	Mg		
Mn	0.205	0.524	1.024	1.249	0.197	0.606	0.676	0.197	0.5840	Mn	0.466	0.297	0.397	0.3860	Mn		
Fe	4.682	4.119	3.534	3.361	4.512	4.009	3.960	4.546	4.0910	Fe	3.652	3.731	3.657	3.6300	Fe		
	6.062	6.032	6.008	6.013	6.060	6.052	6.024	6.050	6.0370		6.040	6.028	6.049	6.0380			

Sample 88-84-3		Pyroxene compositions				
		84-3.1B	84-3.1D	84-3.2J	84-3.2L	average
SiO2		53.56	53.76	53.36	53.32	53.500
Al2O3		1.29	0.79	1.07	1.23	1.095
TiO2		0.18	0.21	0.14	0.21	0.185
FeO		6.91	6.63	6.91	7.14	6.898
MgO		13.91	14.50	14.34	13.99	14.185
MnO		0.35	0.38	0.37	0.40	0.375
Cr2O3		0.55	0.55	0.46	0.44	0.500
CaO		23.38	23.74	23.43	23.47	23.505
Na2O		0.68	0.30	0.59	0.30	0.468
TOTAL		100.81	100.86	100.67	100.50	100.710
32 oxygens						
Si		1.973	1.978	1.970	1.972	1.9733
Al		0.027	0.022	0.030	0.028	0.0268
		2	2	2	2	2
Al		0.029	0.012	0.017	0.026	0.0210
Ti		0.005	0.006	0.004	0.006	0.0053
Fe		0.213	0.204	0.213	0.221	0.2128
Mg		0.764	0.795	0.789	0.771	0.7798
Mn		0.011	0.012	0.012	0.013	0.0120
Cr		0.016	0.016	0.013	0.013	0.0145
		1.038	1.045	1.048	1.050	1.0453
Ca		0.923	0.936	0.927	0.930	0.9290
Na		0.049	0.021	0.043	0.021	0.0335
		0.972	0.957	0.970	0.951	0.9625

APPENDIX 7 **ELECTRON MICROPROBE ANALYSES OF MINERALS** **FROM GARNET-BEARING SAMPLES** **OF THE SCOTIA-QUAAL METAMORPHIC BELT**

This appendix gives the compositions of minerals used for geothermobarometry. Refer to Chapter 2, Section 4 for petrographic discussion of samples, to Appendix 1B for sample locations and to Appendix 2 for UTM coordinates. Analyses are presented in this appendix in the order in which they are discussed in Section 2-4. The analytical procedure for electron microprobe analysis is presented in Appendix 5.

Sample number	Mineral analysed and purpose of analysis				Figure to which analysis refers
Sample 88-104-1	Garnet compositions used for geothermobarometry				Figure 2-17
	Gn 31/56 (Hb matrix)	GN.30 (HB.18&19)	GN.18 (HB.13)	GN.29 (HB.17)	
SiO ₂	37.805	37.56	39.22	37.45	
Al ₂ O ₃	21.080	21.16	20.91	20.98	
TiO ₂	0.070	0.06	0	0	
MgO	4.223	3.66	4.39	3.98	
FeO	25.121	25.83	25.39	25.23	
MnO	2.972	2.88	2.24	2.89	
CaO	8.070	7.97	7.88	8.04	
	99.340	99.14	100.03	98.57	
24 oxygens					
SI	5.9909	5.982	6.132		Analysis number
AL	0.0122	0.018			
	6.0031	6			
AL					
TI	3.9250				Associated minerals for geothermobarometry

Sample 89-137-2 Garnet traverse Figure 2-12

	GN.80	GN.81	GN.82	GN.83	GN.84	GN.85	GN.86	GN.87	GN.88	GN.89	GN.90	GN.91	GN.92
SiO ₂	37.07	37.02	37.05	37.11	36.94	36.86	36.86	36.8	36.86	37.4	37.06	36.99	37.1
Al ₂ O ₃	21.11	21.08	20.65	20.78	20.9	20.91	20.9	21.13	20.91	20.86	21.02	20.67	20.87
TiO ₂	0.06	0	0.15	0.13	0.07	0.03	0.03	0.04	0	0.08	0.09	0.08	0.05
MgO	2.9	3.05	2.85	3.05	3.11	3.05	2.94	2.93	2.83	2.98	2.78	2.63	2.56
FeO	27.49	26.82	26.33	27.14	26.85	26.79	27.09	27.77	27.76	27.59	27.07	26.47	26.3
MnO	2.42	2.75	3.51	3.82	3.8	3.72	4.78	4.08	4	4.23	5.37	5.44	5.65
CaO	8.48	8.4	8.55	7.74	7.88	7.78	6.59	6.54	6.7	6.56	6.56	7.35	7.15
TOTAL	99.53	99.12	99.09	99.77	99.55	99.14	99.19	99.29	99.06	99.7	99.95	99.63	99.68
24 Oxygens													
Si	5.931	5.938	5.959	5.94	5.922	5.931	5.943	5.924	5.95	5.987	5.939	5.951	5.958
Al	0.069	0.062	0.041	0.06	0.078	0.069	0.057	0.076	0.05	0.013	0.061	0.049	0.042
	6	6	6	6	6	6	6	6	6	6	6	6	6
Al	3.912	3.923	3.873	3.861	3.871	3.897	3.915	3.934	3.929	3.922	3.908	3.87	3.91
Ti	0.008	0.001	0.018	0.016	0.009	0.004	0.003	0.005	0	0.01	0.01	0.01	0.006
	3.92	3.924	3.891	3.877	3.88	3.901	3.918	3.939	3.929	3.932	3.918	3.88	3.916
Mg	0.692	0.73	0.683	0.728	0.744	0.73	0.705	0.703	0.68	0.712	0.663	0.63	0.613
Fe	3.678	3.598	3.542	3.634	3.6	3.605	3.653	3.739	3.747	3.693	3.628	3.561	3.532
Mn	0.328	0.373	0.478	0.518	0.515	0.507	0.652	0.556	0.547	0.574	0.728	0.742	0.768
Ca	1.454	1.443	1.473	1.328	1.354	1.342	1.138	1.129	1.159	1.124	1.127	1.267	1.23
	6.152	6.144	6.176	6.208	6.213	6.184	6.148	6.127	6.133	6.103	6.146	6.2	6.143
XCu	0.2363	0.2349	0.2385	0.2139	0.2179	0.2170	0.1851	0.1843	0.1890	0.1842	0.1834	0.2044	0.2002
XCu+XMn	0.2897	0.2956	0.3159	0.2974	0.3008	0.2990	0.2912	0.2750	0.2782	0.2782	0.3018	0.3240	0.3252
Fe/Mg	5.3150	4.9288	5.1859	4.9918	4.8387	4.9384	5.1816	5.3186	5.5103	5.1868	5.4721	5.6524	5.7618
Mg/Mg+Fe	0.1584	0.1687	0.1617	0.1669	0.1713	0.1684	0.1618	0.1583	0.1536	0.1616	0.1545	0.1503	0.1479

Sample 89-137-2		Garnet traverse (end)										Figure 2-12	
		GN.93	GN.94	GN.95	GN.96	GN.97	GN.98	GN.99	GN.100	GN.101	GN.102	GN.103	
SiO ₂		36.89	37.09	37.28	36.72	37.03	37.08	37.01	37.18	37.37	36.93	37.21	
Al ₂ O ₃		20.8	20.74	21.02	20.79	20.71	20.76	20.75	20.99	20.83	21.23	20.76	
TiO ₂		0	0	0.09	0.07	0.02	0.01	0.09	0.03	0	0	0	
MgO		2.91	2.97	3.08	3.22	2.83	3	2.9	2.73	2.32	2.31	1.95	
FeO		26.67	27.21	27.03	27.09	27.14	27.13	27.32	27.48	27.24	28.08	28.17	
MnO		4.51	4.69	3.86	3.68	3.46	3.13	2.82	2.55	2.7	3.08	3.02	
CaO		7.29	6.42	7.4	7.9	8.03	8.02	8.39	8.34	8.88	7.97	8.28	
TOTAL		99.07	99.12	99.76	99.47	99.22	99.13	99.28	99.3	99.34	99.6	99.39	
24 Oxygens													
Si		5.949	5.978	5.954	5.902	5.958	5.961	5.946	5.961	5.995	5.929	5.992	
Al		0.051	0.022	0.046	0.098	0.042	0.039	0.054	0.039	0.005	0.071	0.008	
		6	6	6	6	6	6	6	6	6	6	6	
Al		3.902	3.919	3.912	3.84	3.885	3.895	3.875	3.927	3.934	3.947	3.934	
Ti		0	0.001	0.011	0.008	0.003	0.001	0.011	0.004	0	0	0	
		3.902	3.92	3.923	3.848	3.888	3.896	3.886	3.932	3.934	3.947	3.934	
Mg		0.7	0.714	0.733	0.771	0.68	0.72	0.694	0.654	0.556	0.554	0.467	
Fe		3.597	3.669	3.611	3.641	3.653	3.648	3.671	3.686	3.655	3.771	3.795	
Mn		0.616	0.641	0.522	0.501	0.471	0.426	0.384	0.347	0.367	0.419	0.412	
Ca		1.26	1.108	1.266	1.36	1.385	1.381	1.444	1.433	1.526	1.371	1.429	
		6.173	6.132	6.132	6.273	6.189	6.175	6.193	6.12	6.104	6.115	6.103	
XCa		0.2041	0.1807	0.2065	0.2168	0.2238	0.2236	0.2332	0.2342	0.2500	0.2242	0.2341	
XCa+XMn		0.3039	0.2852	0.2916	0.2967	0.2999	0.2926	0.2952	0.2908	0.3101	0.2927	0.3017	
FE/MG		5.1386	5.1387	4.9263	4.7224	5.3721	5.0667	5.2896	5.6361	6.5737	6.8069	8.1263	
MG/MG+FE		0.1629	0.1629	0.1687	0.1748	0.1569	0.1648	0.1590	0.1507	0.1320	0.1281	0.1096	

Sample 89-137-2	Garnet rim compositions used for geothermobarometry					Figure 2-13
	GN4 (Bt & Hb matrix)	GN5 (Bt & Hb matrix)	GN6 (Bt & Hb matrix)	GN105/207 (BIO 2&3)	GN109/111 (BIO 16/18)	GN114/117 (HBD 8/10)
SiO2	37.25	37.88	37.67	37.11	37.11	37.15
Al2O3	21.34	21.45	21.63	20.97	21.11	21.14
TiO2	0.00	0.01	0.00	0.02	0.03	0.03
MgO	2.36	2.79	2.76	3.03	2.38	2.34
FeO	28.15	27.29	27.66	27.60	27.74	27.63
MnO	3.19	2.54	2.51	2.58	2.77	2.86
CaO	8.30	8.62	8.59	8.43	8.56	8.64
TOTAL	100.59	100.58	100.82	99.74	99.69	99.77
24 oxygens						
Si	5.925	5.979	5.942	5.9317	5.9437	5.9450
Al	0.075	0.021	0.058	0.0683	0.0563	0.0550
	6	6	6	6	6.0000	6
Al	3.925	3.970	3.964	3.8820	3.9283	3.9325
Ti	0.000	0.001	0.000	0.0023	0.0033	0.0033
	3.925	3.971	3.964	3.8843	3.9317	3.9358
Mg	0.561	0.656	0.648	0.7223	0.5693	0.5570
Fe	3.745	3.602	3.649	3.6897	3.7157	3.6973
Mn	0.430	0.340	0.335	0.3500	0.3760	0.3873
Ca	1.414	1.457	1.451	1.4443	1.4683	1.4810
	6.150	6.055	6.083	6.2063	6.1293	6.1225
XCa	0.2299	0.2406	0.2385	0.23272	0.23956	0.24189
XCa+Mn	0.2998	0.2968	0.2936	0.28911	0.30091	0.30514
FE/MG	6.6756	5.4909	5.6312	5.11303	6.53490	6.64713
MG/MG+FE	0.1303	0.1541	0.1508	0.16371	0.13285	0.13096

Sample 89-137-2											
Garnet rim compositions											
	GN1	GN2	GN3	GN4	GN5	GN6	GN7	GN8	GN9	average	
SiO2	37.51	37.69	37.64	37.25	37.88	37.67	37.46	37.61	37.60	37.590	
Al2O3	21.54	21.44	21.70	21.34	21.45	21.63	21.54	21.41	21.35	21.489	
TiO2	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.001	
MgO	2.62	2.43	2.71	2.36	2.79	2.76	2.77	3.00	2.93	2.708	
FeO	27.78	27.66	27.58	28.15	27.29	27.66	27.59	27.30	27.45	27.607	
MnO	2.97	3.07	3.01	3.19	2.54	2.51	2.60	2.67	2.69	2.806	
CaO	8.63	8.18	8.66	8.30	8.62	8.59	8.72	8.47	8.34	8.501	
TOTAL	101.05	100.47	101.30	100.59	100.58	100.82	100.68	100.46	100.36	100.701	
24 oxygens											
Si	5.922	5.974	5.921	5.925	5.979	5.942	5.925	5.949	5.956	5.9437	
Al	0.078	0.026	0.079	0.075	0.021	0.058	0.075	0.051	0.044	0.0563	
	6	6	6	6	6	6	6	6	6	6	
Al	3.931	3.979	3.944	3.925	3.970	3.964	3.940	3.942	3.943	3.9487	
Ti	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.0001	
	3.931	3.979	3.944	3.925	3.971	3.964	3.940	3.942	3.943	3.9488	
Mg	0.616	0.575	0.635	0.561	0.656	0.648	0.653	0.708	0.693	0.6383	
Fe	3.668	3.666	3.628	3.745	3.602	3.649	3.649	3.612	3.637	3.6507	
Mn	0.398	0.412	0.401	0.430	0.340	0.335	0.348	0.358	0.361	0.3759	
Ca	1.461	1.390	1.460	1.414	1.457	1.451	1.477	1.435	1.416	1.4401	
	6.143	6.043	6.124	6.150	6.055	6.083	6.127	6.113	6.107	6.1050	
XCa	0.253	0.2300	0.2384	0.2299	0.2406	0.2385	0.2411	0.2347	0.2319	0.23589	
XCa+Mn	0.3026	0.2982	0.3039	0.2998	0.2968	0.2936	0.2979	0.2933	0.2910	0.29745	
FE/MG	5.9545	6.3757	5.7134	6.6756	5.4909	5.6312	5.5881	5.1017	5.2482	5.75324	
MG/MG+FE	0.1438	0.1356	0.1490	0.1303	0.1541	0.1508	0.1518	0.1639	0.1600	0.14880	

Sample 89-137-2		Biotite compositions for geothermobarometry							Figure 2-13
		BIO.13	BIO.14	BIO.15	BIO.22	BIO.23	BIO.24	BIO.25	BIO.26
SiO ₂		36.31	37.00	36.57	36.16	35.37	35.84	35.95	35.85
Al ₂ O ₃		19.02	19.59	19.10	18.46	18.20	18.65	18.41	18.38
TiO ₂		2.53	2.02	2.57	2.58	2.57	2.46	2.44	2.44
Cr ₂ O ₃		0.00	0.02	0.03	0.07	0.02	0.01	0.01	0.00
FeO		17.89	17.66	18.06	18.00	17.33	17.65	17.16	17.29
MnO		0.00	0.03	0.00	0.09	0.05	0.11	0.03	0.04
MgO		10.58	10.98	10.80	10.85	10.62	10.90	10.93	10.91
CaO		0.00	0.05	0.04	0.04	0.07	0.03	0.06	0.02
K ₂ O		9.24	9.34	9.21	9.16	9.03	9.14	9.23	9.38
Na ₂ O		0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00
TOTAL		95.57	96.69	96.49	95.41	93.26	94.79	94.22	94.31
22 oxygens									
Si		5.447	5.468	5.435	5.444	5.440	5.426	5.464	5.453
Al		2.553	2.532	2.565	2.556	2.560	2.574	2.536	2.547
		8	8	8	8	8	8	8	8
Al		0.809	0.881	0.781	0.720	0.740	0.754	0.763	0.749
Ti		0.285	0.224	0.287	0.292	0.297	0.280	0.278	0.279
Cr		0.000	0.002	0.003	0.008	0.003	0.001	0.001	0.001
Fe		2.244	2.183	2.244	2.267	2.230	2.235	2.181	2.199
Mn		0.000	0.003	0.000	0.012	0.007	0.014	0.004	0.005
Mg		2.365	2.419	2.393	2.435	2.436	2.459	2.476	2.475
		5.703	5.712	5.708	5.734	5.713	5.743	5.703	5.708
Ca		0.000	0.008	0.006	0.007	0.011	0.004	0.010	0.002
K		1.768	1.761	1.747	1.760	1.773	1.765	1.790	1.819
Na		0.000	0.000	0.031	0.000	0.000	0.000	0.000	0.000
		1.768	1.769	1.784	1.767	1.784	1.769	1.800	1.821
X _{Al}		0.1419	0.1542	0.1368	0.1256	0.1295	0.1313	0.1338	0.1312
X _{Ti}		0.0500	0.0392	0.0503	0.0509	0.0520	0.0488	0.0487	0.0489
Fe/Mg		0.9488	0.9024	0.9377	0.9310	0.9154	0.9089	0.8809	0.8885
Mg/Mg+Fe		0.5131	0.5256	0.5161	0.5179	0.5221	0.5239	0.5317	0.5295

Sample 89-137-2		Biotite compositions (continued)				
	BIO.27	BIO.28	average	BIO.2	BIO.3	average
SiO ₂	36.37	36.18	36.160	36.00	35.48	35.740
Al ₂ O ₃	18.87	19.21	18.789	19.47	18.76	19.115
TiO ₂	2.07	2.28	2.396	2.71	2.55	2.630
Cr ₂ O ₃	0.00	0.01	0.017	0.07	0.04	0.055
FeO	17.40	17.47	17.591	16.84	17.12	16.980
MnO	0.03	0.03	0.041	0.11	0.09	0.100
MgO	11.08	11.02	10.867	10.10	10.34	10.220
CaO	0.04	0.18	0.053	0.04	0.02	0.030
K ₂ O	9.20	9.01	9.194	9.13	9.13	9.130
Na ₂ O	0.00	0.00	0.011	0.00	0.00	0.000
TOTAL	95.06	95.39	95.119	94.47	93.53	94.000
22 oxygens						
Si	5.472	5.423	5.4472	5.436	5.433	5.4345
Al	2.528	2.577	2.5528	2.564	2.567	2.5655
	8	8	8	8	8	8
Al	0.817	0.817	0.7831	0.902	0.819	0.8605
Ti	0.234	0.257	0.2713	0.308	0.294	0.3010
Cr	0.000	0.001	0.0020	0.008	0.005	0.0065
Fe	2.190	2.190	2.2163	2.127	2.193	2.1600
Mn	0.004	0.004	0.0053	0.014	0.011	0.0125
Mg	2.485	2.463	2.4406	2.274	2.361	2.3175
	5.730	5.732	5.7186	5.633	5.683	5.6580
Ca	0.007	0.029	0.0084	0.006	0.003	0.0045
K	1.766	1.723	1.7672	1.759	1.783	1.7710
Na	0.000	0.000	0.0031	0.000	0.000	0.0000
	1.773	1.752	1.7787	1.765	1.786	1.7755
X _{Al}	0.1426	0.1425	0.13694	0.1601	0.1441	0.15210
X _{Ti}	0.0408	0.0448	0.04744	0.0547	0.0517	0.05320
Fe/Mg	0.8813	0.8892	0.90841	0.9354	0.9288	0.93210
Mg/Mg+Fe	0.5316	0.5293	0.52408	0.5167	0.5184	0.51755

Sample 89-137-2		Biotite compositions (end)			
		BIO.16	BIO.17	BIO.18	average
SIO2		36.47	35.97	36.05	36.163
AL2O3		19.08	18.78	19.01	18.957
TIO2		1.93	1.93	1.95	1.937
CR2O3		0.02	0.00	0.00	0.007
FEO		17.58	17.67	17.52	17.590
MNO		0.02	0.00	0.06	0.027
MGO		11.10	10.97	10.98	11.017
CAO		0.00	0.05	0.07	0.040
K2O		9.14	9.04	8.99	9.057
NA2O		0.00	0.08	0.00	0.027
TOTAL		95.34	94.49	94.63	94.820
22 oxygens					
SI		5.470	5.455	5.450	5.4583
AL		2.530	2.545	2.550	2.5417
		8	8	8	8
AL		0.843	0.811	0.838	0.8307
TI		0.217	0.220	0.221	0.2193
CR		0.002	0.000	0.000	0.0007
FE		2.205	2.241	2.216	2.2207
MN		0.003	0.000	0.008	0.0037
MG		2.481	2.480	2.474	2.4783
		5.751	5.752	5.757	5.7533
CA		0.001	0.008	0.011	0.0070
K		1.749	1.749	1.734	1.7440
NA		0.000	0.023	0.000	0.0080
		1.750	1.780	1.745	1.7580
XAI		0.1466	0.1410	0.1456	0.14440
XTi		0.0377	0.0382	0.0384	0.03810
FE/MG		0.8888	0.9036	0.8957	0.89600
MG/MG+FE		0.5294	0.5253	0.5275	0.52740

Sample 89-137-2		Hornblende compositions for geothermobarometry							Figure 2-13
		HB.1	HB.3	HB.4	HB.5	HB.6	HB.7	HB.14	HB.15
SIO2		42.36	41.54	41.72	41.83	42.20	42.31	42.02	42.65
AL2O3		16.36	16.77	15.62	16.62	16.23	16.58	15.16	14.89
TIO2		0.48	0.58	0.60	0.68	0.58	0.62	0.63	0.72
FEO		16.94	16.74	16.65	16.64	17.01	16.57	16.85	16.45
MNO		0.15	0.00	0.07	0.10	0.13	0.09	0.04	0.04
CR2O3		0.07	0.00	0.00	0.00	0.08	0.00	0.00	0.00
V2O3		0.08	0.02	0.05	0.16	0.16	0.15	0.15	0.20
MGO		8.57	8.00	8.39	7.85	8.08	8.00	8.50	8.76
CAO		11.82	11.63	11.78	11.66	11.73	11.64	11.81	11.61
K2O		0.75	0.75	0.84	0.92	0.92	0.78	0.75	0.74
NA2O		1.34	1.24	1.16	1.12	1.20	1.32	1.00	1.08
TOTAL		98.92	97.27	96.88	97.58	98.32	98.06	96.91	97.14
23 oxygens									
SI		6.243	6.216	6.280	6.242	6.263	6.272	6.323	6.379
ALIV		1.757	1.784	1.720	1.758	1.737	1.728	1.677	1.621
		8	8	8	8	8	8	8	8
ALVI		1.085	1.174	1.052	1.165	1.103	1.170	1.011	1.005
TI		0.053	0.066	0.068	0.077	0.065	0.069	0.072	0.081
FE		2.088	2.095	2.096	2.076	2.111	2.055	2.120	2.058
MN		0.019	0.000	0.008	0.013	0.017	0.012	0.005	0.005
CR		0.008	0.000	0.000	0.000	0.009	0.000	0.000	0.000
V		0.010	0.002	0.006	0.019	0.019	0.018	0.018	0.024
MG		1.882	1.784	1.882	1.746	1.787	1.767	1.906	1.953
		5.145	5.121	5.112	5.096	5.111	5.091	5.132	5.126
CA		1.867	1.865	1.901	1.864	1.866	1.848	1.904	1.861
K		0.142	0.144	0.160	0.175	0.174	0.147	0.144	0.141
NA		0.383	0.361	0.338	0.325	0.347	0.378	0.293	0.312
		2.392	2.370	2.399	2.364	2.387	2.373	2.341	2.314
FE/MG		1.1095	1.1743	1.1137	1.1890	1.1813	1.1630	1.1123	1.0538
MG/MG+FE		0.4741	0.4599	0.4731	0.4568	0.4584	0.4623	0.4734	0.4869

Sample 89-137-2		Hornblende compositions (continued)			Figure 2-13		
	HB.16	HB.17	average	HB.8	HB.9	HB.10	average
SIO ₂	42.32	42.61	42.156	40.54	41.39	40.47	40.80
AL ₂ O ₃	15.90	15.30	15.943	17.84	17.56	16.32	17.24
TIO ₂	0.65	0.74	0.628	0.55	0.71	0.59	0.62
FE ₂ O ₃	16.67	16.48	16.700	16.78	16.96	16.70	16.81
MNO	0.06	0.11	0.079	0.04	0.12	0.03	0.06
CR ₂ O ₃	0.00	0.00	0.015	0.00	0.01	0.00	0.00
V ₂ O ₃	0.07	0.12	0.116	0.16	0.26	0.09	0.17
MGO	8.47	8.65	8.327	7.13	7.69	7.68	7.50
CAO	11.64	11.53	11.685	11.56	11.74	11.36	11.55
K ₂ O	0.89	0.88	0.822	0.64	0.81	0.70	0.72
NA ₂ O	1.47	1.34	1.227	1.33	1.05	1.01	1.13
TOTAL	98.14	97.76	97.698	96.57	98.30	94.95	96.61
23 oxygens							
SI	6.284	6.342	6.2844	6.117	6.139	5.212	6.16
ALIV	1.716	1.658	1.7156	1.883	1.861	1.788	1.84
	8	8	8	8	8	8	8.00
ALVI	1.068	1.027	1.0860	1.290	1.209	1.166	1.22
TI	0.072	0.083	0.0706	0.062	0.079	0.069	0.07
FE	2.070	2.052	2.0821	2.118	2.103	2.144	2.12
MN	0.007	0.014	0.0100	0.005	0.014	0.005	0.01
CR	0.000	0.000	0.0017	0.000	0.002	0.000	0.00
V	0.008	0.014	0.0138	0.020	0.031	0.010	0.02
MG	1.875	1.919	1.8501	1.605	1.700	1.757	1.69
	5.100	5.109	5.1143	5.100	5.138	5.151	5.13
CA	1.852	1.839	1.8667	1.869	1.866	1.868	1.87
K	0.168	0.167	0.1562	0.123	0.153	0.136	0.14
NA	0.422	0.387	0.3546	0.388	0.302	0.301	0.33
	2.442	2.393	2.3775	2.380	2.321	2.305	2.34
FE/MG	1.1040	1.0693	1.12701	1.3196	1.2371	1.2203	1.26
MG/MG+FE	0.4753	0.4833	0.47035	0.4311	0.4470	0.4504	0.44

Sample 89-137-2		Plagioclase compositions for geothermobarometry						Figure 2-13
		PL.1	PL.2	PL.3	PL.4	PL.5	PL.6	average
SiO ₂		44.98	45.47	45.19	44.86	44.6	47.55	45.44
Al ₂ O ₃		35.93	35.61	35.69	35.9	35.65	38.02	36.14
CaO		19.04	18.41	18.84	18.93	18.93	20.54	19.11
Na ₂ O		0.52	1.3	0.74	0.35	0.8	1.07	0.8
K ₂ O		0	0.06	0	0.02	0.02	0.08	0.03
FeO		0.2	0.09	0.25	0.17	0.11	0.63	0.24
TOTAL		100.67	100.94	100.71	100.23	100.11	107.89	101.76
16 oxygens								
Si		4.123	4.157	4.141	4.125	4.116	4.092	4.125
Al		3.882	3.838	3.855	3.892	3.877	3.856	3.867
		8.005	7.995	7.996	8.017	7.993	7.948	7.992
Ca		1.87	1.803	1.85	1.866	1.871	1.893	1.859
Na		0.093	0.231	0.132	0.062	0.143	0.178	0.14
K		0	0.007	0	0.002	0.003	0.009	0.004
		1.963	2.041	1.982	1.93	2.017	2.08	2.003
Fe		0.015	0.007	0.019	0.013	0.008	0.045	0.018
An		0.95	0.88	0.93	0.97	0.93	0.91	0.93

Sample 88-54-1		Garnet traverse										Figure 2-14			
		GN.1	GN.2	GN.3	GN.4	GN.5	GN.6	GN.7	GN.8	GN.9	GN.10	GN.11	GN.12	GN.13	
SIO2 AL2O3 TiO2 MGO FEO MNO CAO TOTAL		38.02	37.69	38	38.02	38.13	38.08	37.91	38.09	37.82	37.63	38.26	37.93	37.53	
		21.49	21.6	21.53	21.54	21.49	21.24	21.1	21.75	21.39	21.46	21.51	21.4	21.33	
		0.01	0.04	0.1	0.07	0.09	0.12	0.04	0	0.02	0.02	0.08	0.03	0.03	
		4.03	4.09	3.85	3.89	3.83	4.11	3.92	4.17	3.73	3.89	4.17	3.89	3.77	
		26.32	26.54	26.45	26.64	26.6	26.67	26.57	26.78	26.21	26.57	26.32	26.61	26.57	
		3.31	3.14	3.2	3.11	3.31	3.27	3.37	3.41	3.22	3.26	3.31	3.29	3.3	
		7.33	7.33	7.26	7.45	7.47	7.28	7.1	7.09	7.24	7.24	7.2	6.97	7.2	
	100.51	100.43	100.39	100.72	100.92	100.77	100.01	101.29	99.63	100.07	100.85	100.12	99.73		
SI AL		5.975	5.934	5.978	5.967	5.975	5.978	5.997	5.947	5.993	5.951	5.985	5.987	5.959	
		0.025	0.066	0.022	0.033	0.025	0.022	0.003	0.053	0.007	0.049	0.015	0.013	0.041	
		6	6	6	6	6	6	6	6	6	6	6	6	6	
AL TI		3.956	3.943	3.97	3.952	3.945	3.908	3.931	3.949	3.988	3.951	3.952	3.969	3.95	
		0.001	0.005	0.012	0.009	0.011	0.014	0.005	0	0.003	0.002	0.009	0.004	0.004	
		3.957	3.948	3.982	3.961	3.956	3.922	3.936	3.949	3.991	3.953	3.961	3.973	3.954	
MG FE MN CA		0.944	0.96	0.902	0.91	0.894	0.961	0.924	0.97	0.882	0.917	0.973	0.914	0.892	
		3.459	3.494	3.48	3.497	3.486	3.502	3.515	3.496	3.473	3.514	3.443	3.513	3.528	
		0.44	0.418	0.426	0.413	0.439	0.435	0.451	0.451	0.433	0.437	0.439	0.44	0.444	
		1.234	1.237	1.224	1.253	1.254	1.224	1.204	1.186	1.229	1.226	1.208	1.178	1.225	
	6.077	6.109	6.032	6.073	6.073	6.122	6.094	6.094	6.103	6.017	6.094	6.063	6.045	6.089	
XCa XCa+XMn		0.2031	0.2025	0.2029	0.2063	0.2065	0.1999	0.1976	0.1943	0.2043	0.2012	0.1992	0.1949	0.2012	
		0.2755	0.2709	0.2735	0.2743	0.2788	0.2710	0.2716	0.2682	0.2762	0.2729	0.2716	0.2677	0.2741	
FE/MG MG/MG+FE		3.6642	3.6396	3.8581	3.8429	3.8993	3.6441	3.8041	3.6041	3.9376	3.8321	3.5385	3.8435	3.9552	
		0.2144	0.2155	0.2058	0.2065	0.2041	0.2153	0.2082	0.2172	0.2025	0.2070	0.2203	0.2065	0.2018	

Sample 88-54-1	Garnet traverse (end)												Figure 2-14
	GN.14	GN.15	GN.16	GN.17	GN.18	GN.19	GN.20	GN.21	GN.22	GN.23	GN.24		
SiO2	37.29	38.03	37.9	37.68	37.63	37.77	37.64	38.05	37.46	37.75	38.13		
Al2O3	21.02	21.19	21.27	21.53	21.57	21.32	21.25	21.36	21.27	21.48	21.55		
TiO2	0.06	0.11	0.07	0.06	0.08	0.07	0.04	0.02	0.07	0	0		
MgO	4.11	4.26	3.94	3.7	4.02	3.86	3.94	3.77	3.53	3.52	3.62		
FeO	26.23	26.58	26.6	26.5	26.73	26.38	26.16	26.33	26.38	26.6	26.55		
MnO	3.28	3.45	3.29	3.31	3.39	3.14	3.27	3.14	3.69	3.34	3.45		
CaO	7.17	7.19	7.18	7.15	7.37	7.36	7.44	7.25	7.28	7.32	7.19		
TOTAL	99.16	100.81	100.25	99.93	100.79	99.9	99.74	99.92	99.68	100.01	100.49		
Si	5.953	5.969	5.98	5.963	5.917	5.975	5.967	6.009	5.959	5.975	5.997		
Al	0.047	0.031	0.02	0.037	0.083	0.025	0.033	0	0.041	0.025	0.003		
	6	6	6	6	6	6	6	6.009	6	6	6		
Al	3.908	3.889	3.936	3.979	3.914	3.951	3.937	3.975	3.947	3.981	3.993		
Ti	0.007	0.013	0.008	0.007	0.01	0.009	0.005	0.002	0.008	0	0		
	3.915	3.902	3.944	3.986	3.924	3.96	3.942	3.977	3.955	3.981	3.993		
Mg	0.979	0.997	0.926	0.873	0.943	0.91	0.931	0.889	0.837	0.831	0.848		
Fe	3.501	3.489	3.511	3.507	3.516	3.49	3.468	3.477	3.509	3.521	3.493		
Mn	0.443	0.459	0.44	0.443	0.451	0.421	0.44	0.421	0.498	0.447	0.46		
Ca	1.226	1.21	1.213	1.213	1.242	1.247	1.263	1.227	1.241	1.241	1.211		
	6.149	6.155	6.09	6.036	6.152	6.068	6.102	6.014	6.085	6.04	6.012		
XCa	0.1994	0.1966	0.1992	0.2010	0.2019	0.2055	0.2070	0.2040	0.2039	0.2055	0.2014		
XCa+XMn	0.2714	0.2712	0.2714	0.2744	0.2752	0.2749	0.2791	0.2740	0.2858	0.2795	0.2779		
Fe/Mg	3.5761	3.4995	3.7916	4.0172	3.7285	3.8352	3.7250	3.9111	4.1924	4.2371	4.1191		
Mg/MG+FE	0.2185	0.2222	0.2087	0.1993	0.2115	0.2068	0.2116	0.2036	0.1926	0.1909	0.1953		

Sample 88-54-1

Garnet rim compositions used for geothermobarometry

Figure 2-15

	GA.10 (HB.25)	GA.11 (HB.26)	GA.13 (HB.28)	GA.14 (HB.30)	GA.15 (HB.31)	Average rim (N=3) (Av. Hb matrix)	GN.24 (Av. Hb matrix)
SiO2	37.42	37.77	37.34	37.49	37.32	37.733	38.13
Al2O3	21.58	21.6	21.21	21.47	21.02	21.483	21.55
TiO2	0.04	0.01	0.08	0.03	0.08	0.095	0
MgO	3.86	3.99	3.62	3.95	3.97	3.790	3.62
FeO	26.38	26.24	26.58	26.32	25.65	26.460	26.55
MnO	3.05	3.1	3.19	3.28	3.22	3.328	3.45
CaO	7.2	7.26	7.27	6.84	7.45	7.385	7.19
TOTAL	99.53	99.97	99.29	99.38	98.71	100.273	100.49
24 oxygens							
Si	5.941	5.961	5.958	5.959	5.971	5.9538	5.997
Al	0.059	0.039	0.042	0.041	0.029	0.0463	0.003
	6	6	6	6	6	6	6
Al	3.979	3.98	3.947	3.981	3.935	3.9495	3.993
Ti	0.004	0.002	0.01	0.003	0.01	0.0118	0
	3.983	3.982	3.957	3.984	3.945	3.9613	3.993
Mg	0.914	0.94	0.86	0.937	0.947	0.8910	0.848
Fe	3.502	3.463	3.547	3.499	3.432	3.4918	3.493
Mn	0.41	0.414	0.431	0.442	0.437	0.4448	0.46
Ca	1.226	1.228	1.243	1.165	1.278	1.2488	1.211
	6.052	6.045	6.081	6.043	6.094	6.0763	6.012
XCa	0.2026	0.2031	0.2044	0.1928	0.2097	0.20551	0.2014
XCa+XMn	0.2703	0.2716	0.2753	0.2659	0.2814	0.27870	0.2779
Fe/Mg	3.8315	3.6840	4.1244	3.7343	3.6241	3.93867	4.1191
Mg/Mg+Fe	0.2070	0.2135	0.1951	0.2112	0.2163	0.20314	0.1953

Sample 88-54-1		Hornblende compositions for geothermobarometry							Figure 2-15
		HB.20	HB.21	HB.22	HB.23	HB.24	HB.33	HB.34	HB.35
SiO ₂		42.14	42.03	41.46	42.33	41.91	42.28	42.28	42.92
Al ₂ O ₃		16.21	16.12	16.61	15.96	15.76	16.36	15.60	14.99
TiO ₂		0.48	0.53	0.68	0.70	0.78	0.60	0.68	0.60
FeO		16.66	17.56	16.32	16.04	16.05	15.92	15.84	15.77
MnO		0.18	0.19	0.20	0.20	0.17	0.19	0.17	0.20
Cr ₂ O ₃		0.00	0.00	0.06	0.01	0.01	0.00	0.00	0.00
MgO		8.47	8.13	8.66	9.15	8.94	9.02	9.14	9.59
CaO		11.89	11.93	11.62	11.79	11.84	11.78	11.83	11.91
K ₂ O		0.42	0.50	0.59	0.55	0.60	0.52	0.51	0.47
Na ₂ O		0.83	1.57	1.31	1.17	0.96	1.38	1.30	1.30
TOTAL		97.28	98.56	97.51	97.90	97.02	98.05	97.35	97.75
23 oxygens									
SI		6.286	6.239	6.185	6.270	6.269	6.250	6.296	6.360
ALIV		1.714	1.761	1.815	1.730	1.731	1.750	1.704	1.640
		8	8	8	8	8	8	8	8
ALVI		1.136	1.059	1.106	1.056	1.048	1.101	1.035	0.978
TI		0.054	0.060	0.076	0.078	0.087	0.067	0.076	0.066
FE		2.079	2.179	2.036	1.987	2.008	1.968	1.973	1.955
MN		0.023	0.023	0.025	0.026	0.021	0.024	0.021	0.025
CR		0.000	0.000	0.007	0.002	0.001	0.000	0.000	0.000
MG		1.882	1.799	1.925	2.020	1.993	1.987	2.030	2.119
		5.174	5.120	5.175	5.169	5.158	5.147	5.135	5.143
CA		1.900	1.898	1.857	1.871	1.897	1.866	1.888	1.891
K		0.080	0.095	0.111	0.104	0.115	0.098	0.098	0.089
NA		0.241	0.452	0.379	0.335	0.280	0.396	0.375	0.374
		2.221	2.445	2.347	2.310	2.292	2.360	2.361	2.354
FE/MG		1.1047	1.2112	1.0577	0.9837	1.0075	0.9904	0.9719	0.9226
MG/MG+FE		0.4751	0.4522	0.4860	0.5041	0.4981	0.5024	0.5071	0.5201

Sample 88-54-1	Hornblende compositions (end)						Figure 2-15
	HB.36	average	HB.25	HB.26	HB.28	HB.30	HB.31
SIO2	42.36	42.190	41.87	42.00	42.19	42.33	42.12
AL2O3	16.01	15.958	17.19	17.20	16.65	15.93	16.17
TIO2	0.76	0.646	0.33	0.55	0.46	0.45	0.43
FEO	16.03	16.243	16.88	17.27	16.49	17.00	17.33
MNO	0.25	0.194	0.17	0.29	0.16	0.29	0.27
CR2O3	0.04	0.013	0.00	0.00	0.00	0.00	0.04
MGO	8.99	8.899	8.35	8.17	8.58	8.66	8.21
CAO	11.86	11.828	11.72	11.95	11.66	11.88	11.70
K2O	0.59	0.528	0.52	0.55	0.50	0.49	0.53
NA2O	1.61	1.270	1.33	1.77	1.59	1.14	1.30
TOTAL	98.50	97.769	98.36	99.75	98.28	98.17	98.10
23 oxygens							
SI	6.251	6.2673	6.192	6.153	6.237	6.280	6.265
ALIV	1.749	1.7327	1.808	1.847	1.763	1.720	1.735
	8	8	8	8	8	8	8
ALVI	1.035	1.0616	1.189	1.124	1.138	1.065	1.100
TI	0.085	0.0721	0.037	0.061	0.051	0.050	0.048
FE	1.978	2.0181	2.088	2.116	2.039	2.109	2.156
MN	0.031	0.0243	0.022	0.036	0.020	0.036	0.034
CR	0.004	0.0016	0.000	0.000	0.000	0.000	0.004
MG	1.977	1.9702	1.841	1.785	1.891	1.916	1.821
	5.110	5.1479	5.177	5.122	5.139	5.176	5.163
CA	1.875	1.8826	1.858	1.876	1.847	1.889	1.865
K	0.111	0.1001	0.098	0.103	0.095	0.093	0.100
NA	0.461	0.3659	0.381	0.503	0.457	0.329	0.376
	2.447	2.3486	2.337	2.482	2.399	2.311	2.341
FE/MG	1.0005	1.0278	1.1342	1.1854	1.0783	1.1007	1.1840
MG/MG+FE	0.4999	0.4939	0.4686	0.4576	0.4812	0.4760	0.4579

Sample 88-54-1		Plagioclase composition for geothermobarometry										Figure 2-15	
	PL.12	PL.1	PL.2	PL.3	PL.4	PL.5	PL.6	PL.7	PL.8	PL.9			
SiO ₂	59.39	58.59	58.36	58.01	58.33	58.63	57.70	58.72	59.03	58.26			
Al ₂ O ₃	26.27	26.85	27.18	27.29	27.14	27.43	27.92	26.78	26.40	27.06			
CaO	7.40	7.96	8.39	8.60	8.15	8.22	8.70	7.92	7.55	8.38			
Na ₂ O	7.61	6.65	6.56	6.51	6.50	6.66	6.40	7.03	7.20	6.66			
K ₂ O	0.23	0.20	0.16	0.24	0.26	0.18	0.17	0.19	0.25	0.19			
FeO	0.07	0.06	0.12	0.21	0.05	0.03	0.10	0.10	0.05	0.06			
TOTAL	100.97	100.31	100.77	100.86	100.43	101.15	100.99	100.74	100.48	100.61			
16 oxygens													
Si	5.257	5.213	5.178	5.153	5.189	5.178	5.115	5.211	5.247	5.179			
Al	2.741	2.816	2.843	2.857	2.845	2.855	2.917	2.801	2.766	2.836			
	7.998	8.029	8.021	8.010	8.034	8.033	8.032	8.012	8.013	8.015			
Ca	0.702	0.759	0.797	0.818	0.776	0.778	0.826	0.754	0.719	0.798			
Na	1.307	1.147	1.129	1.121	1.121	1.141	1.101	1.209	1.240	1.148			
K	0.026	0.023	0.018	0.027	0.029	0.020	0.019	0.022	0.028	0.022			
	2.035	1.929	1.944	1.966	1.926	1.939	1.946	1.985	1.987	1.968			
Fe	0.005	0.005	0.009	0.016	0.003	0.002	0.008	0.007	0.004	0.005			
An	0.34	0.39	0.41	0.42	0.40	0.40	0.42	0.38	0.36	0.41			

Sample 88-54-1		Plagioclase composition for geothermobarometry (end)								Figure 2-15
		PL.10	PL.11	PL.12	PL.13	PL.14	PL.15	PL.16	Average	
SiO2		58.51	59.03	59.39	57.28	58.38	57.75	58.20	58.386	
Al2O3		26.98	26.47	26.27	27.78	26.72	27.38	27.25	27.056	
CaO		8.22	7.48	7.40	9.17	7.86	8.69	8.27	8.185	
Na2O		6.82	7.37	7.61	6.38	6.90	6.49	6.90	6.790	
K2O		0.21	0.21	0.23	0.16	0.22	0.22	0.19	0.205	
FeO		0.09	0.06	0.07	0.06	0.14	0.09	0.14	0.089	
TOTAL		100.83	100.62	100.97	100.83	100.22	100.62	100.95	100.711	
16 oxygens										
Si		5.191	5.241	5.257	5.096	5.208	5.141	5.163	5.1850	
Al		2.821	2.770	2.741	2.913	2.809	2.873	2.849	2.8320	
		8.012	8.011	7.998	8.009	8.017	8.014	8.012	8.0170	
Ca		0.781	0.711	0.702	0.874	0.751	0.829	0.786	0.7787	
Na		1.174	1.269	1.307	1.101	1.194	1.120	1.187	1.1693	
K		0.023	0.024	0.026	0.018	0.025	0.025	0.022	0.0232	
		1.978	2.004	2.035	1.993	1.970	1.974	1.995	1.9712	
Fe		0.007	0.005	0.005	0.004	0.011	0.007	0.010	0.0068	
An		0.39	0.35	0.34	0.44	0.38	0.42	0.39	0.40	

Sample 88-104-1		Garnet traverse 1										Figure 2-16	
		GN.1	GN.2	GN.3	GN.4	GN.5	GN.6	GN.7	GN.8	GN.9	GN.10		
SiO ₂		37.87	37.91	37.75	37.73	37.55	37.79	37.78	37.92	38.47	39.26		
Al ₂ O ₃		21.4	21.35	21.45	21.45	21.3	21.28	21.27	20.99	20.97	20.79		
TiO ₂		0.07	0.06	0	0.08	0.01	0.01	0.02	0	0.01	0.02		
MgO		4.43	4.54	4.28	4.45	4.25	3.9	3.98	4.05	3.34	3.08		
FeO		25.6	25.65	25.63	25.44	25.46	25.8	26.03	25.45	24.8	25.56		
MnO		3.04	2.36	2.61	2.86	2.76	2.87	3.4	3.09	3.86	4.1		
CaO		7.76	8.07	7.96	8.07	7.79	8.12	7.64	7.68	7.63	7.32		
		100.17	99.94	99.68	100.08	99.12	99.77	100.12	99.18	99.08	100.13		
24 oxygens													
Si		5.956	5.966	5.961	5.939	5.965	5.977	5.966	6.022	6.106	6.175		
Al		0.044	0.034	0.039	0.061	0.035	0.023	0.034	0	0	0		
		6	6	6	6	6	6	6	6.022	6.106	6.175		
Al		3.924	3.925	3.954	3.919	3.953	3.944	3.926	3.93	3.923	3.854		
Ti		0.008	0.007	0	0.009	0.001	0.001	0.003	0	0.002	0.003		
		3.932	3.932	3.954	3.928	3.954	3.945	3.929	3.93	3.925	3.857		
Mg		1.038	1.065	1.008	1.043	1.007	0.92	0.937	0.959	0.791	0.722		
Fe		3.368	3.375	3.385	3.348	3.383	3.413	3.438	3.38	3.292	3.362		
Mn		0.405	0.314	0.349	0.381	0.372	0.385	0.454	0.415	0.52	0.546		
Ca		1.308	1.361	1.346	1.36	1.326	1.376	1.293	1.307	1.297	1.234		
		6.119	6.115	6.088	6.132	6.088	6.094	6.122	6.061	5.9	5.864		
XC _a		0.2138	0.2226	0.2211	0.2218	0.2178	0.2258	0.2112	0.2156	0.2198	0.2104		
XC _a +XM _n		0.2799	0.2739	0.2784	0.2839	0.2789	0.2890	0.2854	0.2841	0.3080	0.3035		
FE/MG		3.2447	3.1690	3.3581	3.2100	3.3595	3.7098	3.6692	3.5245	4.1618	4.6565		
MG/MG+FE		0.2356	0.2399	0.2295	0.2375	0.2294	0.2123	0.2142	0.2210	0.1937	0.1768		

Sample 88-104-1		Garnet traverse 1 (end)										Figure 2-16	
		GN.11	GN.12	GN.13	GN.14	GN.15	GN.16	GN.17	GN.18				
SiO ₂		37.77	37.86	37.86	37.71	37.67	37.7	37.6	39.22				
Al ₂ O ₃		21.19	21.43	21.06	21.33	21.3	21.28	21.44	20.91				
TiO ₂		0.08	0.04	0.01	0	0.09	0.16	0.02	0				
MgO		4.03	3.96	4.1	4.23	4.25	4.52	4.26	4.39				
FeO		25.72	25.79	25.47	25.8	25.77	25.57	25.44	25.39				
MnO		3.12	3.17	2.96	2.65	2.64	2.69	2.3	2.24				
CaO		8.15	7.95	7.79	8.06	7.96	8.13	7.97	7.88				
		100.06	100.2	99.25	99.78	99.68	100.05	99.03	100.03				
24 oxygens													
Si		5.963	5.965	6.009	5.958	5.956	5.938	5.966	6.132				
Al		0.037	0.035	0	0.042	0.044	0.062	0.034	0				
		6	6	6.009	6	6	6	6	6.132				
Al		3.906	3.945	3.939	3.931	3.925	3.889	3.975	3.852				
Ti		0.01	0.004	0.001	0	0.011	0.019	0.003	0				
		3.916	3.949	3.94	3.931	3.936	3.908	3.978	3.852				
Mg		0.949	0.929	0.969	0.996	1.002	1.061	1.007	1.022				
Fe		3.396	3.398	3.38	3.409	3.408	3.368	3.377	3.32				
Mn		0.417	0.423	0.398	0.355	0.353	0.359	0.309	0.296				
Ca		1.379	1.342	1.325	1.365	1.349	1.372	1.355	1.32				
		6.141	6.092	6.072	6.125	6.112	6.16	6.048	5.958				
XCa		0.2246	0.2203	0.2182	0.2229	0.2207	0.2227	0.2240	0.2216				
XCa+XMn		0.2925	0.2897	0.2838	0.2808	0.2785	0.2810	0.2751	0.2712				
FE/MG		3.5785	3.6577	3.4881	3.4227	3.4012	3.1744	3.3535	3.2485				
MG/MG+FE		0.2184	0.2147	0.2228	0.2261	0.2272	0.2396	0.2297	0.2354				

Sample 88-104-1		Garnet traverse 2										Figure 2-16	
		GN.31	GN.32	GN.33	GN.34	GN.35	GN.36	GN.37	GN.38	GN.39			
SIO2 AL2O3 TiO2 MGO FEO MNO CAO	SIO2	37.85	38.15	37.88	38.11	37.9	37.71	37.97	37.67	37.56			
	AL2O3	21.09	21.23	21.4	21.28	21.17	20.86	21.27	20.96	20.93			
	TiO2	0	0.11	0.06	0.01	0.04	0.07	0.08	0.01	0.17			
	MGO	4.41	4.3	4.26	4.43	4.22	3.94	4.35	3.89	4.28			
	FEO	24.96	25.47	25.26	25.35	25.12	24.9	25.08	24.94	25.09			
	MNO	2.66	2.67	2.91	2.8	2.82	2.99	3.14	3.06	3.08			
	CAO	7.92	8.13	8.11	7.97	8.18	8.03	8.04	8.09	8.16			
		98.89	100.06	99.88	99.95	99.45	98.5	99.93	98.62	99.27			
24 oxygens													
Si AL	Si	6.009	5.997	5.97	5.994	5.994	6.024	5.979	6.014	5.966			
	AL	0	0.003	0.03	0.006	0.006	0	0.021	0	0.034			
		6.009	6	6	6	6	6.024	6	6.014	6			
AL Ti	AL	3.946	3.93	3.944	3.94	3.941	3.928	3.927	3.944	3.885			
	Ti	0	0.013	0.007	0.002	0.005	0.009	0.01	0.002	0.02			
		3.946	3.943	3.951	3.942	3.946	3.937	3.937	3.946	3.905			
MG FE MN CA	MG	1.044	1.007	1	1.039	0.994	0.938	1.02	0.926	1.013			
	FE	3.313	3.348	3.328	3.335	3.323	3.326	3.303	3.329	3.333			
	MN	0.358	0.356	0.388	0.374	0.378	0.404	0.418	0.414	0.415			
	CA	1.348	1.37	1.37	1.343	1.387	1.374	1.357	1.384	1.389			
		6.063	6.081	6.086	6.091	6.082	6.042	6.098	6.053	6.15			
XCa XCa+XMn	XCa	0.2223	0.2253	0.2251	0.2205	0.2280	0.2274	0.2225	0.2286	0.2259			
	XCa+XMn	0.2814	0.2838	0.2889	0.2819	0.2902	0.2943	0.2911	0.2970	0.2933			
FE/MG MG/MG+FE	FE/MG	3.1734	3.3247	3.3280	3.2098	3.3431	3.5458	3.2382	3.5950	3.2902			
	MG/MG+FE	0.2396	0.2312	0.2311	0.2375	0.2303	0.2200	0.2359	0.2176	0.2331			

Sample 88-104-1		Garnet traverse 2 (end)						Figure 2-16	
		GN.40	GN.41	GN.42	GN.43	GN.44	GN.45	GN.46	
SiO ₂		37.74	37.92	37.71	37.87	37.86	37.82	37.61	
Al ₂ O ₃		21.06	21.09	20.76	20.82	21.17	21.08	20.87	
TiO ₂		0.1	0.09	0.05	0.01	0.03	0.05	0.53	
MgO		4.16	4.23	3.87	4.29	4.08	4.19	3.95	
FeO		24.88	25.08	25.01	25.2	25.24	24.93	24.97	
MnO		3.2	3.06	3.29	3.22	3.08	3.15	3.02	
CaO		8.17	8.18	8.22	7.97	8.13	8.07	8.26	
		99.31	99.65	98.91	99.38	99.59	99.29	99.21	
24 oxygens									
Si		5.986	5.991	6.014	6.007	5.99	5.996	5.973	
Al		0.014	0.009	0	0	0.01	0.004	0.027	
		6	6	6.014	6.007	6	6	6	
Al		3.922	3.919	3.903	3.893	3.937	3.934	3.881	
Ti		0.012	0.01	0.006	0.001	0.003	0.006	0.063	
		3.934	3.929	3.909	3.894	3.94	3.94	3.944	
Mg		0.983	0.997	0.921	1.015	0.963	0.99	0.936	
Fe		3.3	3.313	3.337	3.343	3.339	3.306	3.317	
Mn		0.43	0.409	0.444	0.432	0.413	0.423	0.406	
Ca		1.388	1.386	1.404	1.354	1.378	1.371	1.406	
		6.101	6.105	6.106	6.144	6.093	6.09	6.065	
XCa		0.2275	0.2270	0.2299	0.2204	0.2262	0.2251	0.2318	
XCa+XMn		0.2980	0.2940	0.3027	0.2907	0.2939	0.2946	0.2988	
Fe/Mg		3.3571	3.3230	3.6232	3.2936	3.4673	3.3394	3.5438	
Mg/Mg+Fe		0.2295	0.2313	0.2163	0.2329	0.2238	0.2304	0.2201	

Sample 88-104-1	Garnet compositions used for geothermobarometry				Figure 2-17
	Gn 31/56 (Hb matrix)	Gn.30 (HB.18&19)	Gn.18 (HB.23)	Gn.29 (HB.17)	
SiO ₂	37.805	37.56	39.22	37.45	
Al ₂ O ₃	21.080	21.16	20.91	20.98	
TiO ₂	0.070	0.06	0	0	
MgO	4.223	3.66	4.39	3.98	
FeO	25.121	25.85	25.39	25.23	
MnO	2.972	2.88	2.24	2.89	
CaO	8.070	7.97	7.88	8.04	
	99.340	99.14	100.03	98.57	
24 oxygens					
Si	5.0649	5.982	6.132	5.988	
Al	0.0122	0.018	0	0.012	
	6.0031	6	6.132	6	
Al	3.9250	3.955	3.852	3.942	
Ti	0.0083	0.007	0	0	
	3.9334	3.962	3.852	3.942	
Mg	0.9974	0.87	1.022	0.95	
Fe	3.3290	3.443	3.32	3.374	
Mn	0.3988	0.389	0.296	0.392	
Ca	1.3704	1.36	1.32	1.378	
	6.0957	6.062	5.958	6.094	
XCa	0.22482	0.2243	0.2216	0.2261	
XCa+XMn	0.29025	0.2885	0.2712	0.2904	
Fe/Mg	3.34211	3.9575	3.2485	3.5516	
Mg/Mg+Fe	0.23049	0.2017	0.2354	0.2197	

Sample 88-104-1		Hornblende compositions (continued)					Figure 2-17
		HB.29	HB.30	HB.31	HB.32	HB.33	average
SIO ₂		42.39	43.12	43.27	43.34	44.43	43.607
AL ₂ O ₃		14.36	13.48	13.32	14.09	12.04	13.174
TIO ₂		1.18	1.21	1.39	0.99	0.96	1.189
FeO		14.86	14.88	14.56	14.87	14.79	14.848
MnO		0.13	0.22	0.24	0.15	0.20	0.201
CR ₂ O ₃		0.04	0.03	0.10	0.03	0.06	0.056
V ₂ O ₃		0.06	0.07	0.12	0.06	0.06	0.093
MgO		10.17	10.08	10.53	10.67	11.28	10.689
CaO		11.71	11.83	11.69	11.70	11.64	11.704
K ₂ O		0.99	0.98	0.98	0.96	0.85	0.943
Na ₂ O		1.59	1.57	1.22	2.17	1.30	1.620
TOTAL		97.48	97.47	97.42	99.03	97.61	98.125
23 oxygens							
SI		6.312	6.419	6.428	6.352	6.576	6.4413
AL		1.688	1.581	1.572	1.648	1.424	1.5587
		8	8	8	8	8	8
AL		0.832	0.784	0.760	0.787	0.677	0.7348
TI		0.132	0.136	0.155	0.109	0.107	0.1322
FE		1.850	1.853	1.809	1.822	1.831	1.8344
MN		0.017	0.028	0.030	0.019	0.025	0.0252
CR		0.005	0.004	0.012	0.003	0.007	0.0066
V		0.007	0.009	0.014	0.007	0.007	0.0112
MG		2.257	2.237	2.331	2.331	2.489	2.3534
		5.100	5.051	5.111	5.078	5.143	5.0978
CA		1.868	1.887	1.860	1.838	1.847	1.8526
K		0.188	0.187	0.186	0.179	0.160	0.1778
NA		0.459	0.452	0.351	0.618	0.374	0.4635
		2.515	2.526	2.397	2.635	2.381	2.4938
FE/MG		0.7930	0.7930	0.7930	0.7930	0.7930	0.79297
MG/MG+FE		0.5577	0.5577	0.5577	0.5577	0.5577	0.55773

Sample 88-104-1		Hornblende compositions (end)			
		HB.17	HB.18	HB.19	HB.23
SIO2		45.57	45.81	46.17	42.87
AL2O3		9.24	9.52	8.95	14.02
TIO2		0.75	0.96	0.88	0.74
FEO		18.79	17.90	17.33	16.24
MNO		0.62	0.41	0.40	0.34
CR2O3		0.01	0.00	0.00	0.00
V2O3		0.02	0.00	0.02	0.06
MGO		9.43	10.28	10.57	9.54
CAO		11.52	11.22	11.18	11.95
K2O		0.45	0.52	0.38	0.80
NA2O		1.09	1.78	1.28	1.86
TOTAL		97.49	98.40	97.16	98.42
23 oxygens					
SI		6.867	6.814	6.916	6.364
AL		1.133	1.186	1.084	1.636
		8	8	8	8
AL		0.509	0.483	0.496	0.818
TI		0.085	0.108	0.099	0.083
FE		2.368	2.227	2.170	2.016
MN		0.079	0.052	0.051	0.043
CR		0.001	0.000	0.000	0.000
V		0.003	0.000	0.002	0.007
MG		2.118	2.280	2.359	2.110
		5.163	5.150	5.177	5.077
CA		1.860	1.788	1.794	1.902
K		0.086	0.099	0.074	0.151
NA		0.320	0.514	0.370	0.536
		2.266	2.401	2.238	2.589
FE/MG		0.7930	0.7930	0.7930	0.7930
MG/MG+FE		0.5577	0.5577	0.5577	0.5577

Sample 88-104-1		Plagioclase compositions for geothermobarometry						Figure 2-17	
		Pl.1	Pl.2	Pl.3	Pl.4	Pl.5	average (matrix)	Pl.7	Pl.8 (garnet zone) average
SiO2		60.01	57.75	58.03	57.93	59.22	58.588	56.35	56.13
Al2O3		25.91	26.95	27.03	26.71	26.53	26.626	27.89	28.09
CaO		6.68	8.54	7.91	8.25	7.27	7.730	9.40	9.35
Na2O		8.12	6.96	7.00	6.62	7.45	7.230	6.31	6.15
K2O		0.30	0.31	0.24	0.32	0.28	0.290	0.35	0.20
FEO		0.14	0.29	0.33	0.19	0.17	0.224	0.32	0.18
TOTAL		101.16	100.80	100.54	100.02	100.92	100.688	100.62	100.10
16 oxygens									
Si		5.300	5.148	5.171	5.186	5.244	5.2098	5.046	5.040
Al		2.697	2.832	2.839	2.819	2.769	2.7912	2.943	2.973
		7.997	7.980	8.010	8.005	8.013	8.0010	7.989	8.013
Ca		0.632	0.816	0.755	0.792	0.690	0.7370	0.902	0.900
Na		1.391	1.203	1.210	1.149	1.279	1.2464	1.096	1.071
K		0.034	0.035	0.027	0.036	0.032	0.0328	0.039	0.022
		2.057	2.054	1.992	1.977	2.001	2.0162	2.037	1.993
Fe		0.010	0.021	0.024	0.014	0.012	0.0162	0.024	0.013
An		0.31	0.40	0.38	0.40	0.34	0.37	0.44	0.45

Sample 87-237-1		Garnet traverse I														Figure 2-18	
		GA.1	GA.2	GA.3	GA.4	GA.5	GA.6	GA.7	GA.8	GA.9	GA.10	GA.11	GA.12	GA.13	GA.14		
SiO2		37.63	37.84	37.62	37.39	37.50	37.41	37.35	37.32	37.28	37.19	39.35	36.99	36.86	37.00		
Al2O3		21.77	21.62	21.16	21.25	21.50	21.31	21.34	21.08	21.20	21.30	21.79	21.19	21.27	21.04		
TiO2		0.06	0.00	0.01	0.00	0.01	0.00	0.02	0.01	0.00	0.04	0.03	0.01	0.09	0.05		
MgO		3.39	3.58	3.45	3.48	3.57	3.61	3.67	3.65	3.67	3.67	3.93	3.68	3.67	3.78		
FeO		31.98	31.88	31.16	32.07	31.49	31.34	31.05	30.71	30.43	30.78	32.20	30.30	30.70	30.22		
MnO		0.44	0.36	0.40	0.40	0.44	0.55	0.41	0.42	0.36	0.47	0.47	0.60	0.59	0.66		
CaO		5.35	5.38	5.84	5.45	5.78	5.56	5.83	5.89	6.05	6.04	6.28	6.15	5.45	5.65		
TOTAL		100.82	100.66	99.64	100.04	100.29	99.78	99.67	99.08	98.99	99.49	104.05	98.92	98.63	98.40		
24 oxygens																	
Si		5.96	5.976	6.000	5.960	5.950	5.965	5.956	5.983	5.975	5.943	6.009	5.942	5.940	5.968		
Al		0.033	0.024	0.000	0.040	0.050	0.035	0.044	0.017	0.025	0.057	0.000	0.058	0.060	0.032		
		6	6	6	6	6	6	6	6	6	6	6.009	6	6	6		
Al		4.015	4.000	3.978	3.953	3.972	3.970	3.967	3.966	3.979	3.955	3.921	3.955	3.980	3.968		
Ti		0.007	0.000	0.001	0.000	0.001	0.000	0.003	0.001	0.000	0.005	0.003	0.002	0.010	0.006		
		4.022	4.000	3.979	3.953	3.973	3.970	3.970	3.967	3.979	3.960	3.924	3.957	3.990	3.974		
Mg		0.798	0.842	0.820	0.828	0.845	0.857	0.874	0.872	0.876	0.875	0.893	0.881	0.882	0.908		
Fe		4.218	4.211	4.158	4.276	4.178	4.180	4.142	4.117	4.078	4.113	4.112	4.072	4.137	4.078		
Mn		0.059	0.048	0.054	0.054	0.059	0.075	0.055	0.057	0.049	0.064	0.060	0.081	0.080	0.090		
Ca		0.905	0.910	0.998	0.931	0.982	0.950	0.995	1.011	1.040	1.034	1.028	1.058	0.942	0.976		
		5.980	6.011	6.030	6.089	6.064	6.062	6.066	6.057	6.043	6.086	6.093	6.092	6.041	6.052		
XCa		0.1513	0.1514	0.1655	0.1529	0.1619	0.1567	0.1640	0.1669	0.1721	0.1699	0.1687	0.1737	0.1559	0.1613		
XCa+XMn		0.1612	0.1594	0.1745	0.1618	0.1717	0.1691	0.1731	0.1763	0.1802	0.1804	0.1786	0.1870	0.1692	0.1761		
Fe/Mg		5.2857	5.0012	5.0707	5.1643	4.9444	4.8775	4.7391	4.7213	4.6553	4.7006	4.6047	4.6220	4.6905	4.4912		
Mg/Mg+Fe		0.1591	0.1666	0.1647	0.1622	0.1682	0.1701	0.1742	0.1748	0.1768	0.1754	0.1784	0.1779	0.1757	0.1821		

Sample 87-237-1		Garnet traverse 1 (continued)														Figure 2-18	
		GA.15	GA.16	GA.17	GA.18	GA.19	GA.20	GA.21	GA.22	GA.23	GA.24	GA.25	GA.26	GA.27	GA.28		
SiO ₂		37.42	37.09	37.84	37.16	37.25	37.33	37.17	37.40	37.51	37.54	37.12	36.96	37.41	37.13		
Al ₂ O ₃		21.17	21.09	21.51	21.15	21.23	21.54	21.30	21.45	21.22	21.32	21.43	21.59	21.34	21.29		
TiO ₂		0.05	0.04	0.01	0.03	0.02	0.02	0.03	0.02	0.08	0.00	0.07	0.04	0.03	0.00		
MgO		4.09	3.91	4.33	4.09	4.13	3.88	3.85	3.88	4.18	4.27	3.96	4.15	4.23	3.93		
FeO		30.88	30.80	31.41	30.59	31.22	30.84	30.91	31.09	30.92	30.56	30.73	31.36	31.35	30.66		
MnO		0.60	0.71	0.73	0.65	0.75	0.74	0.81	0.76	0.82	0.56	0.66	0.62	0.70	0.68		
CaO		5.26	4.86	4.60	5.15	4.76	5.25	5.02	5.05	5.13	5.30	5.27	4.73	4.67	5.16		
TOTAL		99.47	98.50	100.43	98.82	99.36	99.60	99.09	99.65	99.86	99.55	99.24	99.45	99.73	98.85		
24 oxygens																	
Si		5.971	5.977	5.974	5.965	5.958	5.949	5.959	5.961	5.965	5.973	5.937	5.908	5.957	5.960		
Al		0.029	0.023	0.026	0.035	0.042	0.051	0.041	0.039	0.035	0.027	0.063	0.092	0.043	0.040		
		6	6	6	6	6	6	6	6	6	6	6	6	6	6		
Al		3.953	3.983	3.978	3.967	3.960	3.995	3.984	3.990	3.942	3.970	3.977	3.976	3.962	3.988		
Ti		0.006	0.005	0.001	0.003	0.002	0.003	0.003	0.002	0.009	0.000	0.008	0.004	0.004	0.000		
		3.959	3.988	3.979	3.970	3.962	3.998	3.987	3.992	3.951	3.970	3.985	3.980	3.966	3.988		
Mg		0.972	0.940	1.019	0.978	0.985	0.922	0.919	0.922	0.990	1.012	0.943	0.988	1.005	0.940		
Fe		4.121	4.151	4.148	4.107	4.176	4.110	4.144	4.144	4.113	4.067	4.111	4.192	4.175	4.117		
Mn		0.081	0.097	0.098	0.089	0.101	0.099	0.110	0.103	0.110	0.076	0.090	0.084	0.094	0.092		
Ca		0.899	0.840	0.778	0.886	0.815	0.897	0.863	0.862	0.875	0.903	0.904	0.811	0.797	0.888		
		6.073	6.028	6.043	6.060	6.077	6.028	6.036	6.031	6.088	6.058	6.048	6.075	6.071	6.037		
X _{Ca}		0.1480	0.1393	0.1287	0.1462	0.1341	0.1488	0.1430	0.1429	0.1437	0.1491	0.1495	0.1335	0.1313	0.1471		
X _{Ca+XMn}		0.1614	0.1554	0.1450	0.1609	0.1507	0.1652	0.1612	0.1600	0.1618	0.1616	0.1644	0.1473	0.1468	0.1623		
Fe/Mg		4.2397	4.4160	4.0707	4.1994	4.2396	4.4577	4.5092	4.4946	4.1545	4.0188	4.3595	4.2429	4.1542	4.3798		
Mg/Mg+Fe		0.1909	0.1846	0.1972	0.1923	0.1909	0.1832	0.1815	0.1820	0.1940	0.1993	0.1866	0.1907	0.1940	0.1859		

Sample 87-237-1		Garnet traverse 1 (end)										Figure 2-18	
		GA.29	GA.30	GA.31	GA.32	GA.33	GA.34	GA.35	GA.36	GA.37	GA.38		
SiO ₂		37.23	36.74	37.02	37.17	37.08	37.06	37.00	37.10	36.97	37.05		
Al ₂ O ₃		21.02	21.24	21.25	21.22	21.37	21.31	21.15	21.26	21.37	21.33		
TiO ₂		0.05	0.00	0.01	0.04	0.00	0.00	0.06	0.03	0.06	0.08		
MgO		3.94	3.85	3.72	3.60	3.73	3.80	3.45	3.70	3.39	3.59		
FeO		31.15	30.50	30.49	30.76	30.74	31.15	30.95	31.37	30.98	31.58		
MnO		0.72	0.69	0.63	0.60	0.55	0.41	0.35	0.39	0.36	0.32		
CaO		5.28	5.72	5.73	5.54	5.65	5.51	5.70	5.49	5.69	5.58		
TOTAL		99.39	98.74	98.85	98.93	99.12	99.24	98.66	99.34	98.82	99.53		
24 oxygens													
Si		5.961	5.918	5.949	5.969	5.944	5.939	5.963	5.944	5.948	5.930		
Al		0.039	0.082	0.051	0.031	0.056	0.061	0.037	0.056	0.052	0.070		
		6	6	6	6	6	6	6	6	6	6		
Al		3.928	3.952	3.974	3.985	3.981	3.965	3.981	3.959	4.000	3.954		
Ti		0.007	0.000	0.001	0.005	0.000	0.000	0.007	0.004	0.007	0.009		
		3.935	3.952	3.975	3.990	3.981	3.965	3.988	3.963	4.007	3.963		
Mg		0.941	0.924	0.892	0.861	0.890	0.907	0.829	0.885	0.813	0.857		
Fe		4.171	4.108	4.097	4.130	4.121	4.175	4.172	4.203	4.169	4.227		
Mn		0.098	0.095	0.086	0.081	0.074	0.055	0.048	0.053	0.049	0.044		
Ca		0.905	0.987	0.987	0.954	0.970	0.946	0.984	0.942	0.981	0.956		
		6.115	6.114	6.062	6.026	6.055	6.083	6.033	6.083	6.012	6.084		
XCa		0.1480	0.1614	0.1628	0.1583	0.1602	0.1555	0.1631	0.1549	0.1632	0.1571		
XCa+XMn		0.1640	0.1770	0.1770	0.1718	0.1724	0.1646	0.1711	0.1636	0.1713	0.1644		
Fe/Mg		4.4325	4.4459	4.5930	4.7967	4.6303	4.6031	5.0326	4.7492	5.1279	4.9323		
Mg/Mg+Fe		0.1841	0.1836	0.1788	0.1725	0.1776	0.1785	0.1658	0.1739	0.1632	0.1686		

Sample 87-237-1 Garnet traverse 2 Figure 2-18

	GN.61	GN.62	GN.63	GN.64	GN.65	GN.66	GN.67	GN.68	GN.69	GN.70	GN.71	GN.72
SiO ₂	36.88	36.99	37.44	37.25	36.96	36.64	36.91	36.89	36.88	36.81	36.84	36.71
Al ₂ O ₃	20.93	21.18	21.43	20.99	20.91	20.76	20.64	20.56	21.05	20.59	20.76	20.98
TiO ₂	0.00	0.01	0.03	0.14	0.04	0.09	0.08	0.12	0.06	0.06	0.09	0.08
MgO	3.40	3.71	4.14	3.73	3.74	2.55	2.27	1.88	1.68	1.61	1.69	1.86
FeO	32.20	31.27	31.45	30.75	30.76	30.31	29.94	29.44	29.28	28.85	29.09	29.98
MnO	0.31	0.44	0.39	0.79	0.99	1.57	1.93	2.63	2.81	3.06	2.94	2.54
CaO	5.11	5.64	5.20	5.84	5.72	6.81	7.18	7.30	7.66	7.96	8.00	7.31
TOTAL	98.83	99.24	100.08	99.49	99.12	98.73	98.95	98.82	99.42	98.94	99.41	99.46
24 oxygens												
Si	5.960	5.937	5.943	5.959	5.944	5.946	5.978	5.991	5.954	5.979	5.956	5.934
Al	0.040	0.063	0.057	0.041	0.056	0.054	0.022	0.009	0.046	0.021	0.044	0.066
	6	6	6	6	6	6	6	6	6	6	6	6
Al	3.947	3.944	3.952	3.916	3.908	3.916	3.918	3.926	3.960	3.921	3.912	3.931
Ti	0.000	0.001	0.003	0.017	0.005	0.010	0.010	0.015	0.008	0.007	0.011	0.010
	3.947	3.945	3.955	3.933	3.913	3.926	3.928	3.941	3.968	3.928	3.923	3.941
Mg	0.820	0.888	0.979	0.889	0.897	0.618	0.547	0.454	0.405	0.389	0.408	0.448
Fe	4.353	4.197	4.176	4.114	4.137	4.113	4.055	3.999	3.953	3.919	3.934	4.054
Mn	0.042	0.060	0.053	0.107	0.135	0.216	0.265	0.362	0.385	0.422	0.403	0.348
Ca	0.885	0.969	0.885	1.001	0.986	1.185	1.246	1.270	1.325	1.385	1.387	1.266
	6.100	6.114	6.093	6.111	6.155	6.132	6.113	6.085	6.068	6.115	6.132	6.116
XCa	0.1451	0.1585	0.1452	0.1638	0.1602	0.1932	0.2038	0.2087	0.2184	0.2265	0.2262	0.2070
XCa+XMn	0.1520	0.1683	0.1539	0.1813	0.1821	0.2285	0.2472	0.2682	0.2818	0.2955	0.2919	0.2639
FE/MG	5.3085	4.7264	4.2656	4.6277	4.6120	6.6553	7.4132	8.8084	9.7605	10.0746	9.6422	9.0491
MG/MG+FE	0.1585	0.1746	0.1899	0.1777	0.1782	0.1306	0.1189	0.1020	0.0929	0.0903	0.0940	0.0995

Sample 87-237-1		Garnet traverse 2 (end)										Figure 2-18	
		GN.73	GN.74	GN.75	GN.76	GN.77	GN.78	GN.79	GN.80	GN.81	GN.82	GN.83	GN.84
SIO2 AL2O3 TiO2 MGO FEO MNO CAO TOTAL		36.60	37.25	37.36	37.34	37.52	37.49	37.43	37.67	37.58	37.42	37.29	37.25
		20.73	21.00	20.90	21.00	21.18	21.22	21.07	21.39	21.08	20.92	21.10	21.14
		0.17	0.03	0.11	0.02	0.05	0.01	0.00	0.02	0.00	0.04	0.02	0.00
		2.47	2.59	3.36	3.26	3.77	4.11	3.99	4.10	3.61	3.71	3.34	3.47
		30.21	30.91	30.96	30.96	31.44	31.75	31.67	31.37	30.94	31.77	31.60	31.86
		1.58	1.32	1.14	0.86	0.77	0.59	0.54	0.56	0.35	0.42	0.40	0.33
		6.73	6.40	6.09	5.86	5.36	4.78	5.16	5.53	6.17	5.55	5.68	5.67
		98.49	99.80	99.92	99.30	100.09	99.95	99.86	100.64	99.73	99.83	99.43	99.72
	24 oxygens												
	SI	5.951	5.968	5.969	5.991	5.968	5.966	5.968	5.950	5.990	5.976	5.977	5.957
AL TI	AL	0.049	0.032	0.031	0.009	0.032	0.034	0.032	0.050	0.010	0.024	0.023	0.043
		6	6	6	6	6	6	6	6	6	6	6	6
	AL	3.924	3.933	3.904	3.963	3.940	3.946	3.928	3.933	3.950	3.914	3.962	3.943
	TI	0.021	0.004	0.013	0.003	0.006	0.002	0.000	0.002	0.000	0.004	0.003	0.000
MG FE MN CA		3.945	3.937	3.917	3.966	3.946	3.948	3.928	3.935	3.950	3.918	3.965	3.943
	MG	0.598	0.690	0.801	0.779	0.893	0.976	0.947	0.966	0.857	0.883	0.797	0.828
	FE	4.108	4.142	4.137	4.154	4.183	4.224	4.223	4.144	4.124	4.243	4.235	4.262
	MN	0.217	0.179	0.154	0.117	0.104	0.080	0.073	0.075	0.047	0.057	0.054	0.045
	CA	1.173	1.098	1.042	1.007	0.914	0.815	0.881	0.936	1.053	0.950	0.976	0.972
		6.096	6.109	6.134	6.057	6.094	6.095	6.124	6.121	6.081	6.133	6.062	6.107
XCa XCa+XMn	XCa	0.1924	0.1797	0.1699	0.1663	0.1500	0.1337	0.1439	0.1529	0.1732	0.1549	0.1610	0.1592
	XCa+XMn	0.2280	0.2090	0.1950	0.1856	0.1670	0.1468	0.1558	0.1652	0.1809	0.1642	0.1699	0.1665
FE/MG MG/MG+FE	FE/MG	6.8696	6.0029	5.1648	5.3325	4.6842	4.3279	4.4593	4.2899	4.8121	4.8052	5.3137	5.1473
	MG/MG+FE	0.1271	0.1428	0.1622	0.1579	0.1759	0.1877	0.1832	0.1890	0.1721	0.1723	0.1584	0.1627

Sample 87-237-1 Garnet compositions for geothermobarometry			Figure 2-19 Biotite compositions for geothermobarometry			
	GA.1 (B.13&14)	GN.61 (B.8)		B.8	B.13	B.14
SiO ₂	37.83	36.88	SiO ₂	35.94	35.38	36.04
Al ₂ O ₃	21.77	20.93	Al ₂ O ₃	19.24	19.72	19.90
TiO ₂	0.06	0.00	TiO ₂	1.75	1.52	1.54
MgO	3.39	3.40	Cr ₂ O ₃	0.00	0.00	0.02
FeO	31.98	32.20	FeO	18.76	19.39	19.05
MnO	0.44	0.31	MnO	0.07	0.00	0.02
CaO	5.35	5.11	MgO	10.13	10.04	10.46
TOTAL	100.82	98.83	CaO	0.02	0.00	0.00
24 oxygens			K ₂ O	8.78	8.88	8.93
Si	5.967	5.960	BAO	0.15	0.00	0.10
Al	0.033	0.040	Na ₂ O	0.45	0.26	0.46
	6	6	TOTAL	95.29	95.19	96.52
AL	4.015	3.947	22 oxygens			
Ti	0.007	0.000	Si	5.435	5.368	5.382
	4.022	3.947	Al	2.565	2.632	2.618
				8	8	8
MG	0.798	0.820	AL	0.864	0.894	0.884
FE	4.218	4.353	Ti	0.199	0.173	0.172
MN	0.059	0.042	CR	0.000	0.000	0.003
CA	0.905	0.885	FE	2.373	2.460	2.379
	5.980	6.100	MN	0.009	0.001	0.002
			MG	2.283	2.272	2.329
XC _a	0.1513	0.1451		5.728	5.800	5.769
XC _a +XM _n	0.1612	0.1520	CA	0.003	0.000	0.000
			K	1.694	1.719	1.701
FE/MG	5.2857	5.3085	BA	0.009	0.000	0.006
MG/MG+FE	0.1591	0.1585	NA	0.132	0.075	0.133
				1.838	1.794	1.840
			XAl	0.1508	0.1541	0.1532
			XTi	0.0347	0.0298	0.0298
			XFe/XMg	1.0394	1.0827	1.0215
			MG/MG+FE	0.4903	0.4801	0.4947

Sample 87-237-1		Muscovite compositions for geothermobarometry				Figure 2-19	
		MS.1	MS.2	MS.3	MS.4	MS.5	MS.6
SIO2		46.75	45.37	45.94	46.18	45.79	46.38
AL2O3		37.13	35.62	36.22	36.01	36.85	36.30
TIO2		0.33	0.38	0.34	0.32	0.33	0.13
CR2O3		0.04	0.03	0.07	0.11	0.07	0.10
FEO		1.03	1.59	1.15	1.14	1.11	1.19
MNO		0.04	0.00	0.05	0.09	0.05	0.05
MGO		0.74	1.00	0.83	0.89	1.09	0.93
CAO		0.05	0.00	0.00	0.00	0.01	0.00
K2O		9.80	9.38	9.53	9.77	9.68	9.60
BAO		1.24	0.94	1.26	1.20	1.34	1.62
NA2O		0.59	0.71	1.12	0.95	0.61	0.81
TOTAL		97.74	95.02	96.51	96.66	96.93	97.11
22 oxygens							
SI		6.083	6.079	6.073	6.097	6.025	6.102
AL		1.917	1.921	1.927	1.903	1.975	1.898
		8	8	8	8	8	8
AL		3.778	3.705	3.718	3.701	3.740	3.731
TI		0.033	0.038	0.034	0.032	0.033	0.013
CR		0.005	0.004	0.007	0.011	0.007	0.011
FE		0.113	0.178	0.127	0.126	0.122	0.131
MN		0.004	0.000	0.005	0.010	0.006	0.006
MG		0.144	0.199	0.164	0.176	0.213	0.183
		4.077	4.124	4.055	4.056	4.121	4.075
CA		0.007	0.000	0.000	0.000	0.002	0.000
K		1.627	1.604	1.608	1.646	1.625	1.611
BA		0.063	0.049	0.065	0.062	0.069	0.083
NA		0.149	0.184	0.287	0.244	0.155	0.206
		1.846	1.837	1.960	1.952	1.851	1.900
FE/MG		0.7847	0.8945	0.7744	0.7159	0.5728	0.7158
MG/MG+FE		0.5603	0.5279	0.5636	0.5828	0.6358	0.5828

Sample 87-237-1		Muscovite compositions for geothermobarometry					Figure 2-19
		MS.7	MS.8	MS.9	MS.10	MS.11	average
SIO2		45.19	46.10	46.02	46.11	45.92	45.98
AL2O3		36.14	35.76	36.45	36.40	36.53	36.31
TIO2		0.34	0.21	0.24	0.23	0.07	0.27
CR2O3		0.02	0.06	0.06	0.07	0.05	0.06
FEO		1.00	1.22	1.21	1.21	1.16	1.18
MNO		0.01	0.05	0.01	0.05	0.01	0.04
MGO		0.71	0.82	1.05	1.10	0.87	0.91
CAO		0.00	0.02	0.01	0.00	0.00	0.01
K2O		9.69	9.58	9.69	9.67	9.59	9.64
BAO		1.44	1.32	1.17	1.29	1.47	1.30
NA2O		0.64	0.72	1.06	1.19	1.08	0.86
TOTAL		95.18	95.86	96.97	97.32	96.75	96.56
22 oxygens							
SI		6.059	6.131	6.055	6.055	6.064	6.075
AL		1.941	1.869	1.945	1.945	1.936	1.925
		8	8	8	8	8	8
AL		3.771	3.736	3.709	3.689	3.750	3.730
TI		0.034	0.021	0.024	0.023	0.007	0.026
CR		0.003	0.006	0.007	0.007	0.005	0.007
FE		0.112	0.135	0.134	0.133	0.128	0.131
MN		0.001	0.006	0.001	0.005	0.001	0.004
MG		0.142	0.162	0.205	0.215	0.170	0.179
		4.063	4.066	4.080	4.072	4.061	4.077
CA		0.000	0.002	0.001	0.000	0.000	0.001
K		1.658	1.626	1.627	1.621	1.616	1.624
BA		0.076	0.069	0.060	0.066	0.076	0.067
NA		0.167	0.185	0.271	0.303	0.277	0.221
		1.901	1.882	1.959	1.990	1.969	1.913
FE/MG		0.7887	0.8333	0.6537	0.6186	0.7529	0.7318
MG/MG+FE		0.5591	0.5455	0.6047	0.6178	0.5705	0.5774

Sample 87-237-1		Plagioclase compositions for geothermobarometry																Figure 2-19				
	Plagioclase traverse								Plagioclase matrix								Inclusions in Gn				Contact with Gn	
	PL.1	PL.2	PL.3	PL.4	PL.5	PL.6	PL.7	PL.8	PL.9	PL.10	PL.11	PL.12	PL.13	PL.14	PL.15	PL.16	PL.17					
	Rim PT																					
SiO ₂	54.87	56.56	59.66	59.71	59.26	59.56	56.80	53.72	58.84	59.20	52.19	58.28	56.95	59.25	59.69	57.09	58.29					
Al ₂ O ₃	29.88	28.78	26.72	26.51	26.47	26.54	28.55	30.14	26.77	26.64	30.26	27.52	28.19	26.46	26.42	27.81	27.34					
CaO	11.88	10.26	7.96	7.84	7.86	7.79	10.23	12.29	8.41	8.13	13.47	9.21	9.46	7.92	7.92	9.37	8.76					
Na ₂ O	4.73	5.89	7.26	6.89	6.86	6.84	5.93	4.45	6.44	6.80	3.42	6.34	5.91	7.03	7.06	6.24	6.52					
K ₂ O	0.13	0.21	0.22	0.24	0.20	0.21	0.15	0.17	0.22	0.20	0.11	0.21	0.21	0.27	0.22	0.19	0.22					
FeO	0.09	0.14	0.00	0.03	0.10	0.00	0.00	0.12	0.00	0.05	0.07	0.12	0.03	0.24	0.21	0.08	0.20					
TOTAL	101.58	101.84	101.82	101.22	100.75	100.94	101.66	100.89	100.68	101.02	99.52	101.68	100.75	101.17	101.52	100.78	101.33					
16 oxygens																						
Si	4.876	5.001	5.237	5.263	5.250	5.261	5.024	4.817	5.218	5.234	4.751	5.138	5.069	5.239	5.255	5.085	5.155					
Al	3.130	2.999	2.765	2.754	2.764	2.763	2.976	3.186	2.799	2.776	3.247	2.860	2.957	2.758	2.742	2.920	2.850					
	8.006	8.000	8.002	8.017	8.014	8.024	8.000	8.003	8.017	8.010	7.998	7.998	8.026	7.997	7.997	8.005	8.005					
Ca	1.131	0.972	0.749	0.740	0.746	0.737	0.970	1.181	0.799	0.770	1.314	0.871	0.902	0.751	0.747	0.894	0.830					
Na	0.815	1.010	1.235	1.177	1.178	1.171	1.018	0.774	1.108	1.165	0.604	1.085	1.020	1.205	1.205	1.078	1.117					
K	0.014	0.023	0.024	0.027	0.023	0.024	0.017	0.019	0.025	0.023	0.013	0.023	0.024	0.030	0.025	0.022	0.025					
	1.960	2.005	2.008	1.944	1.947	1.932	2.005	1.974	1.932	1.958	1.931	1.979	1.946	1.986	1.977	1.994	1.972					
FE	0.007	0.011	0.000	0.002	0.007	0.000	0.000	0.009	0.000	0.003	0.005	0.009	0.002	0.018	0.015	0.006	0.015					
An	0.58	0.45	0.37	0.38	0.38	0.38	0.48	0.60	0.41	0.39	0.68	0.44	0.46	0.38	0.38	0.45	0.42					

Sample 87-195-3		Garnet traverse										Figure 2-20	
		G.28	G.29	G.30	G.31	G.32	G.33	G.34	G.35	G.36	G.37	G.38	G.39
SiO ₂		37.33	37.25	37.33	37.15	37.54	37.05	37.12	37.06	37.05	36.98	37.18	36.98
Al ₂ O ₃		21.27	21.07	21.33	21.26	21.23	21.49	21.26	20.9	21.07	21.13	21.16	21.02
TiO ₂		0.08	0	0.05	0.06	0.12	0.24	0.13	0.13	0.12	0.11	0.12	0.05
MgO		3.44	3.09	2.89	2.91	2.8	2.66	2.56	2.67	2.83	2.84	2.71	3.55
FeO		26.82	26.5	26.48	25.69	25.15	24.69	24.67	24.85	25.38	25.15	25.46	26.71
MnO		2.49	2.93	3.63	4.44	4.66	5.23	5.38	5.8	5.31	5.06	4.85	2.14
CaO		8.14	8.24	8.22	8.14	8.52	8.34	8.15	7.92	8.16	8.12	8.25	8.06
TOTAL		99.57	99.08	99.93	99.65	100.02	99.7	99.27	99.33	99.92	99.39	99.73	98.51
24 oxygens													
Si		5.942	5.967	5.942	5.932	5.963	5.911	5.948	5.952	5.92	5.927	5.94	5.945
Al		0.058	0.033	0.058	0.068	0.037	0.089	0.052	0.048	0.08	0.073	0.06	0.055
		6	6	6	6	6	6	6	6	6	6	6	6
Al		3.932	3.945	3.944	3.934	3.938	3.952	3.964	3.908	3.888	3.92	3.925	3.929
Ti		0.01	0	0.006	0.008	0.014	0.029	0.016	0.015	0.014	0.013	0.014	0.006
		3.942	3.945	3.95	3.942	3.952	3.981	3.98	3.923	3.902	3.933	3.939	3.935
Mg		0.816	0.738	0.686	0.693	0.663	0.633	0.613	0.64	0.674	0.678	0.645	0.851
Fe		3.569	3.549	3.524	3.431	3.342	3.294	3.307	3.337	3.39	3.372	3.401	3.591
Mn		0.336	0.398	0.489	0.401	0.628	0.706	0.731	0.79	0.719	0.687	0.656	0.292
Ca		1.389	1.414	1.401	1.393	1.45	1.425	1.399	1.364	1.397	1.395	1.412	1.388
		6.11	6.099	6.1	6.118	6.083	6.058	6.05	6.131	6.18	6.132	6.114	6.122
XCa		0.2273	0.2318	0.2297	0.2277	0.2384	0.2352	0.2312	0.2225	0.2261	0.2275	0.2309	0.2267
XCa+XMn		0.2823	0.2971	0.3098	0.3259	0.3416	0.3518	0.3521	0.3513	0.3424	0.3395	0.3382	0.2744
FE/MG		4.3738	4.8089	5.1370	4.9509	5.0407	5.2038	5.3948	5.2141	5.0297	4.9735	5.2729	4.2197
MG/MG+FE		0.1861	0.1721	0.1629	0.1680	0.1655	0.1612	0.1564	0.1609	0.1658	0.1674	0.1594	0.1916

Sample 87-195-3

Garnet

G.39

(Hbd11/14&Bi matrix)

SIO2	36.98
AL2O3	21.02
TIO2	0.05
MGO	3.55
FEO	26.71
MNO	2.14
CAO	8.06
TOTAL	98.51

24 oxygens

SI	5.945
AL	0.055
	6

AL

TI	3.929
	0.006
	3.935

MG

FE	0.851
MN	3.591
CA	0.292
	1.388
	6.122

XCa

XCa+XMn	0.2267
	0.2744

FE/MG

MG/MG+FE	4.2197
	0.1916

Compositions used for geothermobarometry

Hornblende

	HB.11	HB.12	HB.13	HB.14	average
SIO2	43.39	44.24	43.36	43.98	43.743
AL2O3	15.29	14.22	15.07	14.57	14.788
TIO2	0.62	0.54	0.69	0.59	0.610
FEO	13.59	12.45	13.05	13.21	13.075
MNO	0.46	0.37	0.50	0.52	0.463
CR2O3	0.05	0.00	0.06	0.11	0.055
MGO	10.72	11.63	10.97	11.19	11.128
CAO	12.49	12.08	12.25	12.24	12.265
K2O	0.88	0.85	0.88	0.87	0.870
NA2O	0.90	0.77	0.67	0.92	0.815
TOTAL	98.39	97.15	97.50	98.20	97.810
23 oxygens					
SI	6.342	6.493	6.372	6.424	6.4078
ALIV	1.658	1.507	1.628	1.576	1.5923
	8	8	8	8	8
ALVI	0.976	0.953	0.982	0.933	0.9610
TI	0.069	0.059	0.076	0.064	0.0670
FE	1.661	1.528	1.605	1.614	1.6020
MN	0.057	0.046	0.062	0.065	0.0575
CR	0.006	0.000	0.007	0.012	0.0063
MG	2.336	2.544	2.403	2.436	2.4298
	5.105	5.130	5.135	5.124	5.1235
CA	1.956	1.899	1.928	1.915	1.9245
K	0.165	0.160	0.166	0.162	0.1633
NA	0.256	0.219	0.192	0.260	0.2318
	2.377	2.278	2.286	2.337	2.3195

Figure 2-21

Sample 87-195-3		Biotite compositions for geothermobarometry						Figure 2-21
		BI.1	BI.2	BI.3	BI.4	BI.5	BI.6	BI.7
SiO ₂		36.38	36.89	36.07	36.91	36.04	36.5	36.37
Al ₂ O ₃		17.86	17.72	17.77	17.98	17.88	17.78	17.49
TiO ₂		1.4	2.18	2.1	1.91	1.94	2.7	2.01
Cr ₂ O ₃		0	0	0	0.02	0	0	0
FeO		15.37	15.46	15.71	16.05	15.44	15.99	16.17
MnO		0.29	0.26	0.36	0.36	0.33	0.28	0.35
MgO		12.37	12.75	12.51	12.82	12.34	12.05	12.59
CaO		0	0	0	0	0	0	0
K ₂ O		8.79	8.57	8.56	8.91	8.61	8.79	8.43
BAO		1.59	1.83	1.79	1.52	1.73	1.38	2.17
Na ₂ O		0.17	0.46	0.06	0.26	0.59	0.27	0.35
TOTAL		94.22	96.12	94.93	96.74	94.9	95.74	95.93
22 oxygens								
SI		5.543	5.514	5.472	5.491	5.47	5.482	5.487
AL		2.457	2.486	2.528	2.509	2.53	2.518	2.513
		8	8	8	8	8	8	8
AL		0.75	0.636	0.65	0.644	0.67	0.631	0.596
TI		0.161	0.245	0.239	0.214	0.222	0.305	0.228
CR		0	0	0	0.002	0	0	0
FE		1.958	1.933	1.994	1.997	1.959	2.009	2.041
MN		0.038	0.033	0.046	0.045	0.043	0.035	0.045
MG		2.81	2.842	2.828	2.843	2.793	2.698	2.831
		5.717	5.689	5.757	5.745	5.687	5.678	5.741
CA		0	0	0	0	0	0	0
K		1.709	1.634	1.657	1.692	1.667	1.685	1.622
BA		0.095	0.107	0.107	0.089	0.103	0.081	0.128
NA		0.049	0.134	0.016	0.076	0.174	0.078	0.103
		1.853	1.875	1.78	1.857	1.944	1.844	1.853
XAl		0.1312	0.1118	0.1129	0.1121	0.1178	0.1111	0.1038
XTi		0.0282	0.0431	0.0415	0.0372	0.0390	0.0537	0.0397
XFe/XMg		0.6968	0.6802	0.7051	0.7024	0.7014	0.7446	0.7209
MG/MC+FE		0.5893	0.5952	0.5865	0.5874	0.5878	0.5732	0.5811

Sample 87-195-3		Biotite compositions for geothermobarometry (end)						Figure 2-21
		BI.8	BI.9	BI.10	BI.21	BI.22	BI.23	average
SIO2		36.69	36.04	36.08	35.89	36.26	36.22	36.319
AL2O3		18.04	17.88	17.46	17.9	17.89	17.75	17.818
TIO2		1.79	1.88	2.14	1.55	1.7	2.06	1.943
CR2O3		0.02	0	0	0	0	0.03	0.005
FEO		16.31	15.68	16.28	16.56	16.6	16.53	15.980
MNO		0.37	0.27	0.39	0.27	0.27	0.37	0.319
MGO		13.01	12.48	12.5	12.46	12.55	12.22	12.481
CAO		0	0	0	0	0	0.02	0.003
K2O		9.06	8.45	8.7	8.77	8.89	8.67	8.702
BAO		1.04	1.68	2.14	1.24	1.3	0.3	1.539
NA2O		0.12	0.11	0.23	0.3	0.47	0.32	0.296
TOTAL		96.45	94.47	95.92	94.94	95.93	94.49	95.406
22 oxygens								
SI		5.468	5.483	5.458	5.454	5.457	5.484	5.4821
AL		2.532	2.517	2.542	2.546	2.543	2.516	2.5179
		8	8	8	8	8	8	8
AL		0.636	0.688	0.572	0.66	0.632	0.653	0.6524
TI		0.201	0.215	0.243	0.177	0.192	0.235	0.2205
CR		0.002	0	0	0	0	0.003	0.0005
FE		2.033	1.995	2.06	2.104	2.089	2.094	2.0174
MN		0.046	0.035	0.05	0.035	0.034	0.048	0.0408
MG		2.89	2.829	2.818	2.822	2.817	2.758	2.8081
		5.808	5.762	5.743	5.798	5.764	5.791	5.7397
CA		0	0	0	0	0	0.004	0.0006
K		1.722	1.64	1.679	1.699	1.707	1.675	1.6756
BA		0.061	0.1	0.127	0.074	0.077	0.018	0.0911
NA		0.034	0.034	0.066	0.09	0.137	0.093	0.0865
		1.817	1.774	1.872	1.863	1.921	1.79	1.8539
XAl		0.1095	0.1194	0.0996	0.1138	0.1096	0.1128	0.11369
XTi		0.0346	0.0373	0.0423	0.0305	0.0333	0.0406	0.03844
XFe/XMg		0.7035	0.7052	0.7310	0.7456	0.7416	0.7592	0.71860
MG/MG+FE		0.5870	0.5864	0.5777	0.5729	0.5742	0.5684	0.58197

Sample 87-195-3		Plagioclase compositions for geothermobarometry										Figure 2-21	
	low An PT	PL.1	PL.2	PL.3	PL.4	PL.5	PL.6	PL.7	PL.8	PL.9	average		
SiO2		63.32	58.77	54.65	59.67	58.18	58.26	53.79	59.45	55.51	57.95		
Al2O3		23.53	26.80	29.22	25.64	27.10	26.97	29.78	26.05	28.54	27.07		
CaO		4.74	8.22	11.52	6.89	8.73	8.40	11.94	7.44	10.72	8.73		
Na2O		8.61	6.93	4.91	7.43	6.28	6.24	4.53	7.17	5.25	6.37		
K2O		0.46	0.23	0.20	0.19	0.30	0.25	0.21	0.36	0.16	0.26		
FeO		0.10	0.13	0.14	0.39	0.11	0.10	0.28	0.18	0.08	0.17		
TOTAL		100.76	101.08	100.64	100.21	100.70	100.22	100.53	100.65	100.26	100.55		
16 oxygens													
Si		5.565	5.204	4.903	5.313	5.171	5.193	4.841	5.277	4.983	5.163		
Al		2.438	2.797	3.091	2.691	2.839	2.834	3.159	2.725	3.020	2.842		
		8.003	8.001	7.994	8.004	8.010	8.027	8.000	8.002	8.003	8.005		
Ca		0.446	0.780	1.108	0.657	0.832	0.802	1.151	0.708	1.032	0.834		
Na		1.467	1.190	0.855	1.283	1.083	1.079	0.791	1.234	0.913	1.101		
K		0.052	0.026	0.023	0.021	0.034	0.028	0.024	0.040	0.018	0.030		
		1.965	1.996	1.986	1.961	1.949	1.909	1.966	1.982	1.963	1.965		
FE		0.008	0.009	0.011	0.029	0.008	0.008	0.021	0.013	0.006	0.013		
An		0.23	0.39	0.56	0.34	0.43	0.42	0.59	0.36	0.53	0.42		

Sample 87-150-7		Garnet traverse										Figure 2-22	
		GN.1	GN.2	GN.3	GN.4	GN.5	GN.6	GN.7	GN.8	GN.9	GN.10		
SiO ₂		38.28	39.02	38.60	38.52	38.49	38.60	38.71	38.71	38.65	38.73		
Al ₂ O ₃		21.59	21.94	22.04	21.72	21.85	21.73	21.72	21.73	22.20	22.11		
TiO ₂		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00		
MgO		7.05	7.73	8.10	8.26	7.97	8.29	8.05	8.05	8.39	8.20		
FeO		30.58	29.74	29.35	29.13	29.02	29.25	29.32	29.50	29.20	29.31		
MnO		0.81	0.73	0.69	0.62	0.77	0.66	0.70	0.79	0.70	0.67		
CaO		2.20	2.32	2.22	2.24	2.29	2.26	2.30	2.16	2.05	2.10		
TOTAL		100.51	101.48	101.00	100.49	100.39	100.79	100.80	100.96	101.19	101.12		
24 oxygens													
Si		5.971	5.990	5.948	5.963	5.965	5.961	5.978	5.974	5.936	5.954		
Al		0.029	0.010	0.052	0.037	0.035	0.039	0.022	0.026	0.064	0.046		
		6	6	6	6	6	6	6	6	6	6		
Al		3.940	3.960	3.951	3.926	3.956	3.916	3.932	3.926	3.955	3.960		
Ti		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000		
		3.940	3.960	3.951	3.926	3.956	3.916	3.932	3.928	3.955	3.960		
Mg		1.640	1.770	1.860	1.906	1.841	1.908	1.852	1.851	1.921	1.880		
Fe		3.990	3.819	3.783	3.772	3.762	3.778	3.787	3.807	3.751	3.769		
Mn		0.107	0.095	0.091	0.082	0.101	0.086	0.091	0.104	0.091	0.088		
Ca		0.367	0.381	0.366	0.371	0.380	0.375	0.380	0.358	0.338	0.347		
		6.104	6.065	6.100	6.131	6.084	6.147	6.110	6.120	6.101	6.084		
XCa		0.0601	0.0628	0.0600	0.0605	0.0625	0.0610	0.0622	0.0585	0.0554	0.0570		
XCa+XMn		0.0777	0.0785	0.0749	0.0739	0.0791	0.0750	0.0771	0.0755	0.0703	0.0715		
Fe/Mg		2.4329	2.1576	2.0339	1.9790	2.0435	1.9801	2.0448	2.0567	1.9526	2.0048		
Mg/Mg+Fe		0.2913	0.3167	0.3296	0.3357	0.3286	0.3356	0.3284	0.3271	0.3387	0.3328		

Sample 87-150-7		Garnet traverse (continued)										Figure 2-22	
		GN.11	GN.12	GN.13	GN.14	GN.15	GN.16	GN.17	GN.18	GN.19	GN.20		
SiO ₂		38.87	38.55	38.56	38.67	38.44	38.40	38.36	38.23	38.13	38.23		
Al ₂ O ₃		22.13	22.11	22.16	22.07	21.90	22.10	22.10	21.72	21.67	21.30		
TiO ₂		0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00		
MgO		8.33	8.10	7.96	8.42	8.11	7.69	7.81	7.82	7.61	7.59		
FeO		29.55	29.47	29.63	29.48	29.35	29.22	29.14	29.08	29.13	28.76		
MnO		0.70	0.61	0.71	0.70	0.69	0.76	0.70	0.66	0.69	0.53		
CaO		2.11	2.30	2.21	2.21	2.31	2.46	2.65	2.57	2.64	2.76		
TOTAL		101.72	101.14	101.23	101.55	100.80	100.64	100.76	100.08	99.87	99.17		
24 oxygens													
Si		5.946	5.935	5.936	5.929	5.941	5.943	5.930	5.952	5.955	6.001		
Al		0.054	0.065	0.064	0.071	0.059	0.057	0.070	0.048	0.045	0.000		
		6	6	6	6	6	6	6	6	6	6		
Al		3.937	3.947	3.957	3.917	3.930	3.975	3.957	3.938	3.944	3.941		
Ti		0.004	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000		
		3.941	3.947	3.957	3.917	3.930	3.977	3.957	3.938	3.944	3.941		
Mg		1.900	1.860	1.827	1.924	1.868	1.775	1.800	1.814	1.771	1.775		
Fe		3.780	3.795	3.814	3.781	3.793	3.782	3.768	3.787	3.804	3.776		
Mn		0.090	0.079	0.092	0.092	0.091	0.099	0.092	0.087	0.091	0.071		
Ca		0.346	0.379	0.364	0.363	0.383	0.408	0.439	0.428	0.441	0.463		
		6.116	6.113	6.097	6.160	6.135	6.064	6.099	6.116	6.107	6.085		
XCa		0.0566	0.0620	0.0597	0.0589	0.0624	0.0673	0.0720	0.0700	0.0722	0.0761		
XCa+XMn		0.0713	0.0749	0.0748	0.0739	0.0773	0.0836	0.0871	0.0842	0.0871	0.0878		
Fe/Mg		1.9895	2.0403	2.0876	1.9652	2.0305	2.1307	2.0933	2.0877	2.1479	2.1273		
Mg/Mg+Fe		0.3345	0.3289	0.3239	0.3372	0.3300	0.3194	0.3233	0.3239	0.3177	0.3198		

Sample 87-150-7		Garnet traverse (end)										Figure 2-22	
		GN.21	GN.22	GN.23	GN.24	GN.25	GN.26	GN.27	GN.28	GN.29			
SiO ₂		38.15	38.25	37.97	38.06	38.15	38.34	38.10	38.07	38.17			
Al ₂ O ₃		22.10	21.73	21.74	21.78	21.77	22.22	21.81	21.91	21.61			
TiO ₂		0.00	0.00	0.01	0.00	0.02	0.02	0.02	0.02	0.00			
MgO		7.75	7.77	7.76	7.83	7.65	7.93	7.55	7.52	7.08			
FeO		29.24	28.98	28.96	29.03	29.07	29.54	29.12	29.34	29.89			
MnO		0.61	0.69	0.63	0.71	0.66	0.72	0.69	0.64	0.74			
CaO		2.65	2.77	2.68	2.45	2.48	2.34	2.54	2.34	2.20			
TOTAL		100.50	100.19	99.75	99.86	99.80	101.11	99.83	99.84	99.69			
24 oxygens													
Si		5.918	5.949	5.934	5.939	5.954	5.913	5.949	5.944	5.983			
Al		0.082	0.051	0.066	0.061	0.046	0.087	0.051	0.056	0.017			
		6	6	6	6	6	6	6	6	6			
Al		3.958	3.934	3.938	3.946	3.960	3.951	3.963	3.976	3.976			
Ti		0.000	0.000	0.002	0.000	0.002	0.002	0.002	0.002	0.000			
		3.958	3.934	3.940	3.946	3.962	3.953	3.965	3.978	3.976			
Mg		1.791	1.801	1.807	1.821	1.781	1.822	1.756	1.751	1.656			
Fe		3.792	3.770	3.785	3.788	3.795	3.810	3.803	3.832	3.919			
Mn		0.080	0.092	0.084	0.093	0.087	0.094	0.092	0.085	0.098			
Ca		0.441	0.461	0.448	0.410	0.414	0.387	0.426	0.392	0.370			
		6.104	6.124	6.124	6.112	6.077	6.113	6.077	6.060	6.043			
XCu		0.0722	0.0753	0.0732	0.0671	0.0681	0.0633	0.0701	0.0647	0.0612			
XCu+XMn		0.0854	0.0903	0.0869	0.0823	0.0824	0.0787	0.0852	0.0787	0.0774			
Fe/Mg		2.1173	2.0933	2.0946	2.0802	2.1308	2.0911	2.1657	2.1885	2.3665			
Mg/Mg+Fe		0.3208	0.3233	0.3231	0.3247	0.3194	0.3235	0.3159	0.3136	0.2970			

Sample 87-150-7 Garnet compositions for geothermobarometry Figure 2-23

	GN.3 (Bt matrix)	GN.36 (Bt matrix)	GN.49 (Bt matrix)	GN.65	GN.66	GN.67 (Bi 25/27)	GN.71	GN.72	GN.73	average (Bi 31/33)
SiO2	38.60	37.82	38.19	38.14	37.76	37.75	37.57	37.89	37.60	37.687
Al2O3	22.04	21.67	21.78	21.83	21.47	21.62	21.89	21.76	21.99	21.880
TiO2	0.00	0.00	0.02	0.00	0.00	0.04	0.00	0.04	0.01	0.017
MgO	8.10	7.63	7.78	7.15	7.17	7.06	6.96	7.38	7.08	7.140
FeO	29.35	28.97	28.69	30.20	30.46	30.33	30.26	30.15	29.74	30.050
MnO	0.69	0.83	0.69	0.69	0.66	0.56	0.79	0.75	0.70	0.747
CaO	2.22	2.49	2.32	2.46	2.30	2.47	2.13	2.25	2.51	2.297
TOTAL	101.00	99.41	99.47	100.47	99.82	99.83	99.60	100.22	99.63	99.817
24 oxygens										
Si	5.948	5.935	5.968	5.943	5.936	5.930	5.914	5.922	5.905	5.9137
Al	0.052	0.065	0.032	0.057	0.064	0.070	0.086	0.078	0.095	0.0863
	6	6	6	6	6	6	6	6	6	6
Al	3.951	3.944	3.980	3.952	3.914	3.932	3.975	3.930	3.976	3.9603
Ti	0.000	0.000	0.002	0.000	0.000	0.004	0.000	0.004	0.001	0.0017
	3.951	3.944	3.982	3.952	3.914	3.936	3.975	3.934	3.977	3.9620
Mg	1.860	1.785	1.813	1.662	1.681	1.653	1.632	1.719	1.658	1.6697
Fe	3.783	3.802	3.750	3.936	4.004	3.985	3.984	3.941	3.907	3.9440
Mn	0.091	0.110	0.092	0.091	0.088	0.075	0.105	0.100	0.093	0.0993
Ca	0.366	0.418	0.388	0.410	0.387	0.415	0.359	0.376	0.423	0.3860
	6.100	6.115	6.043	6.099	6.160	6.128	6.080	6.136	6.081	6.0990
XCa	0.0600	0.0684	0.0642	0.0672	0.0628	0.0677	0.0590	0.0613	0.0696	0.06329
XCa+XMn	0.0749	0.0863	0.0794	0.0821	0.0771	0.0800	0.0763	0.0776	0.0849	0.07958
Fe/Mg	2.0339	2.1300	2.0684	2.3682	2.3819	2.4108	2.4412	2.2926	2.3565	2.36341
Mg/Mg+Fe	0.3296	0.3195	0.3259	0.2969	0.2957	0.2932	0.2906	0.3037	0.2979	0.29741

Sample 87-150-7		Biotite compositions for geothermobarometry						Figure 2-23
		BI.36	BI.37	BI.38	BI.39	BI.40	BI.41	BI.42 average (GN 3,36&39)
SIO2		36.27	36.29	35.94	36.15	35.69	35.75	35.59
AL2O3		18.73	18.67	18.95	18.50	18.27	18.26	18.53
TIO2		2.50	2.16	2.46	2.34	2.35	2.34	2.23
CR2O3		0.00	0.00	0.07	0.09	0.04	0.00	0.00
FEO		13.35	13.24	13.71	13.68	13.73	14.10	13.99
MNO		0.00	0.00	0.08	0.03	0.04	0.01	0.04
MGO		14.15	14.23	14.16	14.12	14.15	13.78	13.61
CAO		0.08	0.04	0.10	0.03	0.00	0.02	0.00
K2O		7.05	7.07	7.05	7.17	7.31	7.61	7.61
BAO		2.76	2.88	2.39	2.43	2.55	2.44	2.69
NA2O		0.91	0.58	0.57	0.27	0.84	0.47	0.43
TOTAL		95.80	95.16	95.48	94.81	94.97	94.78	94.72
22 oxygens								
SI		5.384	5.418	5.346	5.411	5.365	5.389	5.375
AL		2.616	2.582	2.654	2.589	2.635	2.611	2.625
		8	8	8	8	8	8	8
AL		0.661	0.703	0.667	0.676	0.601	0.634	0.675
TI		0.279	0.242	0.275	0.263	0.266	0.266	0.253
CR		0.000	0.000	0.009	0.011	0.005	0.000	0.000
FE		1.658	1.653	1.705	1.713	1.726	1.777	1.767
MN		0.000	0.000	0.010	0.004	0.005	0.001	0.005
MG		3.131	3.167	3.140	3.152	3.170	3.097	3.065
		5.729	5.765	5.806	5.819	5.773	5.775	5.765
CA		0.013	0.007	0.016	0.004	0.000	0.003	0.000
K		1.336	1.346	1.339	1.370	1.402	1.464	1.466
BA		0.160	0.169	0.139	0.142	0.150	0.144	0.159
NA		0.261	0.169	0.165	0.078	0.244	0.137	0.127
		1.77	1.691	1.659	1.594	1.796	1.748	1.752
XAl		0.1154	0.1219	0.1149	0.1162	0.1041	0.1098	0.1171
XTi		0.0487	0.0420	0.0474	0.0452	0.0461	0.0461	0.0439
XFe/XMg		0.5295	0.5219	0.5430	0.5435	0.5445	0.5738	0.5765
MG/MG+FE		0.6538	0.6571	0.6481	0.6479	0.6475	0.6354	0.6343

Sample 87-150-7 Biotite compositions for geothermobarometry (end) Figure 2-23								
	BI.25	BI.26	BI.27	average (Gn.65/67)	BI.31	BI.32	BI.33	average (Gn.71/73)
SIO2	36.84	36.32	36.32	36.493	36.42	36.17	36.98	36.523
AL2O3	18.54	18.56	18.23	18.443	18.63	18.60	18.50	18.577
TIO2	1.64	1.69	1.96	1.763	2.00	1.70	2.21	1.970
CR2O3	0.01	0.04	0.04	0.030	0.10	0.00	0.13	0.077
FEO	14.41	14.48	14.50	14.463	14.50	14.46	14.80	14.587
MNO	0.01	0.00	0.08	0.030	0.06	0.02	0.00	0.027
MGO	14.29	13.90	14.05	14.080	14.19	13.85	14.07	14.037
CAO	0.08	0.04	0.04	0.053	0.12	0.03	0.03	0.060
K2O	7.01	6.97	6.88	6.953	6.94	6.93	7.08	6.983
BAO	2.57	2.71	2.68	2.653	2.77	2.55	2.82	2.713
NA2O	0.54	0.65	0.58	0.590	0.82	0.84	0.62	0.760
TOTAL	95.94	95.36	95.36	95.553	96.55	95.15	97.24	96.313
22 oxygens								
SI	5.462	5.434	5.433	5.4430	5.390	5.421	5.433	5.4147
AL	2.538	2.566	2.567	2.5570	2.610	2.579	2.567	2.5853
	8	8	8	8	8	8	8	8
AL	0.702	0.706	0.648	0.6853	0.639	0.706	0.636	0.6603
TI	0.183	0.190	0.221	0.1980	0.222	0.192	0.244	0.2193
CR	0.001	0.004	0.005	0.0033	0.012	0.000	0.015	0.0090
FE	1.787	1.811	1.815	1.8043	1.794	1.813	1.818	1.8083
MN	0.001	0.000	0.011	0.0040	0.007	0.002	0.000	0.0030
MG	3.158	3.101	3.133	3.1307	3.131	3.094	3.081	3.1020
	5.832	5.812	5.833	5.8257	5.805	5.807	5.794	5.8020
CA	0.013	0.007	0.006	0.0087	0.019	0.004	0.005	0.0093
K	1.326	1.330	1.313	1.3230	1.310	1.325	1.328	1.3210
BA	0.150	0.159	0.157	0.1553	0.161	0.150	0.163	0.1580
NA	0.154	0.189	0.169	0.1707	0.234	0.244	0.176	0.2180
	1.643	1.685	1.645	1.6577	1.724	1.723	1.672	1.7063
XAl	0.1204	0.1215	0.1111	0.11765	0.1101	0.1216	0.1098	0.11381
XTi	0.0314	0.0327	0.0379	0.03399	0.0382	0.0331	0.0421	0.03781
XFe/XMg	0.5659	0.5840	0.5793	0.57640	0.5730	0.5860	0.5901	0.58301
MG/MG+FE	0.6386	0.6313	0.6332	0.63437	0.6357	0.6305	0.6289	0.63172

Sample 87-150-7		Plagioclase compositions for geothermobarometry											Figure 2-23	
		PL.7	PL.8	PL.9	PL.10	PL.11	PL.12	PL.13	PL.14	PL.15	average			
SIO2		60.42	61.11	60.64	60.97	60.69	60.53	60.57	61.01	61.11	60.78			
AL2O3		26.17	25.90	25.85	25.86	25.64	25.42	25.67	25.35	25.66	25.72			
CAO		7.09	6.83	6.99	6.74	6.99	6.65	6.73	6.46	6.69	6.80			
NA2O		7.26	7.63	7.46	8.01	7.47	7.41	7.75	7.86	7.69	7.61			
K2O		0.22	0.24	0.18	0.25	0.17	0.19	0.23	0.23	0.17	0.21			
FEO		0.00	0.10	0.11	0.06	0.02	0.10	0.10	0.11	0.03	0.07			
TOTAL		101.16	101.81	101.23	101.89	100.98	100.3	101.95	101.02	101.35	101.19			
16 oxygens														
SI		5.315	5.344	5.334	5.335	5.348	5.365	5.340	5.375	5.362	5.346			
AL		2.713	2.669	2.680	2.667	2.663	2.656	2.668	2.633	2.654	2.667			
		8.028	8.013	8.014	8.002	8.011	8.021	8.008	8.008	8.016	8.013			
CA		0.668	0.640	0.659	0.632	0.660	0.632	0.635	0.610	0.629	0.641			
NA		1.239	1.293	1.272	1.359	1.277	1.274	1.325	1.342	1.308	1.299			
K		0.025	0.027	0.021	0.028	0.019	0.021	0.026	0.026	0.020	0.024			
		1.932	1.960	1.952	2.019	1.956	1.927	1.986	1.978	1.957	1.964			
FE	0		0.008	0.008	0.005	0.002	0.008	0.007	0.008	0.002	0.005			
An	0.35		0.33	0.34	0.31	0.34	0.33	0.32	0.31	0.32	0.33			

Sample 87-46-1 Garnet traverse 1 Figure 2-24

	GN47	GN48	GN49	GN50	GN51	GN52	GN53	GN54	GN55	GN56	GN57	GN58	GN59
SiO2	37.65	37.8	37.46	37.78	37.61	37.93	37.39	37.37	37.69	37.49	37.42	37.46	37.2
Al2O3	21.11	21.22	21.04	21.2	21	21.17	20.91	21.07	21.23	21.3	21.32	21.48	20.93
TiO2	0.06	0.1	0.07	0	0.04	0.08	0.16	0.12	0.11	0.16	0.15	0.12	0.02
CR2O3	0	0	0	0	0	0	0	0	0	0	0	0	0
FeO	27.43	26.27	26.79	26.3	25.73	25.94	26.22	25.96	26.61	26.2	26.1	26.64	27.07
MnO	0.96	2.08	2	2.3	2.79	2.69	2.24	2.7	2.02	2.21	2.2	1.82	1.64
MgO	3.52	3.01	3.09	3.03	2.82	3.22	3.24	3.03	3.04	3.2	3.3	3.26	3.19
CaO	8.66	9.21	8.88	9.01	9.17	9.39	9.03	9.12	9.1	8.96	9.1	8.78	8.86
K2O	0	0	0	0	0	0	0	0	0	0	0	0	0
Na2O	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	99.39	99.69	99.33	99.62	99.16	100.42	99.19	99.37	99.8	99.52	99.61	99.56	98.91
22 oxygens													
Si	5.486	5.494	5.478	5.499	5.504	5.482	5.472	5.465	5.479	5.462	5.447	5.452	5.466
Al	2.514	2.506	2.522	2.501	2.496	2.518	2.528	2.535	2.521	2.538	2.553	2.548	2.534
	8	8	8	8	8	8	8	8	8	8	8	8	8
Al	1.111	1.13	1.105	1.136	1.126	1.088	1.079	1.096	1.117	1.118	1.104	1.137	1.091
Ti	0.006	0.011	0.008	0	0.005	0.008	0.017	0.013	0.012	0.017	0.016	0.013	0.003
CR	0	0	0	0	0	0	0	0	0	0	0	0	0
Fe	3.342	3.193	3.276	3.201	3.149	3.135	3.21	3.175	3.235	3.192	3.18	3.242	3.326
Mn	0.119	0.257	0.248	0.283	0.346	0.329	0.278	0.334	0.249	0.272	0.272	0.224	0.204
Mg	0.764	0.653	0.673	0.658	0.616	0.693	0.708	0.66	0.66	0.695	0.716	0.707	0.7
	5.322	5.244	5.31	5.278	5.242	5.253	5.292	5.278	5.273	5.294	5.288	5.323	5.324
Ca	1.353	1.434	1.391	1.405	1.438	1.454	1.417	1.429	1.417	1.398	1.42	1.369	1.394
K	0	0	0	0	0	0	0	0	0	0	0	0	0
Na	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.353	1.434	1.391	1.405	1.438	1.454	1.417	1.429	1.417	1.398	1.42	1.369	1.394

Sample 87-46-1		Garnet traverse 2										Figure 2-24	
		GN60	GN61	GN62	GN63	GN64	GN65	GN66	GN67	GN68			
SiO ₂		38.24	37.75	38.02	37.92	37.63	37.69	37.52	37.54	37.42			
Al ₂ O ₃		21.83	21.16	21.81	21.57	21.32	21.17	21.41	21.65	21.04			
TiO ₂		0.15	0	0.04	0.01	0.09	0	0.05	0.11	0			
Cr ₂ O ₃		0	0	0	0	0	0	0	0	0			
FeO		27.92	27.15	27.52	26.97	26.16	25.75	26.45	25.68	25.9			
MnO		0.53	0.98	1.37	2.27	3.05	3.24	3.17	3.54	3.1			
MgO		3.46	3.37	3.52	3.31	2.89	2.85	2.95	2.76	2.56			
CaO		9.16	8.95	8.69	8.85	8.88	9.24	8.04	9.14	9.07			
K ₂ O		0	0	0	0	0	0	0	0	0			
Na ₂ O		0	0	0	0	0	0	0	0	0			
TOTAL		101.29	99.36	100.97	100.9	100.02	99.94	99.59	100.42	99.09			
22 oxygens													
Si		5.46	5.498	5.452	5.457	5.468	5.483	5.474	5.437	5.493			
Al		2.54	2.502	2.548	2.543	2.532	2.517	2.526	2.563	2.507			
		8	8	8	8	8	8	8	8	8			
Al		1.133	1.13	1.139	1.115	1.121	1.113	1.156	1.133	1.134			
Ti		0.016	0	0.004	0.001	0.01	0	0.006	0.012	0			
Cr		0	0	0	0	0	0	0	0	0			
Fe		3.334	3.307	3.3	3.245	3.18	3.133	3.228	3.11	3.181			
Mn		0.064	0.121	0.167	0.277	0.375	0.399	0.391	0.435	0.385			
Mg		0.737	0.732	0.754	0.711	0.627	0.618	0.642	0.595	0.56			
		5.284	5.29	5.364	5.349	5.313	5.263	5.423	5.285	5.26			
Ca		1.402	1.396	1.335	1.365	1.383	1.44	1.256	1.419	1.427			
K		0	0	0	0	0	0	0	0	0			
Na		0	0	0	0	0	0	0	0	0			
		1.402	1.396	1.335	1.365	1.383	1.44	1.256	1.419	1.427			

Sample 87-46-1		Garnet traverse 2 (end)										Figure 2-24	
		GN69	GN70	GN71	GN72	GN73	GN74	GN75	GN76				
SiO ₂		37.78	37.79	38.13	37.81	37.94	37.72	38.22	37.47				
Al ₂ O ₃		21.53	21.39	21.32	21.54	21.66	21.47	21.68	21.17				
TiO ₂		0.06	0.02	0.09	0.1	0.07	0.04	0.07	0.21				
Cr ₂ O ₃		0	0	0	0	0	0	0	0				
FeO		26.17	26.22	26.9	27.29	27.43	27.89	27.84	27.54				
MnO		3	2.67	1.7	1.28	0.81	0.61	0.52	0.53				
MgO		3.14	3.1	3.46	3.4	3.59	3.69	3.59	3.62				
CaO		8.86	9.02	8.82	8.8	9.07	8.61	8.76	9.14				
K ₂ O		0	0	0	0	0	0	0	0				
Na ₂ O		0	0	0	0	0	0	0	0				
TOTAL		100.54	100.21	100.42	100.22	100.57	100.03	100.68	99.68				
22 oxygens													
Si		5.456	5.473	5.496	5.462	5.456	5.458	5.483	5.447				
Al		2.544	2.527	2.504	2.538	2.544	2.542	2.517	2.553				
		8	8	8	8	8	8	8	8				
Al		1.122	1.125	1.119	1.131	1.127	1.12	1.15	1.074				
Ti		0.006	0.002	0.01	0.011	0.008	0.004	0.007	0.023				
Cr		0	0	0	0	0	0	0	0				
Fe		3.161	3.176	3.243	3.298	3.299	3.375	3.341	3.347				
Mn		0.367	0.327	0.207	0.157	0.098	0.075	0.063	0.065				
Mg		0.677	0.668	0.743	0.733	0.77	0.797	0.768	0.784				
		5.333	5.298	5.322	5.33	5.302	5.371	5.329	5.293				
Ca		1.371	1.4	1.362	1.363	1.398	1.335	1.347	1.423				
K		0	0	0	0	0	0	0	0				
Na		0	0	0	0	0	0	0	0				
		1.371	1.4	1.362	1.363	1.398	1.335	1.347	1.423				

Sample 87-46-1 Garnet compositions for geothermobarometry

Figure 2-25

	GN48	GN49	GN50	GN51	GN64	GN65	GN66	GN67	average (Hb matrix)	GA.3 (Hb4)	GA.4 (Hb5)	GA.7 (Hb15)
SiO ₂	37.80	37.46	37.78	37.61	37.63	37.69	37.52	37.54	37.629	37.77	37.89	37.77
Al ₂ O ₃	21.22	21.04	21.20	21.00	21.32	21.17	21.41	21.65	21.251	21.16	21.09	21.37
TiO ₂	0.10	0.07	0.00	0.04	0.09	0.00	0.05	0.11	0.058	0.05	0.1	0
MgO	3.01	3.09	3.03	2.82	2.89	2.85	2.95	2.76	2.925	3.51	3.36	3.28
FeO	26.27	26.79	26.30	25.73	26.16	25.75	26.45	25.68	26.141	27.61	27.3	26.27
MnO	2.08	2.00	2.30	2.79	3.05	3.24	3.17	3.54	2.771	1.09	0.95	2.49
CaO	9.21	8.88	9.01	9.17	8.88	9.24	8.04	9.14	8.946	8.7	9.2	8.97
TOTAL	99.69	99.33	99.62	99.16	100.02	99.94	99.59	100.42	99.721	99.89	99.89	100.15
Si	5.993	5.976	5.999	6.005	5.966	5.981	5.972	5.931	5.9779	5.98	5.994	5.967
Al	0.007	0.024	0.001	0.000	0.034	0.019	0.028	0.069	0.0228	0.02	0.006	0.033
	6	6	6	6.005	6	6	6	6	6.0006	6	6	6
Al	3.959	3.933	3.966	3.952	3.951	3.940	3.989	3.963	3.9566	3.928	3.926	3.947
Ti	0.012	0.008	0.000	0.005	0.011	0.000	0.006	0.013	0.0069	0.006	0.012	0
	3.971	3.941	3.966	3.957	3.962	3.940	3.995	3.976	3.9635	3.934	3.938	3.947
Mg	0.712	0.734	0.718	0.672	0.684	0.675	0.700	0.649	0.6930	0.828	0.793	0.772
Fe	3.483	3.574	3.492	3.435	3.469	3.418	3.521	3.393	3.4731	3.656	3.611	3.471
Mn	0.280	0.270	0.309	0.378	0.409	0.435	0.427	0.474	0.3728	0.147	0.127	0.333
Ca	1.565	1.518	1.533	1.569	1.509	1.571	1.371	1.548	1.5230	1.476	1.559	1.518
	6.040	6.096	6.052	6.054	6.071	6.099	6.019	6.064	6.0619	6.107	6.09	6.094
XCa	0.2591	0.2490	0.2533	0.2592	0.2486	0.2576	0.2278	0.2553	0.25122	0.2417	0.2560	0.2491
XCa+XMn	0.3055	0.2933	0.3044	0.3216	0.3159	0.3289	0.2987	0.3334	0.31272	0.2658	0.2768	0.3037
Fe/Mg	4.8919	4.8692	4.8635	5.1116	5.0716	5.0637	5.0300	5.2280	5.01620	4.4155	4.5536	4.4961
Mg/Mg+Fe	0.1697	0.1704	0.1705	0.1636	0.1647	0.1649	0.1658	0.1606	0.16629	0.1847	0.1801	0.1819

Sample 87-46-1		Hornblende compositions for geothermobarometry						Figure 2-25
		HB.7	HB.8	HB.9	HB.10	HB.13	HB.14	average
SIO ₂		42.10	43.38	41.23	41.32	43.38	41.30	42.118
AL ₂ O ₃		15.56	14.04	16.60	16.94	11.91	16.77	15.303
TIO ₂		0.64	0.65	0.68	0.73	0.68	0.69	0.678
FeO		17.36	17.68	17.20	17.13	17.55	16.60	17.253
MnO		0.13	0.14	0.13	0.06	0.15	0.03	0.107
CR ₂ O ₃		0.03	0.00	0.02	0.00	0.02	0.04	0.018
MgO		8.44	8.62	7.63	8.08	9.20	8.53	8.417
CaO		11.60	11.74	11.63	11.52	11.61	11.43	11.588
K ₂ O		0.69	0.62	0.83	0.83	0.50	0.73	0.700
Na ₂ O		1.13	1.07	1.11	1.44	0.79	1.42	1.160
TOTAL		97.68	97.94	97.06	98.05	95.79	97.54	97.343
23 oxygens								
SI		6.293	6.464	6.206	6.156	6.611	6.166	6.3160
ALIV		1.707	1.536	1.794	1.844	1.389	1.834	1.6840
		8	8	8	8	8	8	8
ALVI		1.035	0.931	1.152	1.131	0.751	1.117	1.0195
TI		0.072	0.073	0.077	0.081	0.078	0.078	0.0765
FE		2.170	2.203	2.166	2.134	2.237	2.073	2.1638
MN		0.017	0.018	0.017	0.007	0.019	0.004	0.0137
CR		0.003	0.000	0.002	0.000	0.002	0.004	0.0018
MG		1.880	1.916	1.711	1.795	2.091	1.899	1.8820
		5.177	5.141	5.125	5.148	5.178	5.175	5.1573
CA		1.858	1.875	1.876	1.839	1.896	1.828	1.8620
K		0.131	0.118	0.159	0.158	0.098	0.139	0.1338
NA		0.327	0.31	0.324	0.416	0.235	0.411	0.3372
		2.316	2.303	2.359	2.413	2.229	2.378	2.3330
FE/MG		1.1543	1.1498	1.2659	1.1889	1.0698	1.0916	1.15338
MG/MG+FE		0.4642	0.4652	0.4413	0.4569	0.4831	0.4781	0.46479

Sample 87-46-1		Hornblende (end)		
		HB.4	HB.5	HB.15
SIO ₂		42.25	41.86	42.85
AL ₂ O ₃		15.92	16.34	14.63
TIO ₂		0.65	0.7	0.55
FeO		17.17	16.19	16.96
MNO		0	0.05	0.11
CR ₂ O ₃		0	0	0
MGO		8.3	8.52	8.87
CAO		11.7	11.54	11.51
K ₂ O		0.73	0.76	0.63
NA ₂ O		1.11	1.17	0.49
TOTAL		97.83	97.13	96.6
23 oxygens				
SI		6.293	6.255	6.438
ALIV		1.707	1.745	1.562
		8	8	8
ALVI		1.088	1.133	1.028
TI		0.073	0.079	0.062
FE		2.139	2.023	2.131
MN		0.000	0.006	0.014
CR		0.000	0.000	0.000
MG		1.843	1.897	1.986
		5.143	5.138	5.221
CA		1.866	1.847	1.853
K		0.138	0.144	0.121
NA		0.319	0.338	0.142
		2.323	2.329	2.116
FE/MG		1.1606	1.0664	1.0730
MG/MG+FE		0.4628	0.4839	0.4824

Plagioclase compositions for geothermobarometry													Figure 2-25
Sample 87-46-1	PL.1	PL.4	PL.5	PL.7	PL.8	PL.9	PL.10	PL.11	PL.13	PL.14	average		
SiO2	59.75	56.50	58.02	59.24	58.00	59.26	59.59	58.67	59.42	58.80	58.725		
Al2O3	27.08	27.21	27.93	26.82	26.58	26.91	26.79	26.86	26.81	26.56	26.960		
CaO	8.08	8.74	9.11	7.83	7.90	8.05	7.84	8.03	7.77	7.77	8.112		
Na2O	7.36	6.26	6.50	7.02	7.21	7.05	7.62	6.78	7.42	6.69	6.991		
K2O	0.20	0.12	0.23	0.25	0.22	0.22	0.23	0.25	0.24	0.21	0.217		
FeO	0.21	0.25	0.06	0.17	0.22	0.09	0.11	0.22	0.15	0.15	0.163		
TOTAL	102.68	99.08	101.9	101.33	100.13	101.58	102.18	100.81	101.81	100.18	101.768		
16 oxygens													
Si	5.211	5.112	5.107	5.225	5.19	5.216	5.222	5.205	5.222	5.237	5.1947		
Al	2.784	2.902	2.903	2.788	2.804	2.792	2.767	2.909	2.778	2.789	2.8116		
	7.995	8.014	8.010	8.013	7.994	8.008	7.989	8.014	8.000	8.026	8.0063		
Ca	0.755	0.847	0.860	0.740	0.758	0.759	0.737	0.764	0.732	0.742	0.7694		
Na	1.244	1.098	1.109	1.201	1.252	1.203	1.295	1.167	1.265	1.155	1.1989		
K	0.022	0.014	0.026	0.029	0.026	0.025	0.026	0.028	0.027	0.023	0.0246		
	2.021	1.959	1.995	1.970	2.036	1.987	2.058	1.959	2.024	1.920	1.9929		
Fe	0.015	0.019	0.004	0.012	0.016	0.006	0.008	0.017	0.011	0.011	0.0119		
An	0.37	0.43	0.43	0.38	0.37	0.38	0.36	0.39	0.36	0.39	0.39		

Sample 87-46-1		Plagioclase compositions for geothermobarometry (end)				
		PL.3	PL.12	PL.15	PL.16	average
SiO2		52.89	51.39	56.01	52.06	53.088
Al2O3		30.96	31.53	29.16	30.83	30.620
CaO		12.83	13.57	13.69	12.65	13.185
Na2O		4.23	4.05	2.49	4.17	3.735
K2O		0.27	0.10	0.12	0.15	0.160
FeO		0.26	0.23	0.17	0.20	0.215
TOTAL		101.44	100.87	101.64	100.06	101.003
16 oxygens						
Si		4.734	4.639	4.954	4.720	4.7618
Al		3.266	3.355	3.041	3.294	3.2390
		8.000	7.994	7.995	8.014	8.0008
Ca		1.230	1.313	1.298	1.229	1.2675
Na		0.734	0.709	0.426	0.733	0.6505
K		0.030	0.011	0.013	0.017	0.0178
		1.994	2.033	1.737	1.979	1.9358
Fe		0.019	0.017	0.012	0.015	0.0158
An		0.62	0.65	0.75	0.62	0.66

Sample 89-69-2 Garnet traverse I Figure 2-26

	GN15	GN16	GN17	GN18	GN19	GN20	GN21	GN22	GN23	GN24	GN25	GN26	GN27	GN28
SiO ₂	37.33	37.1	37.42	37.72	37.21	37.09	37.46	37.01	37.34	37.41	37.25	37.39	37.19	36.94
Al ₂ O ₃	21.32	21.3	21.49	21.24	21.27	21.48	21.28	21.18	21.43	21.19	21.54	21.36	21.05	21.06
TiO ₂	0	0	0	0.05	0.05	0.01	0	0.02	0	0	0	0	0.02	0.04
MgO	4.24	4.29	4.84	4.7	4.89	4.84	4.96	4.9	4.83	4.86	4.73	5.04	4.64	3.82
FeO	33.31	33.33	33.13	33.34	33.77	33.58	33.72	33.8	33.67	33.5	33.43	33.35	33.22	33.88
MnO	1.79	1.75	1.13	0.73	0.52	0.76	0.72	0.86	0.8	0.97	1.15	1.23	1.47	2.28
CaO	2.14	1.55	2.32	2.56	2.31	1.89	1.94	1.61	1.58	1.67	1.58	1.67	1.53	1.39
TOTAL	100.13	99.32	100.33	100.34	100.02	99.65	100.08	99.38	99.65	99.6	99.68	100.04	99.12	99.41
24 oxygens														
Si	5.959	5.965	5.94	5.983	5.932	5.929	5.961	5.94	5.963	5.979	5.95	5.952	5.982	5.965
Al	0.041	0.035	0.06	0.017	0.068	0.071	0.039	0.06	0.037	0.021	0.05	0.048	0.018	0.035
	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Al	3.97	4.001	3.961	3.954	3.929	3.976	3.952	3.948	3.996	3.971	4.006	3.961	3.972	3.973
Ti	0	0	0	0.006	0.006	0.001	0	0.003	0	0	0	0	0.002	0.005
	3.97	4.001	3.961	3.96	3.935	3.977	3.952	3.951	3.996	3.971	4.006	3.961	3.974	3.978
Mg	1.01	1.028	1.144	1.111	1.161	1.154	1.176	1.171	1.15	1.157	1.125	1.195	1.113	0.92
Fe	4.447	4.482	4.399	4.433	4.502	4.49	4.488	4.537	4.497	4.478	4.466	4.439	4.469	4.575
Mn	0.242	0.239	0.152	0.098	0.071	0.103	0.098	0.117	0.108	0.131	0.155	0.165	0.2	0.311
Ca	0.366	0.268	0.394	0.435	0.395	0.323	0.331	0.276	0.27	0.287	0.27	0.284	0.264	0.241
	6.065	6.017	6.089	6.066	6.129	6.07	6.093	6.101	6.025	6.053	6.016	6.083	6.046	6.047
X _{Ca}	0.0603	0.0445	0.0647	0.0717	0.0644	0.0532	0.0543	0.0452	0.0448	0.0474	0.0449	0.0467	0.0437	0.0399
X _{Ca+XMn}	0.1002	0.0843	0.0897	0.0879	0.0760	0.0702	0.0704	0.0644	0.0627	0.0691	0.0706	0.0738	0.0767	0.0913
X _{Fe/XMg}	4.4030	4.3599	3.8453	3.9901	3.8777	3.8908	3.8163	3.8745	3.9104	3.8704	3.9698	3.7146	4.0153	4.9728
Mg/Mg+Fe	0.1851	0.1866	0.2064	0.2004	0.2050	0.2045	0.2076	0.2052	0.2036	0.2053	0.2012	0.2121	0.1994	0.1674

Sample 89-69-2		Garnet traverse 2										Figure 2-26	
		GN31	GN32	GN33	GN34	GN35	GN36	GN37	GN38	GN39	GN40		
SiO ₂		37.54	37.65	37.52	37.35	37.59	37.43	37.67	37.78	37.45	37.38		
Al ₂ O ₃		21.52	21.48	21.2	21.66	21.29	21.34	21.42	21.5	21.52	21.09		
TiO ₂		0	0	0	0.01	0	0	0	0	0	0		
MgO		3.63	4.56	4.6	4.59	4.86	4.74	4.85	4.63	4.61	3.82		
FeO		33.51	33.91	33.77	33.63	33.59	33.52	33.49	33.19	33.45	33.48		
MnO		2.53	1.92	1.86	1.9	1.79	1.75	1.75	1.81	1.85	2.67		
CaO		1.68	1.52	1.57	1.49	1.56	1.53	1.47	1.54	1.84	1.57		
TOTAL		100.41	101.04	100.52	100.63	100.68	100.31	100.65	100.45	100.72	100.01		
24 oxygens													
Si		5.986	5.957	5.969	5.929	5.962	5.957	5.967	5.989	5.939	5.933		
Al		0.014	0.043	0.031	0.071	0.038	0.043	0.033	0.011	0.061	0.007		
		6	6	6	6	6	6	6	6	6	6		
Al		4.031	3.963	3.944	3.982	3.941	3.96	3.966	4.006	3.962	3.978		
Ti		0	0	0	0.001	0	0	0	0	0	0		
		4.031	3.963	3.944	3.983	3.941	3.96	3.966	4.006	3.962	3.978		
Mg		0.864	1.075	1.091	1.087	1.148	1.125	1.145	1.094	1.09	0.914		
Fe		4.469	4.487	4.493	4.465	4.455	4.461	4.437	4.4	4.437	4.49		
Mn		0.341	0.257	0.251	0.256	0.24	0.236	0.235	0.243	0.248	0.362		
Ca		0.287	0.258	0.267	0.253	0.264	0.261	0.25	0.261	0.312	0.27		
		5.961	6.077	6.102	6.061	6.107	6.083	6.067	5.988	6.087	6.036		
XCa		0.0481	0.0425	0.0438	0.0417	0.0432	0.0429	0.0412	0.0436	0.0513	0.0447		
XCa+XMn		0.1054	0.0847	0.0849	0.0840	0.0825	0.0817	0.0799	0.0842	0.0920	0.1047		
XFe/XMg		5.1725	4.1740	4.1182	4.1076	3.8807	3.9653	3.8751	4.0219	4.0706	4.9125		
MG/MG+FE		0.1620	0.1933	0.1954	0.1958	0.2049	0.2014	0.2051	0.1991	0.1972	0.1691		

Sample 89-69-2		Garnet compositions used for geothermobarometry								Figure 2-27	
		GNI (BI)	GA12 (BI12)	GA13 (BI13)	GA1 (BI1)	GA10 (BI10)	GA18 (BI18)	GA19 (BI19)			
SiO2		37.57	37.21	36.91	37.2	36.67	36.56	36.95			
Al2O3		21.43	21.15	21.04	21.2	20.6	20.93	21.04			
TiO2		0	0	0	0	0.05	0.02	0			
MgO		4.39	4.84	4.34	3.86	3.6	4.02	4.11			
FeO		33.92	33.51	34.43	34.54	34.12	33.83	33.95			
MnO		1.44	0.76	1.1	1.59	2.27	2.81	2.23			
CaO		1.56	1.66	1.64	1.42	1.66	1.5	1.47			
TOTAL		100.31	99.13	99.46	99.81	98.97	99.67	99.75			
24 oxygens											
Si		5.979	5.974	5.946	5.977	5.969	5.912	5.949			
Al		0.021	0.026	0.054	0.023	0.031	0.088	0.051			
		6	6	6	6	6	6	6			
Al		3.998	3.976	3.941	3.991	3.921	3.902	3.942			
Ti		0	0	0	0	0.006	0.003	0			
		3.998	3.976	3.941	3.991	3.927	3.905	3.942			
Mg		1.042	1.159	1.043	0.924	0.874	0.969	0.985			
Fe		4.513	4.5	4.639	4.641	4.645	4.574	4.571			
Mn		0.194	0.103	0.149	0.217	0.313	0.384	0.304			
Ca		0.265	0.286	0.282	0.244	0.289	0.26	0.253			
		6.014	6.048	6.113	6.026	6.121	6.187	6.113			
XCa		0.0441	0.0473	0.0461	0.0405	0.0472	0.0420	0.0414			
XCa+XMn		0.0763	0.0643	0.0705	0.0765	0.0983	0.1041	0.0911			
XFe/XMg		4.3311	3.8827	4.4477	5.0227	5.3146	4.7203	4.6406			
Mg/MG+FE		0.1876	0.2048	0.1836	0.1660	0.1584	0.1748	0.1773			

Sample 89-69-2		Biotite compositions for geothermobarometry						Figure 2-27
		BI	BI12	BI.13	BI.1	BI10	BI18	BI19
SIO2		34.07	34.71	34.46	34.95	33.52	34.19	34.50
AL2O3		19.07	19.81	19.44	19.84	19.86	19.76	19.55
TIO2		3.41	3.86	3.97	3.51	2.30	3.12	3.69
CR2O3		0.12	0.13	0.31	0.09	0.00	0.08	0.14
FEO		19.46	17.78	18.25	20.07	24.21	20.84	21.00
MNO		0.03	0.00	0.05	0.02	0.14	0.13	0.02
MGO		8.62	9.91	10.05	8.99	7.77	8.76	8.40
CAO		0.00	0.00	0.00	0.00	0.00	0.00	0.04
K2O		8.78	8.91	8.96	8.77	8.02	8.53	8.60
NA2O		0.02	0.41	0.04	0.08	0.01	0.00	0.21
TOTAL		93.58	95.52	95.53	96.32	95.83	95.41	96.15
SI		5.282	5.225	5.205	5.258	5.169	5.219	5.23
AL		2.718	2.775	2.795	2.742	2.831	2.781	2.77
		8	8	8	8	8	8	8
AL		0.767	0.741	0.666	0.776	0.777	0.774	0.724
TI		0.397	0.437	0.451	0.397	0.266	0.358	0.420
CR		0.015	0.015	0.037	0.011	0.000	0.009	0.017
FE		2.524	2.239	2.305	2.525	3.122	2.659	2.662
MN		0.004	0.000	0.006	0.002	0.018	0.017	0.003
MG		1.993	2.225	2.262	2.016	1.787	1.994	1.898
		5.700	5.657	5.727	5.727	5.970	5.811	5.724
CA		0.000	0.000	0.000	0.000	0.000	0.000	0.006
K		1.738	1.711	1.726	1.683	1.578	1.661	1.664
NA		0.005	0.120	0.011	0.024	0.003	0.000	0.062
		1.743	1.831	1.737	1.707	1.581	1.661	1.732
XAl		0.1346	0.1310	0.1163	0.1355	0.1302	0.1332	0.1265
XTi		0.0696	0.0772	0.0787	0.0693	0.0446	0.0516	0.0734
FE/MG		1.2664	1.0063	1.0190	1.2525	1.7471	1.3335	1.4025
MG/MG+FE		0.4412	0.4984	0.4953	0.4440	0.3640	0.4285	0.4162

Sample 89-69-2		Muscovite compositions for geothermobarometry						Figure 2-27
	MU2	MU3	MU4	MU5	MU6	MU8	MU9	average
SIO2	45.47	45.10	43.20	42.56	43.32	48.21	43.78	44.520
AL2O3	32.44	35.47	34.17	34.18	35.45	31.85	34.31	33.981
TIO2	0.87	0.88	1.89	2.08	1.44	1.45	1.01	1.374
CR2O3	0.02	0.20	0.48	0.69	0.16	0.19	0.25	0.284
FEO	3.53	1.29	1.48	1.75	1.33	1.84	2.99	2.030
MNO	0.05	0.04	0.06	0.10	0.10	0.02	0.05	0.060
MGO	1.41	0.69	0.78	0.71	0.93	0.73	0.97	0.889
CAO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
K2O	9.71	10.06	9.14	9.04	9.40	8.91	10.00	9.466
NA2O	0.23	0.39	0.49	0.34	0.61	0.00	0.22	0.326
TOTAL	93.73	94.12	91.69	91.45	92.74	93.20	93.58	92.930
22 oxygens								
SI	6.208	6.072	5.978	5.918	5.925	6.489	5.997	6.0839
AL	1.792	1.928	2.022	2.082	2.075	1.511	2.003	1.9161
	8	8	8	8	8	8	8	8
AL	3.428	3.701	3.551	3.520	3.640	3.541	3.537	3.5597
TI	0.090	0.089	0.197	0.218	0.148	0.147	0.140	0.1470
CR	0.002	0.021	0.053	0.075	0.017	0.020	0.027	0.0307
FE	0.403	0.145	0.172	0.204	0.152	0.207	0.342	0.2321
MN	0.005	0.004	0.006	0.012	0.012	0.002	0.006	0.0067
MG	0.287	0.138	0.162	0.148	0.190	0.146	0.197	0.1811
	4.215	4.098	4.141	4.177	4.159	4.063	4.213	4.1523
CA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0000
K	1.691	1.728	1.614	1.604	1.641	1.530	1.747	1.6507
NA	0.061	0.101	0.130	0.091	0.163	0.000	0.058	0.0863
	1.752	1.829	1.744	1.695	1.804	1.530	1.805	1.7370
FE/MG	1.4042	1.0507	1.0617	1.3784	0.8000	1.4178	1.7360	1.28155
MG/MG+FE	0.4159	0.4876	0.4850	0.4205	0.5556	0.4136	0.3655	0.43830

Sample 89-69-2

Plagioclase compositions for geothermobarometry

Figure 2-27

	PL1 (GNI)	PL2	PL3	PL4	PL5	PL6	PL7	PL8	PL9	PL10	PL11	PL12 (GA12)	PL13 (GA13)	PL14	PL15	PL16	average
SiO ₂	59.73	59.42	59.52	59.89	59.51	59.08	58.82	58.83	59.37	58.86	58.80	58.68	58.63	57.71	58.65	58.60	59.006
Al ₂ O ₃	26.45	26.45	26.66	26.34	26.68	26.40	26.87	26.79	26.54	27.07	26.87	26.51	27.04	27.63	26.87	26.50	26.729
CaO	7.46	7.67	7.78	7.55	7.64	7.53	8.06	8.12	7.69	8.05	8.02	7.97	8.15	8.99	7.92	8.01	7.913
Na ₂ O	7.45	7.58	7.39	7.11	7.11	7.20	7.12	7.38	7.43	6.97	6.92	6.98	7.10	6.66	6.88	7.07	7.141
K ₂ O	0.31	0.34	0.27	0.28	0.27	0.28	0.31	0.35	0.29	0.27	0.39	0.32	0.33	0.43	0.33	0.27	0.315
FeO	0.07	0.05	0.05	0.14	0.15	0.06	0.12	0.05	0.30	0.17	0.32	0.24	0.25	0.38	0.12	0.22	0.168
TOTAL	101.47	101.51	101.67	101.31	101.36	100.55	101.30	101.52	101.62	101.39	101.22	100.70	101.50	101.80	100.77	100.67	101.273
16 oxygens																	
Si	5.259	5.240	5.236	5.275	5.244	5.248	5.200	5.197	5.232	5.195	5.203	5.218	5.180	5.102	5.205	5.214	5.2155
Al	2.745	2.750	2.765	2.735	2.771	2.764	2.800	2.789	2.757	2.816	2.802	2.778	2.816	2.880	2.811	2.778	2.7848
	8.004	7.990	8.001	8.010	8.015	8.012	8.000	7.986	7.989	8.011	8.005	7.996	7.996	7.982	8.016	7.992	8.0003
Ca	0.704	0.725	0.733	0.712	0.722	0.717	0.764	0.768	0.726	0.762	0.761	0.760	0.772	0.852	0.753	0.763	0.7496
Na	1.273	1.297	1.260	1.215	1.215	1.240	1.221	1.264	1.270	1.194	1.170	1.203	1.217	1.142	1.184	1.220	1.2241
K	0.035	0.038	0.030	0.031	0.031	0.032	0.035	0.039	0.032	0.031	0.044	0.037	0.037	0.049	0.037	0.031	0.0356
	2.012	2.060	2.023	1.958	1.968	1.989	2.020	2.071	2.028	1.987	1.975	2.000	2.026	2.043	1.974	2.014	2.0093
Fe	0.005	0.004	0.004	0.010	0.011	0.005	0.009	0.004	0.022	0.012	0.024	0.018	0.018	0.028	0.009	0.016	0.0124
An	0.35	0.35	0.36	0.36	0.37	0.36	0.38	0.37	0.36	0.38	0.39	0.38	0.38	0.42	0.38	0.38	0.37

Sample 89-106-3		Garnet traverse I										Figure 2-28	
		GA.1	GA.2	GA.3	GA.4	GA.5	GA.6	GA.7	GA.8	GA.9	GA.10	GA.11	GA.12
SiO ₂		36.96	37.26	36.83	37.21	37.19	37.16	37.13	37.24	37.27	36.92	37.02	36.79
Al ₂ O ₃		20.15	20.13	20.00	20.09	20.48	20.18	20.30	20.25	20.26	20.40	20.22	20.00
TiO ₂		0.08	0.10	0.11	0.09	0.16	0.19	0.11	0.10	0.17	0.10	0.23	0.57
MgO		0.93	1.00	1.17	1.15	1.19	1.09	1.00	1.13	1.02	1.16	1.09	1.03
FeO		23.65	23.82	23.30	23.66	24.03	23.45	23.71	23.64	23.50	23.79	23.67	23.54
MnO		5.99	6.04	6.02	6.10	6.61	6.44	6.39	6.63	6.73	6.62	6.46	6.55
CaO		11.34	11.53	11.33	11.32	11.12	11.14	11.07	10.79	10.72	10.73	11.05	10.88
TOTAL		99.10	99.88	98.76	99.62	100.78	99.65	99.71	99.78	99.67	99.72	99.74	99.36
2+ oxygens													
Si		5.991	5.996	5.987	5.998	5.942	5.990	5.984	5.996	6.004	5.955	5.967	5.956
Al		0.009	0.004	0.013	0.002	0.058	0.010	0.016	0.004	0.000	0.045	0.033	0.044
		6	6	6	6	6	6	6	6	6.004	6	6	6
Al		3.841	3.814	3.819	3.815	3.799	3.823	3.841	3.838	3.847	3.834	3.809	3.772
Ti		0.010	0.012	0.013	0.011	0.019	0.023	0.014	0.013	0.021	0.012	0.028	0.070
		3.851	3.826	3.832	3.826	3.818	3.846	3.855	3.851	3.868	3.846	3.837	3.842
Mg		0.225	0.240	0.284	0.276	0.284	0.261	0.240	0.271	0.246	0.278	0.262	0.249
Fe		3.206	3.205	3.168	3.191	3.211	3.161	3.196	3.183	3.166	3.209	3.192	3.188
Mn		0.823	0.823	0.829	0.833	0.895	0.879	0.872	0.904	0.918	0.905	0.883	0.898
Ca		1.969	1.989	1.973	1.955	904	1.924	1.912	1.861	1.850	1.854	1.909	1.888
		6.223	6.257	6.254	6.255	6.94	6.225	6.220	6.219	6.180	6.246	6.246	6.223
XCa		0.3164	0.3179	0.3155	0.3125	0.3025	0.3091	0.3074	0.2992	0.2994	0.2968	0.3056	0.3034
XCa+XMn		0.4487	0.4494	0.4480	0.4457	0.4447	0.4503	0.4476	0.4446	0.4479	0.4417	0.4470	0.4477
FE/MG		14.2489	13.3542	11.1549	11.5616	11.3063	12.1111	13.3167	11.7454	12.8699	11.5432	12.1832	12.8032
MG/MG+FE		0.0656	0.0697	0.0823	0.0796	0.0813	0.0763	0.0698	0.0785	0.0721	0.0797	0.0759	0.0724

Sample 89-106-3		Garnet traverse 1 (continued)												Figure 2-28	
		GA.13	GA.14	GA.15	GA.16	GA.17	GA.18	GA.19	GA.20	GA.21	GA.22	GA.23	GA.24		
SiO ₂		37.09	36.86	36.91	36.92	36.78	36.85	36.97	36.86	37.12	36.86	36.87	36.96		
Al ₂ O ₃		20.25	20.07	20.52	20.48	20.44	20.55	20.37	20.53	20.47	20.28	20.43	19.97		
TiO ₂		0.36	0.25	0.04	0.08	0.03	0.06	0.03	0.07	0.03	0.02	0.21	0.23		
MgO		1.19	1.04	1.09	0.97	0.97	0.76	0.98	0.97	1.04	1.01	1.12	1.22		
FeO		23.65	23.91	24.73	22.94	22.67	22.14	21.92	22.94	22.15	23.48	23.84	23.37		
MnO		6.78	6.88	7.40	7.56	8.38	7.32	7.43	7.36	7.64	8.07	6.67	6.72		
CaO		10.82	10.37	9.31	10.71	10.12	11.53	11.14	10.76	11.16	9.60	10.37	10.89		
TOTAL		100.14	99.38	100.00	99.66	99.39	99.21	98.84	99.49	99.61	99.32	99.51	99.36		
24 oxygens															
Si		5.958	5.975	5.958	5.960	5.960	5.963	5.994	5.957	5.980	5.982	5.956	5.982		
Al		0.042	0.025	0.042	0.040	0.040	0.037	0.006	0.043	0.020	0.018	0.044	0.018		
		6	6	6	6	6	6	6	6	6	6	6	6		
Al		3.792	3.809	3.861	3.856	3.865	3.882	3.887	3.867	3.867	3.862	3.847	3.791		
Ti		0.044	0.031	0.004	0.010	0.003	0.007	0.004	0.008	0.004	0.002	0.026	0.028		
		3.836	3.840	3.865	3.866	3.868	3.889	3.891	3.875	3.871	3.864	3.873	3.819		
Mg		0.284	0.251	0.261	0.233	0.234	0.183	0.237	0.233	0.250	0.245	0.270	0.295		
Fe		3.177	3.241	3.338	3.097	3.073	2.997	2.973	3.101	2.984	3.187	3.222	3.163		
Mn		0.923	0.944	1.012	1.034	1.151	1.004	1.021	1.008	1.042	1.109	0.913	0.921		
Ca		1.862	1.802	1.609	1.852	1.757	1.999	1.935	1.863	1.927	1.669	1.795	1.889		
		6.246	6.238	6.220	6.216	6.215	6.183	6.166	6.205	6.203	6.210	6.200	6.268		
XCa		0.2981	0.2889	0.2587	0.2979	0.2827	0.3233	0.3138	0.3002	0.3107	0.2688	0.2895	0.3014		
XCa+XMn		0.4459	0.4402	0.4214	0.4643	0.4679	0.4857	0.4794	0.4627	0.4786	0.4473	0.4368	0.4483		
Fe/Mg		11.1866	12.9124	12.7893	13.2918	13.1325	16.3770	12.5443	13.3090	11.9360	13.0082	11.9333	10.7220		
Mg/Mg+Fe		0.0821	0.0719	0.0725	0.0700	0.0708	0.0575	0.0738	0.0699	0.0773	0.0714	0.0773	0.0853		

Sample 89-106-3		Garnet traverse 1 (end)										Figure 2-28	
		GA.25	GA.26	GA.27	GA.28	GA.29	GA.30	GA.31	GA.32				
SiO ₂		36.65	36.88	36.79	36.62	36.71	37.23	37.03	36.98				
Al ₂ O ₃		19.87	20.38	20.34	19.89	20.11	19.92	20.38	20.02				
TiO ₂		0.16	0.04	0.13	0.14	0.04	0.08	0.14	0.12				
MgO		0.98	0.98	1.07	0.94	0.91	0.99	1.06	0.99				
FeO		23.57	23.94	23.90	23.44	23.50	23.59	23.44	23.43				
MnO		7.03	6.78	6.53	6.21	5.97	5.89	5.86	5.97				
CaO		10.59	10.63	10.55	11.36	11.22	11.40	11.58	11.50				
TOTAL		98.85	99.63	99.31	98.60	98.46	99.10	99.49	99.01				
24 oxygens													
Si		5.977	5.962	5.959	5.977	5.988	6.029	5.970	5.997				
Al		0.023	0.038	0.041	0.023	0.012	0.000	0.030	0.003				
		6	6	6	6	6	6.029	6	6				
Al		3.798	3.844	3.842	3.804	3.855	3.802	3.844	3.823				
Ti		0.020	0.005	0.016	0.017	0.005	0.010	0.017	0.015				
		3.818	3.849	3.858	3.821	3.860	3.812	3.861	3.838				
Mg		0.237	0.236	0.258	0.230	0.221	0.238	0.255	0.240				
Fe		3.215	3.236	3.239	3.199	3.206	3.195	3.161	3.178				
Mn		0.971	0.928	0.896	0.859	0.825	0.807	0.801	0.821				
Ca		1.851	1.841	1.832	1.986	1.962	1.979	2.000	1.999				
		6.274	6.241	6.225	6.274	6.214	6.219	6.217	6.238				
XCa		0.2950	0.2950	0.2943	0.3165	0.3157	0.3182	0.3217	0.3205				
XCa+XMn		0.4498	0.4437	0.4382	0.4535	0.4485	0.4480	0.4505	0.4521				
FE/MG		13.5654	13.7119	12.5543	13.9087	14.5068	13.4244	12.3961	13.2417				
MG/MG+FE		0.0687	0.0680	0.0738	0.0671	0.0645	0.0693	0.0746	0.0702				

Sample 89-106-3		Garnet traverse 2										Figure 2-28	
		GA.36	GA.37	GA.38	GA.39	GA.40	GA.41	GA.42	GA.43	GA.44	GA.45	GA.46	GA.47
SiO ₂		36.98	37.25	36.99	36.74	36.96	37.14	36.86	36.87	37.05	36.76	36.65	36.99
Al ₂ O ₃		20.37	20.41	20.18	20.05	20.16	20.35	20.28	19.97	19.92	20.20	20.06	19.90
TiO ₂		0.16	0.19	0.17	0.20	0.10	0.14	0.06	0.16	0.12	0.16	0.29	0.20
MgO		1.24	1.21	1.15	1.16	1.20	1.10	0.92	1.24	0.95	1.13	0.97	1.00
FeO		23.31	23.42	23.76	23.29	23.85	23.81	23.73	23.57	23.28	23.72	23.94	24.25
MnO		6.32	6.44	6.41	6.39	6.52	6.58	6.35	6.24	6.81	6.85	6.84	6.89
CaO		11.40	11.26	11.22	11.53	10.94	10.88	10.95	11.43	11.17	10.92	10.56	10.20
TOTAL		99.78	100.18	99.88	99.36	99.73	99.15	99.48	99.30	99.74	99.31	99.43	99.96
24 oxygens													
Si		5.952	5.969	5.959	5.950	5.965	5.972	5.977	5.964	6.003	5.941	5.952	5.998
Al		0.048	0.031	0.041	0.050	0.035	0.028	0.023	0.036	0.000	0.059	0.048	0.002
		6	6	6	6	6	6	6	6	6.003	6	6	6
Al		3.815	3.824	3.791	3.778	3.801	3.828	3.853	3.772	3.803	3.789	3.793	3.803
Ti		0.019	0.023	0.020	0.024	0.012	0.017	0.008	0.020	0.015	0.020	0.035	0.024
		3.834	3.847	3.811	3.802	3.813	3.845	3.861	3.792	3.818	3.809	3.828	3.827
Mg		0.297	0.289	0.277	0.279	0.289	0.265	0.223	0.299	0.231	0.273	0.234	0.242
Fe		3.137	3.138	3.202	3.154	3.219	3.201	3.219	3.188	3.155	3.206	3.252	3.288
Mn		0.862	0.874	0.875	0.877	0.892	0.896	0.872	0.855	0.934	0.938	0.941	0.946
Ca		1.965	1.933	1.937	2.001	1.893	1.874	1.902	1.980	1.940	1.890	1.838	1.772
		6.261	6.234	6.291	6.311	6.293	6.236	6.216	6.322	6.260	6.307	6.265	6.248
XCa		0.3138	0.3101	0.3079	0.3171	0.3008	0.3005	0.3060	0.3132	0.3099	0.2997	0.2934	0.2836
XCa+XMn		0.4515	0.4503	0.4470	0.4560	0.4426	0.4442	0.4463	0.4484	0.4591	0.4484	0.4436	0.4350
FE/MG		10.5623	10.8581	11.5596	11.3047	11.1384	12.0792	14.4350	10.6622	13.6580	11.7436	13.8974	13.5868
MG/MG+FE		0.0865	0.0843	0.0796	0.0813	0.0824	0.0765	0.0648	0.0857	0.0682	0.0785	0.0671	0.0686

Sample 89-106-3		Garnet traverse 2 (end)										Figure 2-28	
		GA.48	GA.49	GA.50	GA.51	GA.52	GA.53	GA.54	GA.55	GA.56	GA.57	GA.58	GA.71
SiO ₂		37.14	37.02	36.62	36.93	36.66	36.95	36.83	36.81	36.73	37.13	37.46	36.89
Al ₂ O ₃		20.10	20.50	20.63	20.08	20.35	19.98	20.01	20.13	20.37	20.08	20.16	20.09
TiO ₂		0.14	0.05	0.08	0.15	0.16	0.17	0.11	0.10	0.00	0.08	0.20	0.01
MgO		1.21	0.94	1.05	1.28	1.15	1.19	0.99	0.85	0.98	1.07	1.13	0.97
FeO		24.75	24.38	24.70	24.46	23.84	23.47	23.68	23.85	23.73	23.85	23.68	23.73
MnO		7.24	6.89	6.74	6.75	6.76	6.88	6.61	6.76	6.51	6.37	6.12	6.16
CaO		9.38	10.48	9.48	9.44	10.56	10.95	10.85	10.52	10.61	10.84	10.91	10.93
TOTAL		100.26	99.30	99.30	99.09	99.48	99.59	99.08	99.02	98.93	99.42	99.66	98.78
24 oxygens													
Si		5.994	5.955	5.942	5.997	5.935	5.974	5.984	5.986	5.969	6.003	6.025	6.000
Al		0.006	0.045	0.058	0.003	0.065	0.026	0.016	0.014	0.031	0.000	0.000	0.000
		6	6	6	6	6	6	6	6	6	6.003	6.025	6
Al		3.818	3.842	3.887	3.841	3.82	3.781	3.816	3.845	3.871	3.826	3.821	3.852
Ti		0.017	0.005	0.010	0.018	0.019	0.021	0.013	0.013	0.000	0.010	0.024	0.002
		3.835	3.847	3.897	3.859	3.839	3.802	3.829	3.858	3.871	3.836	3.845	3.854
Mg		0.291	0.226	0.253	0.309	0.278	0.286	0.241	0.205	0.238	0.259	0.271	0.236
Fe		3.340	3.279	3.352	3.322	3.228	3.173	3.217	3.243	3.226	3.225	3.185	3.228
Mn		0.989	0.938	0.927	0.929	0.927	0.943	0.910	0.931	0.896	0.873	0.834	0.848
Ca		1.621	1.806	1.647	1.643	1.832	1.897	1.890	1.834	1.847	1.878	1.880	1.905
		6.241	6.249	6.179	6.203	6.265	6.301	6.258	6.213	6.207	6.235	6.170	6.217
XCa		0.2597	0.2890	0.2665	0.2649	0.2924	0.3011	0.3020	0.2952	0.2976	0.3012	0.3047	0.3064
XCa+XMn		0.4182	0.4391	0.4166	0.4146	0.4404	0.4507	0.4474	0.4450	0.4419	0.4412	0.4399	0.4428
Fe/Mg		11.4777	14.5088	13.2490	10.7508	11.6115	11.0174	13.3485	15.8195	13.5546	12.4517	11.7528	13.6780
Mg/MG+FE		0.0801	0.0645	0.0702	0.0851	0.0793	0.0832	0.0697	0.0595	0.0687	0.0743	0.0784	0.0681

Sample 89-106-3		Garnet compositions for geothermobarometry						
	GA.1	GA.2	GA.32	GA.59	average (Bt matrix)	GA.33 (HBD 1) (BIO+HBD15)	GA.36 (BIO+HBD15)	GA.70 (BIO1)
SiO ₂	36.96	37.26	36.98	36.94	37.035	36.98	36.98	37.12
Al ₂ O ₃	20.15	20.13	20.02	20.30	20.150	20.19	20.37	20.11
TiO ₂	0.08	0.10	0.12	0.13	0.108	0.06	0.16	0.08
MgO	0.93	1.00	0.99	1.12	1.010	1.02	1.24	1.18
FeO	23.65	23.82	23.43	24.66	23.890	23.70	23.31	23.40
MnO	5.99	6.04	5.97	6.82	6.205	6.52	6.32	6.22
CaO	11.34	11.53	11.50	9.44	10.953	10.88	11.40	11.15
TOTAL	99.10	99.88	99.01	99.41	99.350	99.35	99.78	99.26
24 oxygens								
Si	5.991	5.996	5.997	5.984	5.9920	5.986	5.952	6.001
Al	0.009	0.004	0.003	0.016	0.0080	0.014	0.048	0.000
	6	6	6	6	6	6	6	6.001
Al	3.841	3.814	3.823	3.86	3.8345	3.838	3.815	3.832
Ti	0.010	0.012	0.015	0.016	0.0133	0.008	0.019	0.010
	3.851	3.826	3.838	3.876	3.8478	3.846	3.834	3.842
Mg	0.225	0.240	0.240	0.271	0.2440	0.247	0.297	0.283
Fe	3.206	3.205	3.178	3.340	3.2323	3.208	3.137	3.164
Mn	0.823	0.823	0.821	0.936	0.8508	0.893	0.862	0.851
Ca	1.969	1.989	1.999	1.639	1.8990	1.887	1.965	1.931
	6.223	6.257	6.238	6.186	6.2260	6.235	6.261	6.229
XCa	0.3164	0.3179	0.3205	0.2650	0.30492	0.3026	0.3138	0.3100
XMn	0.1323	0.1315	0.1316	0.1513	0.1366	0.4459	0.4515	0.4466
FE/MG	14.2489	13.3542	13.2417	12.3247	13.29236	12.9879	10.5623	11.1802
MG/MG+FE	0.0656	0.0697	0.0702	0.0750	0.07013	0.0715	0.0865	0.0821

Sample 89-106-3		Biotite compositions for geothermobarometry							
		BT.10	BT.11	BT.12	BT.13	BT.14	average	BT.1	BT.4
SiO ₂		34.26	34.53	34.57	34.08	34.37	34.362	34.34	34.17
Al ₂ O ₃		15.83	16.00	15.54	15.20	15.36	15.586	16.01	15.52
TiO ₂		3.05	2.90	3.36	2.93	2.96	3.040	2.69	2.97
Cr ₂ O ₃		0.00	0.02	0.04	0.00	0.00	0.012	0.00	0.00
FeO		25.78	26.11	25.88	26.74	26.31	26.164	27.39	27.00
MnO		0.21	0.26	0.26	0.31	0.28	0.264	0.35	0.29
MgO		6.77	7.06	6.78	6.78	6.92	6.862	5.98	6.35
CaO		0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00
K ₂ O		8.93	8.99	9.06	8.84	8.95	8.954	8.99	8.82
Na ₂ O		0.00	0.34	0.03	0.06	0.09	0.104	0.00	0.02
Na ₂ O		0.67	0.51	0.20	0.45	0.28	0.422	0.33	0.63
TOTAL		95.50	96.72	95.72	95.39	95.52	95.770	96.08	95.77
22 oxygens									
Si		5.412	5.400	5.445	5.423	5.443	5.4246	5.427	5.417
Al		2.588	2.600	2.555	2.577	2.557	2.5754	2.573	2.583
		8	8	8	8	8	8	8	8
Al		0.359	0.350	0.331	0.273	0.309	0.3244	0.410	0.318
Ti		0.362	0.341	0.398	0.351	0.353	0.3610	0.320	0.353
Cr		0.000	0.002	0.005	0.000	0.000	0.0014	0.000	0.000
Fe		3.406	3.415	3.409	3.558	3.485	3.4546	3.620	3.579
Mn		0.028	0.035	0.035	0.041	0.038	0.0354	0.047	0.039
Mg		1.595	1.646	1.592	1.608	1.634	1.6150	1.408	1.501
		5.750	5.789	5.770	5.831	5.819	5.7918	5.805	5.790
Ca		0.000	0.000	0.000	0.000	0.000	0.0000	0.000	0.000
K		1.801	1.794	1.820	1.794	1.808	1.8034	1.812	1.783
Ba		0.000	0.021	0.002	0.004	0.005	0.0064	0.000	0.001
Na		0.204	0.154	0.060	0.139	0.086	0.1286	0.102	0.194
		2.005	1.969	1.882	1.937	1.899	1.9384	1.914	1.978
X _{Al}		0.0624	0.0605	0.0574	0.0468	0.0531	0.05604	0.0706	0.0549
X _{Ti}		0.0630	0.0589	0.0690	0.0602	0.0607	0.06234	0.0551	0.0610
X _{Fe} /X _{Mg}		2.1354	2.0747	2.1413	2.2127	2.1328	2.13939	2.5710	2.3844
Mg/Mg+Fe		0.3189	0.3252	0.3183	0.3113	0.3192	0.31859	0.2800	0.2955

Sample 89-106-3		Hornblende compositions for geothermobarometry	
		HO.1	HO.15
SIO2		38.39	39.07
AL2O3		13.47	13.82
TIO2		0.67	0.72
FEO		25.93	24.87
MNO		0.55	0.54
CR2O3		0.01	0.01
V2O3		0.16	0.12
MGO		3.88	4.64
CAO		10.97	10.82
K2O		1.26	1.27
NA2O		2.62	2.04
TOTAL		97.91	97.92
23 oxygens			
SI		6.096	6.140
ALIV		1.904	1.860
		8	8
ALVI		0.618	0.699
TI		0.081	0.085
FE		3.443	3.269
MN		0.074	0.072
CR		0.001	0.001
V		0.020	0.015
MG		0.918	1.087
		5.155	5.228
CA		1.367	1.822
K		0.256	0.255
NA		0.806	0.621
		2.929	2.698
FE/MG		3.7505	3.0074
MG/MG+FE		0.2105	0.2495

Sample 89-106-3 Plagioclase compositions for geothermobarometry												
	Pl.1	Pl.2	Pl.3	Pl.4	Pl.5	Pl.6 (GA.36)	Pl.7	Pl.8	Pl.9	Pl.10 (GA.36)	average	
SiO2	64.37	64.87	63.97	64.12	64.12	64.58	63.62	64.42	64.25	63.07	64.139	
Al2O3	21.71	21.66	22.07	21.69	22.15	21.56	22.13	21.52	22.02	22.63	21.914	
CaO	3.10	2.95	3.40	3.48	3.53	3.14	3.92	3.00	3.48	4.12	3.412	
Na2O	9.62	10.16	9.65	9.79	9.65	9.79	9.33	9.69	9.61	9.25	9.654	
K2O	0.39	0.46	0.33	0.41	0.34	0.44	0.26	0.47	0.39	0.29	0.378	
FeO	0.04	0.18	0.24	0.16	0.22	0.18	0.14	0.25	0.24	0.26	0.191	
TOTAL	99.23	100.28	99.56	99.65	100.01	99.69	99.40	99.35	99.99	99.62	99.688	
16 oxygens												
Si	5.720	5.719	5.675	5.693	5.670	5.722	5.659	5.726	5.682	5.608	5.6874	
Al	2.274	2.251	2.308	2.270	2.309	2.252	2.320	2.254	2.295	2.372	2.2905	
	7.994	7.970	7.983	7.963	7.979	7.974	7.979	7.980	7.977	7.980	7.9779	
Ca	0.295	0.279	0.323	0.331	0.334	0.298	0.373	0.286	0.330	0.393	0.3242	
Na	1.658	1.736	1.660	1.685	1.654	1.682	1.609	1.670	1.648	1.594	1.6596	
K	0.044	0.052	0.037	0.046	0.039	0.050	0.029	0.053	0.044	0.033	0.0427	
	1.997	2.067	2.020	2.062	2.027	2.030	2.011	2.009	2.022	2.020	2.0265	
Fe	0.003	0.013	0.018	0.012	0.017	0.014	0.011	0.019	0.018	0.019	0.0144	
An	0.15	0.13	0.16	0.16	0.16	0.15	0.19	0.14	0.16	0.19	0.16	

Sample 86-4A-2		Garnet traverse										Figure 2-29	
		GN.1	GN.2	GN.3	GN.4	GN.5	GN.6	GN.7	GN.8	GN.9	GN.10		
SiO ₂		37.71	37.67	37.70	37.57	36.70	37.29	37.60	37.45	37.44	37.79		
Al ₂ O ₃		21.12	21.32	21.36	21.24	21.41	21.17	21.09	21.13	21.38	21.33		
TiO ₂		0.15	0.13	0.06	0.10	0.18	0.10	0.10	0.12	0.06	0.11		
MgO		1.98	1.73	1.63	1.41	1.60	1.66	1.88	1.96	1.62	1.67		
FeO		24.50	23.37	21.98	21.78	21.95	22.52	23.01	23.00	23.09	22.32		
MnO		6.04	7.66	8.77	9.40	8.75	8.08	7.65	7.43	7.26	8.11		
CaO		8.81	8.93	8.99	9.03	8.74	8.97	9.11	8.85	8.68	8.82		
TOTAL		100.31	100.81	100.49	100.53	99.33	99.79	100.44	99.94	99.53	100.15		
24 oxygens													
Si		5.994	5.970	5.988	5.980	5.909	5.969	5.979	5.977	5.993	6.009		
Al		0.005	0.030	0.012	0.020	0.091	0.031	0.021	0.023	0.007	0.000		
		6	6	6	6	6	6	6	6	6	6		
Al		3.952	3.953	3.986	3.964	3.973	3.964	3.933	3.952	4.026	3.998		
Ti		0.018	0.016	0.007	0.012	0.022	0.013	0.012	0.014	0.007	0.013		
		3.970	3.969	3.993	3.976	3.995	3.977	3.945	3.966	4.033	4.011		
Mg		0.469	0.410	0.385	0.333	0.384	0.397	0.446	0.467	0.388	0.395		
Fe		3.256	3.098	2.919	2.899	2.956	3.014	3.060	3.071	3.091	2.968		
Mn		0.813	1.028	1.175	1.267	1.194	1.095	1.030	1.005	0.984	1.092		
Ca		1.500	1.517	1.529	1.540	1.507	1.539	1.553	1.513	1.488	1.503		
		6.038	6.053	6.012	6.039	6.041	6.045	6.089	6.056	5.951	5.958		
XCu		0.2484	0.2506	0.2543	0.2550	0.2495	0.2546	0.2551	0.2498	0.2500	0.2523		
XCu+XMn		0.3831	0.4205	0.4504	0.4648	0.4471	0.4357	0.4242	0.4158	0.4154	0.4355		
Fe/Mg		6.9424	7.5561	7.5818	8.7057	7.6979	7.5919	6.8610	6.5760	7.9665	7.5139		
Mg/Mg+Fe		0.1259	0.1169	0.1165	0.1030	0.1150	0.1164	0.1272	0.1320	0.1115	0.1175		

Sample 86-4A-2 Garnet compositions for geothermobarometry							
	GN.1	GN.7	GN.8	GN.20	average (Bt matrix)	GN.15 (Bt13)	GN.21 (Bt matrix)
SiO2	37.71	37.60	37.45	37.47	37.558	36.95	37.06
Al2O3	21.12	21.09	21.13	21.21	21.138	21.20	21.03
TiO2	0.15	0.10	0.12	0.12	0.123	0.12	0.09
MgO	1.98	1.88	1.96	1.97	1.948	1.83	1.49
FeO	24.50	23.01	23.00	21.82	23.083	22.67	20.02
MnO	6.04	7.65	7.43	8.13	7.313	7.79	8.17
CaO	8.81	9.11	8.85	8.74	8.878	8.74	10.90
TOTAL	100.31	100.44	99.94	99.46	100.038	99.30	98.76
24 oxygens							
Si	5.994	5.979	5.977	5.993	5.9858	5.943	5.970
Al	0.006	0.021	0.023	0.007	0.0143	0.057	0.030
	6	6	6	6	6	6	6
Al	3.952	3.933	3.952	3.991	3.9570	3.962	3.962
Ti	0.018	0.012	0.014	0.014	0.0145	0.015	0.010
	3.970	3.945	3.966	4.005	3.9715	3.977	3.972
Mg	0.469	0.446	0.467	0.471	0.4633	0.440	0.358
Fe	3.256	3.060	3.071	2.918	3.0763	3.049	2.697
Mn	0.813	1.030	1.005	1.101	0.9873	1.061	1.115
Ca	1.500	1.553	1.513	1.498	1.5160	1.506	1.882
	6.038	6.089	6.056	5.988	6.0428	6.056	6.052
XCa	0.2484	0.2551	0.2498	0.2502	0.25087	0.2487	0.3110
XCa+XMn	0.3831	0.4242	0.4158	0.4340	0.4143	0.4239	0.4952
Fe/Mg	6.9424	6.8610	6.5760	6.1953	6.64369	6.9295	7.5335
Mg/Mg+Fe	0.1259	0.1272	0.1320	0.1390	0.13102	0.1261	0.1172

Sample 86-4A-2		Biotite compositions for geothermobarometry						
	BI.19	BI.20	BI.21	BI.23	BI.24	BI.25	average	BIO.13
SiO ₂	36.65	36.11	36.10	36.34	36.54	36.60	36.390	36.57
Al ₂ O ₃	17.26	17.57	17.55	17.54	17.43	17.76	17.518	17.51
TiO ₂	1.83	1.63	1.66	1.85	1.73	1.74	1.740	1.58
Cr ₂ O ₃	0.00	0.00	0.02	0.03	0.00	0.02	0.012	0.03
FeO	18.37	18.23	18.15	18.38	18.52	18.27	18.320	18.49
MnO	0.32	0.31	0.30	0.37	0.36	0.36	0.337	0.44
MgO	10.91	10.61	10.54	10.57	10.49	10.68	10.633	10.99
CaO	0.02	0.00	0.18	0.05	0.04	0.00	0.048	0.07
K ₂ O	9.17	9.18	8.65	9.17	9.27	9.24	9.113	9.36
Na ₂ O	0.09	0.00	0.00	0.00	0.00	0.04	0.022	0.00
TOTAL	94.62	93.64	93.15	94.30	94.38	94.71	94.133	95.04
22 oxygens								
Si	5.583	5.559	5.569	5.558	5.588	5.565	5.5703	5.557
Al	2.417	2.441	2.431	2.442	2.412	2.435	2.4297	2.443
	8	8	8	8	8	8	8.0000	8
Al	0.683	0.746	0.760	0.719	0.729	0.748	0.7308	0.694
Ti	0.209	0.189	0.193	0.213	0.199	0.199	0.2003	0.181
Cr	0.000	0.000	0.003	0.004	0.000	0.003	0.0017	0.003
Fe	2.340	2.347	2.342	2.350	2.369	2.323	2.3452	2.350
Mn	0.041	0.041	0.040	0.048	0.046	0.046	0.0437	0.056
Mg	2.478	2.435	2.423	2.409	2.391	2.421	2.4262	2.490
	5.751	5.758	5.761	5.743	5.734	5.740	5.7478	5.774
Ca	0.003	0.000	0.030	0.008	0.006	0.000	0.0078	0.011
K	1.781	1.803	1.703	1.790	1.809	1.793	1.7798	1.815
Na	0.025	0.000	0.000	0.000	0.000	0.013	0.0063	0.000
	1.809	1.803	1.733	1.798	1.815	1.806	1.7940	1.826
XAl	0.1188	0.1296	0.1319	0.1252	0.1271	0.1303	0.12715	0.1202
XTi	0.0363	0.0328	0.0335	0.0371	0.0347	0.0347	0.03485	0.0313
XFe/XMg	0.9443	0.9639	0.9666	0.9755	0.9908	0.9595	0.96676	0.9438
Mg/Mg+Fe	0.5143	0.5092	0.5085	0.5062	0.5023	0.5103	0.50848	0.5145

Sample 86-4A-2 Plagioclase composition	
	PL.9
SIO2	58.05
AL2O3	27.19
CAO	8.18
NA2O	6.84
K2O	0.33
FEO	0.16
TOTAL	100.75
16 oxygens	
SI	5.162
AL	2.85
	8.012
CA	0.78
NA	1.18
K	0.037
	1.997
FE	0.012

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PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

Sample 87-124-1		Garnet traverse										Figure 2-30	
		GN22	GN23	GN24	GN25	GN26	GN27	GN28	GN29	GN30	GN31		
SiO ₂		36.84	36.80	36.76	36.51	36.90	36.83	36.86	36.55	36.98	36.28		
Al ₂ O ₃		21.54	21.38	21.20	20.89	20.95	21.02	21.12	20.98	21.35	21.14		
TiO ₂		0.00	0.00	0.02	0.06	0.00	0.07	0.04	0.00	0.01	0.02		
MgO		1.83	1.84	1.74	1.70	1.41	1.43	1.23	1.16	1.44	1.52		
FeO		39.40	39.28	39.56	39.66	38.90	38.77	37.83	37.55	37.14	39.42		
MnO		0.00	0.00	0.00	0.07	0.54	1.14	1.69	1.87	2.28	0.61		
CaO		1.78	1.71	1.95	1.70	1.90	2.26	2.43	2.55	2.54	1.99		
TOTAL		101.39	101.01	101.23	100.59	100.60	101.52	101.20	100.66	101.74	100.98		
24 oxygens													
Si		5.920	5.930	5.930	5.940	5.990	5.940	5.950	5.940	5.930	5.890		
Al		0.080	0.070	0.070	0.070	0.020	0.060	0.050	0.060	0.070	0.110		
		6	6	6	6	6	6	6	6	6	6		
Al		4.000	4.000	3.960	3.940	3.990	3.930	3.970	3.960	3.970	3.930		
Ti		0.000	0.000	0.000	0.010	0.000	0.010	0.010	0.000	0.000	0.000		
		4.000	4.000	3.960	3.950	3.990	3.940	3.980	3.960	3.970	3.940		
Mg		0.440	0.440	0.420	0.410	0.340	0.340	0.300	0.280	0.350	0.370		
Fe		5.290	5.300	5.340	5.390	5.280	5.230	5.110	5.100	4.980	5.350		
Mn		0.000	0.000	0.000	0.010	0.070	0.160	0.230	0.260	0.310	0.080		
Ca		0.310	0.300	0.340	0.300	0.330	0.390	0.420	0.440	0.440	0.350		
		6.040	6.040	6.090	6.110	6.020	6.120	6.060	6.090	6.080	6.150		
XCa		0.0513	0.0497	0.0558	0.0491	0.0548	0.0637	0.0693	0.0722	0.0724	0.0569		
XCa+XMn		0.0513	0.0497	0.0558	0.0507	0.0664	0.0899	0.1073	0.1149	0.1234	0.0699		
FE/MG		12.0227	12.0455	12.7143	13.1463	15.5294	15.3824	17.0333	18.2143	14.2286	14.4595		
MG/MG+FE		0.0768	0.0767	0.0729	0.0707	0.0605	0.0610	0.0555	0.0520	0.0657	0.0647		

Sample 87-124-1		Garnet traverse (end)				Figure 2-30	
		GN32	GN33	GN34	GN35	GN36	
SiO ₂		36.38	36.49	36.39	36.33	36.40	
Al ₂ O ₃		20.69	20.86	20.94	20.97	20.82	
TiO ₂		0.00	0.00	0.03	0.01	0.01	
MgO		1.13	1.30	1.29	1.37	1.42	
FeO		38.84	38.89	38.40	38.39	38.62	
MnO		0.74	1.13	1.21	1.02	0.63	
CaO		1.97	1.91	2.20	2.12	2.02	
TOTAL		99.75	100.58	100.46	100.21	99.92	
24 oxygens							
Si		5.970	5.940	5.930	5.930	5.950	
Al		0.030	0.060	0.070	0.070	0.050	
		6	6	6	6	6	
Al		3.970	3.950	3.950	3.970	3.970	
Ti		0.000	0.000	0.000	0.000	0.000	
		3.970	3.950	3.960	3.970	3.970	
Mg		0.280	0.320	0.310	0.330	0.350	
Fe		5.330	5.300	5.230	5.240	5.280	
Mn		0.100	0.160	0.170	0.140	0.090	
Ca		0.350	0.330	0.390	0.370	0.350	
		6.060	6.110	6.100	6.090	6.070	
XCa		0.0578	0.0540	0.0639	0.0608	0.0577	
XCa+XMn		0.0743	0.0802	0.0918	0.0837	0.0725	
Fe/Mg		19.0357	16.5625	16.8710	15.8788	15.0857	
Mg/Mg+Fe		0.0499	0.0569	0.0560	0.0592	0.0622	

Sample 87-124-1		Garnet compositions used for geothermobarometry										
		GN51	GN52	GN53	GN54	GN55	GN56	GN57	GN58	GN59	GN60	GN61 av. homogenized (Bt matrix)
SiO2		36.77	36.66	36.57	36.89	36.74	36.53	36.88	36.73	36.58	36.59	36.77
Al2O3		20.99	20.99	21.18	21.16	21.16	21.3	21.08	21.05	21.08	21.12	21.119
TiO2		0.02	0	0	0.03	0	0	0.03	0.04	0	0	0.012
MgO		1.92	1.92	1.87	1.98	1.81	1.89	1.99	1.83	2.06	1.84	1.81
FeO		38.98	38.95	39.02	39.02	38.83	38.93	38.59	38.96	38.94	38.79	39.11
MnO		0	0.01	0.01	0.03	0	0.02	0	0.05	0.05	0	0
CaO		1.77	1.78	1.74	1.73	1.7	1.69	1.72	1.72	1.74	1.67	1.79
TOTAL		100.45	100.31	100.39	100.84	100.24	100.36	100.29	100.38	100.45	100.01	100.69
24 oxygens												
Si		5.961	5.953	5.935	5.955	5.963	5.927	5.974	5.958	5.932	5.953	5.948
Al		0.039	0.047	0.065	0.045	0.037	0.073	0.026	0.042	0.068	0.047	0.052
		6	6	6	6	6	6	6	6	6	6	6
Al		3.972	3.971	3.987	3.98	4.01	4	3.998	3.984	3.963	4.004	3.991
Ti		0.002	0	0	0.003	0	0	0.004	0.005	0	0	0.001
		3.974	3.971	3.987	3.983	4.01	4	4.002	3.989	3.963	4.004	3.992
Mg		0.464	0.466	0.451	0.477	0.437	0.456	0.48	0.443	0.499	0.447	0.436
Fe		5.285	5.29	5.297	5.267	5.27	5.283	5.228	5.286	5.282	5.278	5.2779
Mn		0	0.002	0.001	0.003	0	0.003	0	0.007	0.007	0.001	0
Ca		0.307	0.31	0.303	0.299	0.296	0.295	0.299	0.299	0.303	0.292	0.31
		6.056	6.068	6.052	6.046	6.003	6.037	6.007	6.035	6.091	6.018	6.0409
XCa		0.0507	0.0511	0.0501	0.0495	0.0493	0.0489	0.0498	0.0495	0.0497	0.0485	0.0514
XCa+XMn		0.0507	0.0514	0.0502	0.0500	0.0493	0.0494	0.0498	0.0507	0.0509	0.0487	0.0514
Fe/Mg		11.3901	11.3519	11.7450	11.0419	12.0595	11.5855	10.8917	11.9323	10.5852	11.8076	12.1353
Mg/Mg+Fe		0.0807	0.0810	0.0785	0.0830	0.0766	0.0795	0.0841	0.0773	0.0863	0.0781	0.0761
												0.08010

Sample 87-124-1 Garnet compositions used for geothermobarometry (end)				
	GN.1	GN21	av. rim (Bt matrix)	GN61 (BIO 15)
SiO ₂	36.68	37.15	36.915	36.77
Al ₂ O ₃	20.78	21.05	20.915	21.2
TiO ₂	0.01	0.01	0.01	0.01
MgO	1.86	1.95	1.905	1.81
FeO	38.53	39.08	38.805	39.11
MnO	0	0	0	0
CaO	1.77	1.93	1.85	1.79
TOTAL	99.63	101.17	100.4	100.69
24 oxygens				
Si	5.988	5.976	5.982	5.948
Al	0.012	0.024	0.018	0.052
	6	6	6	6
Al	3.987	3.967	3.977	3.991
Ti	0.002	0.001	0.0015	0.001
	3.989	3.968	3.9785	3.992
Mg	0.452	0.468	0.46	0.436
Fe	5.26	5.258	5.259	5.291
Mn	0	0	0	0
Ca	0.31	0.333	0.3215	0.31
	6.022	6.059	6.0405	6.037
X _{Ca}	0.0515	0.0550	0.05322	0.0514
X _{Ca+XMn}	0.0515	0.0550	0.05325	0.0514
Fe/Mg	11.6372	11.2350	11.4326	12.1353
Mg/Mg+Fe	0.0791	0.0817	0.08043	0.07996

Sample 87-124-1		Biotite compositions for geothermobarometry					
		BIO.8	BIO.9	BIO.13	BIO.14	BIO.15	BIO.16
SIO2		34.48	34.49	33.84	34.34	34.79	34.39
AL2O3		19.10	18.97	18.45	17.98	19.16	18.51
TIO2		1.97	2.03	1.99	2.61	1.92	2.02
CR2O3		0.00	0.00	0.06	0.00	0.00	0.00
FEO		26.95	26.78	26.54	26.72	26.10	27.04
MNO		0.00	0.00	0.00	0.01	0.00	0.07
MGO		5.41	5.31	5.62	5.37	5.47	5.68
CAO		0.00	0.00	0.00	0.00	0.00	0.00
K2O		9.16	9.16	8.96	9.02	8.94	8.79
NA2O		0.06	0.16	0.10	0.04	0.38	0.00
TOTAL		97.13	96.9	95.56	96.09	96.76	96.5
22 oxygens							
SI		5.334	5.347	5.328	5.375	5.375	5.355
AL		2.666	2.653	2.672	2.625	2.625	2.645
		8	8	8	8	8	8
AL		0.818	0.814	0.751	0.692	0.864	0.752
TI		0.229	0.237	0.235	0.308	0.223	0.236
CR		0.000	0.000	0.008	0.000	0.000	0.000
FE		3.487	3.473	3.494	3.498	3.372	3.522
MN		0.000	0.000	0.000	0.001	0.000	0.009
MG		1.247	1.228	1.318	1.252	1.259	1.319
		5.781	5.752	5.806	5.751	5.718	5.838
CA		0.000	0.000	0.000	0.000	0.000	0.000
K		1.808	1.811	1.800	1.802	1.762	1.746
NA		0.019	0.050	0.029	0.014	0.114	0.000
		1.827	1.861	1.829	1.816	1.876	1.746
XAL		0.1415	0.1415	0.1293	0.1203	0.1511	0.1288
XTI		0.0396	0.0412	0.0405	0.0536	0.0390	0.0404
FE/MG		2.7960	2.8280	2.6510	2.7940	2.6780	2.6700
MG/MG+FE		0.2634	0.2612	0.2739	0.2636	0.2719	0.2725

Sample 87-124-1		Biotite compositions for geothermobarometry (end)					
		BIO.17	BIO.18	BIO.19	BIO.20	BIO.21	average
SIO2		34.25	31.56	34.51	34.32	34.18	34.105
AL2O3		18.85	19.64	18.48	18.47	18.82	18.766
TIO2		1.92	1.50	2.24	1.97	1.97	2.013
CR2O3		0.00	0.00	0.00	0.00	0.00	0.005
FEO		26.48	28.84	26.44	26.49	26.15	26.775
MNO		0.00	0.00	0.00	0.00	0.00	0.007
MGO		5.70	6.29	5.48	5.86	5.60	5.617
CAO		0.00	0.00	0.00	0.00	0.00	0.000
K2O		8.91	6.82	9.15	9.15	9.19	8.841
NA2O		0.15	0.13	0.00	0.01	0.00	0.094
TOTAL		96.26	94.78	96.3	96.27	95.91	96.224
22 oxygens							
SI		5.337	5.029	5.378	5.355	5.346	5.3235
AL		2.663	2.971	2.622	2.645	2.654	2.6765
		8	8	8	8	8	8.0000
AL		0.799	0.718	0.772	0.752	0.815	0.7770
TI		0.225	0.179	0.262	0.231	0.232	0.2361
CR		0.000	0.000	0.000	0.000	0.000	0.0007
FE		3.450	3.843	3.446	3.458	3.420	3.4966
MN		0.000	0.000	0.000	0.000	0.000	0.0009
MG		1.324	1.494	1.273	1.362	1.304	1.3073
		5.798	6.234	5.753	5.803	5.771	5.8186
CA		0.000	0.000	0.000	0.000	0.000	0.0000
K		1.772	1.387	1.820	1.822	1.834	1.7604
NA		0.047	0.040	0.000	0.003	0.000	0.0287
		1.819	1.427	1.820	1.825	1.834	1.7891
XAL		0.1378	0.1152	0.1342	0.1296	0.1412	0.13354
XTI		0.0388	0.0287	0.0455	0.0398	0.0402	0.04057
FE/MG		2.6060	2.5720	2.7070	2.5390	2.6230	2.67855
MG/MG+FE		0.2773	0.2799	0.2698	0.2826	0.2760	0.27201

Sample 87-124-1		Muscovite compositions for geothermobarometry					
		MS1	MS2	MS3	MS4	MS5	MS6
SiO ₂		46.12	46.31	45.27	45.49	45.43	46.26
Al ₂ O ₃		34.87	34.07	34.57	34.18	33.24	35.86
TiO ₂		0.72	0.71	0.66	0.75	0.81	0.73
Cr ₂ O ₃		0.09	0.03	0.05	0.08	0.05	0.05
FeO		2.67	2.91	2.65	2.51	2.97	2.45
MnO		0.05	0.01	0.05	0.08	0.07	0.09
MgO		0.81	0.94	0.78	0.82	1.13	0.64
CaO		0	0	0	0	0	0
K ₂ O		10	10.14	9.76	9.82	10.03	8.99
Na ₂ O		0.87	0.65	0.54	0.8	0.58	1.75
TOTAL		96.2	95.77	94.33	94.53	94.31	96.82
22 oxygens							
Si		6.12	6.178	6.114	6.137	6.166	6.073
Al		1.88	1.822	1.886	1.863	1.834	1.927
		8	8	8	8	8	8
Al		3.574	3.535	3.618	3.573	3.484	3.621
Ti		0.072	0.072	0.067	0.076	0.083	0.072
Cr		0.01	0.004	0.006	0.009	0.005	0.005
Fe		0.296	0.324	0.299	0.283	0.337	0.269
Mn		0.006	0.002	0.005	0.009	0.008	0.01
Mg		0.16	0.187	0.157	0.166	0.229	0.126
		4.118	4.124	4.152	4.116	4.146	4.103
Ca		0	0	0	0	0	0
K		1.693	1.725	1.682	1.691	1.737	1.505
Na		0.224	0.168	0.142	0.209	0.153	0.445
		1.917	1.893	1.824	1.9	1.89	1.95
Fe/Mg		1.8500	1.7326	1.9045	1.7048	1.4716	2.1349
Mg/Mg+Fe		0.3509	0.3659	0.3443	0.3697	0.4046	0.3190

Sample 87-124-1		Muscovite compositions for geothermobarometry (end)				
	MS7	MS8	MS9	MS10	MS11	average
SiO ₂	46.01	45.88	45.88	44.8	45.27	45.7
Al ₂ O ₃	36.56	36.04	33.94	35.93	35.1	34.94
TiO ₂	0.54	0.63	0.74	0.54	0.61	0.68
Cr ₂ O ₃	0.04	0.05	0.09	0	0.02	0.05
FeO	2.34	2.42	3.1	2.34	3.18	2.69
MnO	0	0	0.07	0.01	0.02	0.04
MgO	0.67	0.71	1	0.28	0.72	0.77
CaO	0	0	0	0	0	0
K ₂ O	8.71	9.24	9.96	8.07	9.28	9.45
Na ₂ O	1.89	1.6	0.4	1.72	0.69	1.04
TOTAL	96.76	96.57	95.18	93.69	94.89	95.36
22 oxygens						
Si	6.03	6.044	6.159	6.042	6.077	6.103
Al	1.97	1.956	1.841	1.958	1.923	1.897
	8	8	8	8	8	8
Al	3.678	3.64	3.529	3.753	3.631	3.603
Ti	0.053	0.062	0.075	0.055	0.062	0.068
Cr	0.004	0.005	0.01	0	0.002	0.005
Fe	0.256	0.267	0.348	0.264	0.357	0.3
Mn	0	0	0.008	0.001	0.003	0.005
Mg	0.131	0.139	0.201	0.056	0.143	0.154
	4.122	4.113	4.171	4.129	4.198	4.135
Ca	0	0	0	0	0	0
K	1.457	1.552	1.706	1.388	1.59	1.611
Na	0.48	0.409	0.103	0.449	0.178	0.27
	1.937	1.961	1.809	1.837	1.768	1.881
Fe/Mg	1.9542	1.9209	1.7313	4.7143	2.4965	1.94805
Mg/Mg+Fe	0.3385	0.3424	0.3661	0.1750	0.2860	0.33921

Sample 87-124-1 Plagioclase compositions

	PL.1	PL.2	PL.3	PL.4	PL.5	PL.6	PL.7	PL.8	PL.9	PL.10	PL.11	Average
SiO ₂	70.84	67.06	67.57	67.19	68.44	68.04	68.44	67.92	67.72	67.79	66.48	67.954
Al ₂ O ₃	16.14	20.40	17.57	20.57	20.43	20.39	20.21	20.63	20.45	20.76	20.16	19.792
CaO	0.39	0.51	0.38	0.69	0.29	0.28	0.17	0.58	0.33	0.81	0.52	0.450
Na ₂ O	9.10	11.01	9.67	11.14	11.21	11.15	11.40	11.53	11.04	10.79	10.46	10.773
K ₂ O	0.28	0.26	0.24	0.31	0.26	0.26	0.29	0.24	0.34	0.26	0.19	0.266
FeO	0.68	0.27	0.38	0.14	0.15	0.13	0.29	0.21	0.25	0.17	0.40	0.279
TOTAL	97.43	99.51	95.81	100.04	100.78	100.25	100.80	101.11	100.13	100.58	98.21	99.514
16 oxygens												
Si	6.289	5.902	6.127	5.887	5.936	5.932	5.942	5.892	5.918	5.897	5.917	5.9672
Al	1.689	2.166	1.877	2.125	2.089	2.095	2.068	2.110	2.107	2.128	2.115	2.0517
	7.978	8.018	8.004	8.012	8.025	8.027	8.010	8.002	8.025	8.025	8.032	8.0144
Ca	0.037	0.048	0.037	0.065	0.027	0.027	0.016	0.054	0.031	0.076	0.050	0.0425
Na	1.567	1.879	1.700	1.892	1.885	1.885	1.919	1.940	1.871	1.821	1.806	1.8332
K	0.032	0.029	0.028	0.034	0.029	0.029	0.032	0.027	0.038	0.029	0.021	0.0298
	1.636	1.956	1.765	1.991	1.941	1.941	1.967	2.021	1.940	1.926	1.877	1.9055
Fe	0.051	0.020	0.029	0.010	0.011	0.010	0.021	0.015	0.019	0.012	0.030	0.0207
An	0.02	0.02	0.02	0.03	0.01	0.01	0.01	0.03	0.02	0.04	0.03	0.02

Sample 87-111-2		Compositions for geothermobarometry					Biotite	
Garnet		GN.84	GN.86	GN.87	GN.88	GN.89		BIO.92
	(BIO.92)							
SIO2	36.92	37.42	37.50	37.15	37.19	SIO2		37.77
AL2O3	20.90	21.00	20.96	21.10	21.19	AL2O3		18.97
TIO2	0.04	0.01	0.07	0.00	0.05	TIO2		1.27
MGO	5.47	5.93	6.03	5.85	6.24	CR2O3		0
FEO	34.17	32.11	33.70	32.53	32.77	FEO		14.91
MNO	2.12	2.50	2.44	2.30	2.13	MNO		0.09
CAO	1.02	1.20	1.13	1.05	1.08	MGO		14.03
TOTAL	100.64	100.17	101.83	99.98	100.65	CAO		0
24 oxygens						K2O		8.26
SI	5.888	5.941	5.895	5.920	5.887	NA2O		0.36
AL	0.112	0.059	0.105	0.080	0.113	TOTAL		95.66
	6	6	6	6	6	22 oxygens		
AL	3.816	3.870	3.777	3.883	3.841	SI		5.538
TI	0.004	0.002	0.009	0.000	0.006	AL		2.462
	3.821	3.872	3.786	3.883	3.847			8
MG	1.301	1.404	1.412	1.389	1.473	AL		0.815
FE	4.557	4.263	4.429	4.335	4.339	TI		0.140
MN	0.286	0.336	0.325	0.311	0.286	CR		0.000
CA	0.175	0.204	0.190	0.178	0.183	FE		1.187
	6.318	6.206	6.356	6.213	6.281	MN		0.011
						MG		3.066
								5.219
XCa	0.02767	0.03282	0.02992	0.02871	0.02920	CA		0.000
XCa+XMn	0.07289	0.08692	0.08099	0.07875	0.07465	K		1.545
						NA		0.103
FE/MG	3.50238	3.03712	3.13668	3.12006	2.94475			1.6478
MG/MG+FE	0.22210	0.24770	0.24174	0.24271	0.25350	XAl		0.1562
						XTi		0.0269
						FE/MG		0.3873
						MG/MG+FE		0.7208

APPENDIX 8 **ELECTRON MICROPROBE ANALYSES OF HORNBLLENDE FROM** **SAMPLES COLLECTED IN THE ECSTALL PLUTON**

This appendix gives the compositions of hornblende from samples of the Ecstall pluton used for Al-in-hornblende geobarometry. Refer to Chapter 2, Section 5 for petrographic discussion of samples, to Appendix 1B for sample locations and to Appendix 2 for UTM coordinates. Analyses are presented in this appendix in the order in which they are discussed in Section 2-5. The analytical procedure for electron microprobe analysis is presented in Appendix 5.

Sample number	Mineral analysed and purpose of analysis				Tables to which analysis refers
Sample 87-96-1	Hornblende for ...				Tables 2-4 ...
	C rim HB.26	D core HB.27	E core HB.28	F core HB.30	
SiO ₂	41.00	41.23	41.12	42.31	
Al ₂ O ₃	12.24	11.84	12.38	11.42	
TiO ₂	0.86	0.90	0.89	0.84	
FeO	18.99	18.61	18.76	18.37	
MnO	0.40	0.31	0.42	0.35	
Cr ₂ O ₃	0.00	0.01	0.00	0.00	
MgO	9.12	8.96	9.50	9.72	
CaO	11.75	11.78	11.71	11.71	
K ₂ O	1.39	1.39	1.40	1.22	
Na ₂ O	1.06	0.69	1.39	1.38	
TOTAL	96.81	95.69	97.64	97.30	
23 oxygens					
SI	6.318	6.403	6.293		
AL	1.683	1.598	1.707		
	8	8			Analysis number
AL	0.542				
II					

Sample 87-19-1 Homblende compositions for Al-in-hornblende geobarometry

Tables 2-4, 2-5 and 2-6

	A rim						A core					
	HB.8	HB.12	HB.13	HB.14	HB.15	HB.16 Average (6)	HB.9	HB.10	HB.11	HB.17	HB.18 Average (5)	
SiO2	40.93	40.37	40.81	39.83	40.73	40.55	40.537	41.19	40.75	41.08	40.82	
Al2O3	13.02	13.03	12.91	12.06	13.15	12.87	12.840	12.48	12.90	13.16	12.69	
TiO2	0.97	0.88	0.99	0.87	0.98	0.98	0.945	1.05	0.96	1.02	0.91	
FeO	17.68	19.02	18.25	20.27	18.13	18.24	18.598	17.90	18.10	18.06	18.42	
MnO	0.49	0.50	0.50	0.54	0.55	0.53	0.518	0.54	0.46	0.49	0.40	
CR2O3	0.00	0.00	0.01	0.02	0.06	0.00	0.015	0.04	0.00	0.05	0.00	
MGO	9.14	8.83	9.05	9.12	9.37	9.20	9.118	9.51	9.01	9.26	9.07	
CAO	11.38	11.23	11.22	10.76	11.26	11.23	11.180	11.21	11.23	11.15	11.22	
K2O	1.68	1.53	1.59	1.51	1.51	1.49	1.552	1.52	1.52	1.55	1.49	
NA2O	1.71	1.61	1.53	1.12	1.37	1.52	1.477	1.23	1.77	2.03	1.67	
TOTAL	97.00	97.00	96.86	96.10	97.11	96.61	96.780	96.67	96.70	97.85	96.69	
23 oxygens												
SI	6.272	6.225	6.273	6.236	6.236	6.25	6.2487	6.323	6.272	6.247	6.288	
AL	1.728	1.775	1.727	1.764	1.764	1.75	1.7513	1.677	1.728	1.753	1.712	
	8	8	8	8	8	8	8	8	8	8	8	
AL	0.624	0.593	0.611	0.461	0.610	0.589	0.5813	0.580	0.612	0.606	0.593	
TI	0.112	0.103	0.114	0.103	0.113	0.114	0.1098	0.121	0.111	0.116	0.105	
FE	2.266	2.452	2.346	2.654	2.322	2.352	2.3987	2.298	2.329	2.296	2.373	
MN	0.064	0.065	0.065	0.072	0.071	0.069	0.0677	0.071	0.060	0.063	0.052	
CR	0.000	0.000	0.001	0.002	0.008	0.000	0.0018	0.005	0.000	0.006	0.000	
MG	2.088	2.030	2.074	2.129	2.138	2.114	2.0955	2.176	2.067	2.100	2.083	
	5.154	5.243	5.211	5.421	5.262	5.238	5.2548	5.251	5.179	5.187	5.206	
CA	1.868	1.855	1.848	1.805	1.848	1.855	1.8465	1.843	1.853	1.816	1.852	
K	0.329	0.301	0.312	0.302	0.296	0.292	0.3053	0.298	0.298	0.301	0.292	
NA	0.508	0.481	0.456	0.339	0.406	0.454	0.4407	0.365	0.529	0.598	0.499	
	2.705	2.637	2.616	2.446	2.550	2.601	2.5925	2.506	2.680	2.715	2.643	

Sample 87-19-1		Hornblende compositions for Al-in-hornblende geobarometry (continued)										Tables 2-4, 2-5 and 2-6			
		B rim					B core								
		HB.19	HB.20	HB.21	HB.22	HB.24 Average (5)	HB.25	HB.26	HB.27	HB.28 Average (4)					
		40.65	40.98	40.88	40.56	40.69	40.52	40.66	40.72	40.57	40.618				
		13.36	12.80	12.53	13.00	12.97	13.02	12.93	12.85	13.00	12.950				
		0.98	0.98	0.95	0.67	0.59	0.97	1.10	1.10	1.09	1.065				
		18.31	18.06	17.88	18.81	18.75	18.31	17.99	17.95	18.02	18.068				
		0.47	0.50	0.45	0.47	0.57	0.46	0.43	0.51	0.39	0.448				
		0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.015				
		9.26	9.45	9.36	9.08	9.07	9.05	9.19	9.41	9.45	9.275				
		11.48	11.23	11.28	11.11	11.05	11.28	11.25	11.24	11.26	11.258				
		1.58	1.53	1.58	1.50	1.41	1.60	1.58	1.62	1.63	1.608				
		1.77	1.69	1.94	1.36	1.75	1.57	1.56	1.91	1.60	1.660				
		97.86	97.27	96.85	96.56	96.85	99.78	96.69	97.33	97.05	96.963				
23 oxygens															
SI		6.195	6.268	6.284	6.263	6.267	6.240	6.254	6.234	6.223	6.2378				
AL		1.805	1.732	1.716	1.737	1.733	1.760	1.746	1.766	1.777	1.7623				
		8	8	8	8	8	8	8	8	8	8				
AL		0.594	0.575	0.555	0.629	0.622	0.603	0.598	0.553	0.574	0.5820				
TI		0.112	0.112	0.110	0.077	0.069	0.113	0.127	0.126	0.125	0.1228				
FE		2.333	2.310	2.299	2.430	2.415	2.359	2.315	2.298	2.311	2.3208				
MN		0.060	0.064	0.059	0.061	0.075	0.061	0.056	0.066	0.051	0.0585				
CR		0.000	0.006	0.000	0.000	0.000	0	0	0.003	0.005	0.0020				
MG		2.104	2.156	2.145	2.090	2.082	2.079	2.108	2.147	2.16	2.1235				
		5.203	5.223	5.168	5.287	5.263	5.215	5.204	5.193	5.226	5.2095				
CA		1.875	1.841	1.858	1.838	1.824	1.861	1.855	1.844	1.851	1.8528				
K		0.308	0.298	0.310	0.296	0.277	0.314	0.310	0.317	0.319	0.3150				
NA		0.522	0.501	0.577	0.408	0.522	0.469	0.466	0.568	0.476	0.4948				
		2.705	2.640	2.745	2.542	2.623	2.644	2.631	2.729	2.646	2.6625				

Sample 87-19-1 Hornblende compositions for Al-in-hornblende geobarometry (continued)

Tables 2-4, 2-5 and 2-6

	C rim								C core							
	HB.29	HB.30	HB.31	HB.32	HB.34	HB.36	HB.46	Average (7)	HB.35	HB.37	HB.38	HB.39	HB.40	Average (5)		
SiO2	40.31	40.30	40.15	40.03	40.81	40.63	40.59	40.403	41.04	40.61	41.13	40.85	40.25	40.776		
Al2O3	13.20	13.23	12.80	12.14	12.36	12.46	12.98	12.739	11.68	12.80	12.38	12.00	12.86	12.344		
TiO2	0.49	0.83	0.94	0.79	0.87	0.96	0.74	0.803	1.03	1.17	1.03	1.04	0.96	1.046		
FeO	19.13	17.31	17.75	18.19	18.06	18.28	18.44	18.166	17.42	17.83	17.33	17.59	17.82	17.598		
MnO	0.58	0.46	0.53	0.55	0.47	0.52	0.63	0.534	0.41	0.43	0.47	0.47	0.53	0.462		
Cr2O3	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.006	0.00	0.00	0.03	0.00	0.00	0.006		
MgO	8.87	10.05	9.67	9.33	9.27	9.64	8.93	9.394	9.96	9.60	9.67	9.91	9.63	9.754		
CaO	11.27	11.24	11.30	11.14	11.20	11.18	11.29	11.231	11.21	11.41	11.25	11.32	11.41	11.320		
K2O	1.36	1.51	1.62	1.24	1.25	1.45	1.40	1.404	1.34	1.58	1.53	1.45	1.55	1.490		
Na2O	2.00	1.43	1.77	1.72	1.65	1.58	1.41	1.651	1.78	1.71	1.96	1.61	1.76	1.764		
TOTAL	97.21	96.36	96.56	95.13	95.94	96.71	96.41	96.331	95.87	97.14	96.78	96.24	96.77	96.560		
23 oxygens																
Si	6.212	6.201	6.199	6.276	6.321	6.260	6.271	6.2486	6.351	6.224	6.308	6.306	6.200	6.2778		
Al	1.788	1.799	1.801	1.724	1.679	1.740	1.729	1.7514	1.649	1.776	1.692	1.694	1.800	1.7222		
	8	8	8	8	8	8	8	8	8	8	8	8	8	8		
Al	0.608	0.601	0.530	0.520	0.577	0.522	0.634	0.5703	0.482	0.536	0.545	0.490	0.536	0.5178		
Ti	0.056	0.096	0.109	0.093	0.101	0.111	0.087	0.0933	0.120	0.135	0.118	0.121	0.111	0.1210		
Fe	2.465	2.228	2.292	2.385	2.339	2.356	2.382	2.3496	2.254	2.285	2.223	2.271	2.296	2.2658		
Mn	0.076	0.060	0.069	0.073	0.062	0.068	0.082	0.0700	0.053	0.055	0.060	0.061	0.070	0.0598		
Cr	0.000	0.000	0.004	0.000	0.000	0.001	0.000	0.0007	0.000	0.000	0.004	0.000	0.000	0.0008		
Mg	2.037	2.304	2.226	2.181	2.141	2.215	2.057	2.1659	2.297	2.193	2.212	2.281	2.212	2.2390		
	5.242	5.289	5.230	5.252	5.220	5.273	5.242	5.2497	5.206	5.204	5.162	5.224	5.225	5.2042		
Ca	1.860	1.853	1.869	1.872	1.858	1.845	1.869	1.8609	1.858	1.873	1.849	1.872	1.883	1.8670		
K	0.266	0.296	0.318	0.248	0.247	0.285	0.275	0.2764	0.265	0.309	0.299	0.285	0.305	0.2926		
Na	0.597	0.426	0.529	0.523	0.494	0.471	0.422	0.4946	0.533	0.508	0.584	0.482	0.525	0.5264		
	2.723	2.575	2.716	2.643	2.599	2.601	2.566	2.6319	2.656	2.690	2.732	2.639	2.713	2.6860		

Sample 87-19-1		Hornblende compositions for Al-in-hornblende geobarometry (end)										Tables 2-4, 2-5 and 2-6	
		D core HB.2	E rim HB.3	E core HB.5	F rim HB.6	F core HB.7	G core HB.41	H core HB.42	I core HB.43	J core HB.45			
SiO2		41.16	41.21	40.66	40.43	40.48	41.40	41.05	40.40	40.51			
Al2O3		12.75	12.30	12.92	12.76	13.00	12.91	12.81	12.94	12.97			
TiO2		1.02	0.78	0.90	0.83	0.89	1.00	1.00	0.97	1.06			
FeO		17.78	18.67	18.82	19.40	18.58	17.99	17.84	18.29	17.88			
MnO		0.50	0.53	0.55	0.48	0.50	0.45	0.48	0.42	0.49			
CR2O3		0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00			
MGO		9.77	9.09	9.16	8.47	9.05	9.84	9.68	9.19	9.29			
CAO		11.21	11.08	11.22	11.07	11.27	11.38	11.51	11.38	11.45			
K2O		1.49	1.16	1.39	1.49	1.61	1.51	1.46	1.63	1.54			
NA2O		1.69	1.69	1.42	1.49	1.79	1.73	1.52	1.23	1.56			
TOTAL		97.38	96.51	97.05	96.42	97.17	98.21	97.35	96.45	96.75			
23 oxygens													
Si		6.275	6.352	6.248	6.274	6.226	6.262	6.263	6.240	6.231			
AL		1.725	1.648	1.752	1.726	1.774	1.738	1.737	1.760	1.767			
		8	8	8	8	8	8	8	8	8			
AL		0.566	0.587	0.588	0.608	0.582	0.564	0.567	0.595	0.582			
TI		0.117	0.090	0.105	0.097	0.102	0.114	0.114	0.113	0.123			
FE		2.267	2.406	2.419	2.518	2.389	2.276	2.276	2.363	2.301			
MN		0.065	0.069	0.072	0.063	0.065	0.057	0.062	0.056	0.064			
CR		0.001	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000			
MG		2.221	2.089	2.098	1.961	2.075	2.218	2.202	2.115	2.130			
		5.237	5.241	5.284	5.247	5.213	5.229	5.221	5.242	5.200			
CA		1.832	1.830	1.847	1.842	1.856	1.845	1.881	1.884	1.887			
K		0.290	0.229	0.273	0.295	0.316	0.291	0.285	0.322	0.303			
NA		0.500	0.506	0.422	0.450	0.533	0.507	0.450	0.368	0.465			
		2.622	2.565	2.542	2.587	2.705	2.643	2.616	2.574	2.655			

Sample 87-107-1 Hornblende compositions for Al-in-hornblende geobarometry Tables 2-4, 2-5 and 2-6

	A rim						A core					
	HB.52	HB.54	HB.55	HB.56	HB.57	Average (5)	HB.51	HB.59	HB.60	HB.61	Average (4)	
SiO2	41.82	42.97	41.09	40.97	40.83	41.536	43.08	43.14	43.74	42.93	43.223	
Al2O3	12.26	11.45	12.29	12.30	12.45	12.150	10.92	11.37	11.05	10.67	11.003	
TiO2	0.97	0.87	0.71	0.72	0.70	0.794	1.36	1.10	1.03	1.21	1.175	
FeO	17.46	17.33	18.12	17.77	17.61	17.658	16.86	17.57	17.63	17.46	17.380	
MnO	0.28	0.32	0.33	0.40	0.35	0.336	0.44	0.38	0.32	0.40	0.385	
Cr2O3	0.00	0.03	0.00	0.00	0.04	0.014	0.00	0.00	0.00	0.00	0.000	
MgO	9.45	10.24	9.30	9.39	9.15	9.506	10.16	10.29	11.02	10.54	10.503	
CaO	11.98	11.87	11.65	11.81	11.64	11.790	11.84	12.00	12.12	12.12	12.020	
K2O	1.39	1.23	1.43	1.46	1.39	1.380	1.31	1.28	1.23	1.26	1.270	
Na2O	1.28	1.44	1.64	1.29	1.24	1.378	0.90	1.27	1.23	1.27	1.168	
TOTAL	96.89	97.75	96.56	96.11	95.40	96.542	96.87	98.40	99.37	97.86	98.125	
23 oxygens												
Si	6.384	6.483	6.332	6.333	6.344	6.3752	6.539	6.472	6.491	6.487	6.4973	
Al	1.616	1.517	1.668	1.667	1.656	1.6248	1.461	1.528	1.509	1.513	1.5028	
	8	8	8	8	8	8	8	8	8	8	8	
Al	0.590	0.519	0.564	0.573	0.625	0.5742	0.493	0.483	0.424	0.387	0.4468	
Ti	0.111	0.099	0.082	0.084	0.082	0.0916	0.156	0.124	0.115	0.137	0.1330	
Fe	2.229	2.187	2.336	2.297	2.289	2.2676	2.140	2.204	2.188	2.207	2.1848	
Mn	0.037	0.041	0.043	0.053	0.047	0.0442	0.057	0.048	0.040	0.051	0.0490	
Cr	0.000	0.004	0.000	0.000	0.005	0.0018	0.000	0.000	0.000	0.000	0.0000	
Mg	2.151	2.302	2.135	2.163	2.119	2.1740	2.298	2.302	2.438	2.374	2.3530	
	5.118	5.152	5.160	5.170	5.167	5.1534	5.144	5.161	5.205	5.156	5.1665	
Ca	1.959	1.918	1.924	1.956	1.939	1.9392	1.925	1.930	1.927	1.963	1.9363	
K	0.271	0.238	0.281	0.287	0.276	0.2706	0.254	0.246	0.233	0.242	0.2438	
Na	0.378	0.421	0.489	0.388	0.375	0.4102	0.265	0.369	0.354	0.371	0.3398	
	2.608	2.577	2.694	2.631	2.590	2.6200	2.444	2.545	2.514	2.576	2.5198	

Sample 87-107-1													Hornblende compositions for Al-in-hornblende geobarometry (continued)													Tables 2-4, 2-5 and 2-6					
		B rim						B core																							
		HB.67	HB.68	HB.69	HB.70	HB.71	HB.72 Average (6)	HB.73	HB.74	HB.75	HB.76 Average (4)																				
SiO2		44.18	41.59	42.26	42.68	41.64	43.82	43.95	44.04	44.48	43.66	44.033																			
Al2O3		10.23	11.89	12.02	12.53	12.84	11.02	10.54	10.22	10.45	10.12	10.333																			
TiO2		1.03	0.69	1.05	0.81	0.71	0.86	0.858	1.25	1.28	1.24	1.265																			
FeO		16.71	17.95	17.85	18.32	18.92	17.24	17.332	16.95	17.31	17.03	17.090																			
MnO		0.42	0.33	0.34	0.38	0.33	0.32	0.353	0.42	0.34	0.46	0.415																			
CR2O3		0.03	0.00	0.04	0.02	0.00	0.05	0.023	0.07	0.00	0.03	0.025																			
MGO		11.06	11.58	10.04	9.67	9.23	10.83	10.043	11.13	10.91	10.69	10.843																			
CAO		12.07	11.58	11.02	11.94	11.91	12.07	11.765	11.96	12.04	12.02	12.003																			
K2O		1.05	1.32	1.37	1.38	1.52	1.15	1.298	1.18	1.19	1.16	1.180																			
NA2O		0.66	1.51	1.20	1.68	1.45	1.30	1.300	1.52	1.88	1.41	1.613																			
TOTAL		97.44	96.29	97.19	99.41	98.55	98.66	97.923	98.74	99.88	97.82	98.798																			
23 O																															
SI		6.638	6.406	6.419	6.369	6.298	6.534	6.4440	6.566	6.563	6.578	6.5658																			
AL		1.362	1.594	1.581	1.631	1.702	1.466	1.5560	1.434	1.437	1.422	1.4343																			
		8	8	8	8	8	8	8	8	8	8	8																			
AL		0.450	0.566	0.570	0.574	0.588	0.472	0.5367	0.363	0.380	0.374	0.3815																			
TI		0.116	0.079	0.120	0.091	0.081	0.096	0.0972	0.140	0.142	0.141	0.1420																			
FE		2.099	2.312	2.267	2.286	2.393	2.151	2.2513	2.113	2.136	2.146	2.1313																			
MN		0.053	0.043	0.044	0.048	0.043	0.040	0.0452	0.053	0.042	0.058	0.0520																			
CR		0.004	0.000	0.004	0.003	0.000	0.006	0.0028	0.008	0.000	0.003	0.0028																			
MG		2.478	2.166	2.274	2.151	2.082	2.407	2.2597	2.474	2.400	2.402	2.4105																			
		5.200	5.166	5.279	5.153	5.187	5.172	5.1928	5.151	5.100	5.124	5.1200																			
CA		1.942	1.911	1.794	1.908	1.930	1.929	1.9023	1.911	1.904	1.940	1.9178																			
K		0.200	0.260	0.266	0.263	0.294	0.219	0.2503	0.224	0.224	0.223	0.2243																			
NA		0.191	0.452	0.355	0.485	0.426	0.376	0.3808	0.438	0.537	0.413	0.4655																			
		2.333	2.623	2.415	2.656	2.650	2.524	2.5335	2.573	2.665	2.576	2.6075																			

Hornblende compositions for Al-in-hornblende geobarometry (end)													Tables 2-4, 2-5 and 2-6			
Sample 87-107-1																
	C rim HB.62	C core HB.63	HB.64 Average (2)	D core HB.48	E core HB.49	F core HB.50	G core HB.53	H core HB.77	I core HB.78	J core HB.79	K core HB.80					
SiO2	42.30	43.87	43.38	43.625	42.21	41.53	43.15	43.84	41.99	42.73	42.23					
Al2O3	12.34	10.35	9.67	10.010	12.06	11.56	10.51	10.48	12.24	11.61	12.23					
TiO2	0.99	1.03	1.10	1.065	0.92	1.08	1.22	0.96	0.94	1.13	0.97					
FeO	17.45	16.44	16.44	16.440	17.18	17.55	16.87	16.81	17.67	17.27	17.92					
MnO	0.36	0.34	0.35	0.345	0.35	0.46	0.32	0.37	0.41	0.36	0.34					
Cr2O3	0.00	0.00	0.04	0.020	0.04	0.00	0.00	0.00	0.02	0.03	0.00					
MgO	10.01	11.19	11.09	11.140	9.76	9.41	10.70	10.92	10.00	10.23	9.74					
CaO	11.95	11.98	11.83	11.905	11.91	11.87	11.83	12.08	11.91	12.02	11.99					
K2O	1.34	1.11	1.05	1.080	1.35	1.35	1.21	1.16	1.48	1.32	1.42					
Na2O	1.62	1.40	1.04	1.220	1.11	1.15	1.46	1.24	1.23	1.50	1.19					
TOTAL	98.36	97.71	95.99	96.850	96.89	95.96	97.27	97.86	97.89	98.20	98.03					
23 O																
Si	6.362	6.586	6.630	6.6080	6.426	6.415	6.533	6.582	6.354	6.428	6.379					
Al	1.638	1.414	1.370	1.3920	1.574	1.585	1.467	1.418	1.646	1.572	1.621					
	8	8	8	8	8	8	8	8	8	8	8					
Al	0.548	0.418	0.371	0.3945	0.590	0.519	0.409	0.437	0.538	0.486	0.558					
Ti	0.112	0.116	0.126	0.1210	0.105	0.126	0.138	0.109	0.107	0.128	0.110					
Fe	2.195	2.064	2.101	2.0825	2.187	2.266	2.136	2.111	2.237	2.173	2.264					
Mn	0.045	0.044	0.046	0.0450	0.046	0.060	0.042	0.047	0.053	0.046	0.043					
Cr	0.000	0.000	0.005	0.0025	0.005	0.000	0.000	0.000	0.002	0.004	0.000					
Mg	2.243	2.504	2.527	2.5155	2.215	2.166	2.415	2.444	2.256	2.293	2.194					
	5.143	5.146	5.176	5.1610	5.148	5.137	5.140	5.148	5.193	5.130	5.169					
Ca	1.926	1.927	1.937	1.9320	1.943	1.964	1.919	1.943	1.931	1.937	1.941					
K	0.258	0.213	0.206	0.2095	0.261	0.266	0.234	0.222	0.286	0.253	0.274					
Na	0.472	0.407	0.310	0.3585	0.327	0.346	0.430	0.360	0.362	0.437	0.349					
	2.656	2.547	2.453	2.5000	2.531	2.576	2.583	2.525	2.579	2.627	2.564					

Sample 87-96-1		Hornblende compositions for Al-in-hornblende geobarometry										Tables 2-4, 2-5 and 2-6			
		A rim					A core								
		HB.1	HB.2	HB.3	HB.5	HB.6 Average (5)	HB.7	HB.8	HB.9	HB.10 Average (4)					
	SiO2	41.59	41.83	41.43	41.43	42.45	41.744								
	Al2O3	12.90	12.46	12.83	12.51	12.42	12.622								
	TiO2	0.87	0.88	0.82	0.82	0.96	0.868								
	FeO	19.16	19.06	19.42	19.33	19.18	19.226								
	MnO	0.36	0.35	0.35	0.43	0.38	0.374								
	Cr2O3	0.00	0.00	0.00	0.04	0.00	0.008								
	MgO	8.92	9.23	8.91	9.07	9.31	9.085								
	CaO	11.98	11.75	11.67	11.85	11.89	11.828								
	K2O	1.42	1.44	1.48	1.44	1.32	1.416								
	Na2O	1.29	1.20	1.61	0.92	0.96	1.192								
	TOTAL	98.47	98.18	98.50	97.82	98.85	98.363								
23 oxygens															
	Si	6.297	6.342	6.286	6.318	6.380	6.3245								
	Al	1.703	1.658	1.715	1.682	1.620	1.6755								
		8	8	8	8	8	8								
	Al	0.600	0.570	0.580	0.567	0.580	0.5790								
	Ti	0.099	0.101	0.094	0.095	0.109	0.0991								
	Fe	2.426	2.418	2.464	2.466	2.411	2.4368								
	Mn	0.046	0.045	0.046	0.055	0.048	0.0479								
	Cr	0.000	0.000	0.000	0.005	0.000	0.0010								
	Mg	2.013	2.087	2.015	2.063	2.085	2.0521								
		5.183	5.219	5.197	5.249	5.232	5.2159								
	Ca	1.944	1.910	1.898	1.937	1.915	1.9204								
	K	0.274	0.278	0.286	0.280	0.253	0.2740								
	Na	0.377	0.352	0.474	0.271	0.278	0.3502								
		2.595	2.539	2.658	2.487	2.445	2.5446								

Sample 87-96-1		Hornblende compositions for Al-in-hornblende geobarometry (continued)										Tables 2-4, 2-5 and 2-6			
	B rim					B core									
	HB.16	HB.17	HB.19	HB.19	HB.20	HB.21	Average (6)	HB.22	HB.23	HB.24	HB.25	Average(4)			
SiO2	41.02	41.27	41.02	40.60	41.27	40.96	41.019	41.01	40.89	41.31	41.25	41.113			
Al2O3	12.31	12.72	12.41	12.81	12.72	12.24	12.533	12.52	12.73	12.25	12.79	12.571			
TiO2	0.79	0.82	0.80	0.86	0.94	0.89	0.849	0.91	0.91	0.90	0.90	0.904			
FeO	19.61	18.91	19.06	19.29	19.05	18.79	19.115	19.23	19.27	18.81	19.17	19.116			
MnO	0.42	0.42	0.38	0.39	0.40	0.42	0.403	0.43	0.39	0.32	0.37	0.376			
Cr2O3	0.01	0.00	0.00	0.00	0.02	0.04	0.012	0.03	0.00	0.00	0.01	0.009			
MgO	8.52	9.16	9.00	8.62	9.23	8.96	8.913	9.26	9.30	9.65	9.29	9.371			
CaO	11.69	11.76	11.61	11.71	11.78	11.82	11.728	11.78	11.79	11.76	11.76	11.773			
K2O	1.34	1.34	1.40	1.43	1.46	1.38	1.388	1.45	1.42	1.41	1.44	1.425			
Na2O	1.66	1.73	1.58	1.46	1.41	1.18	1.499	1.39	1.05	1.48	1.42	1.331			
TOTAL	97.35	98.10	97.24	97.15	98.26	96.66	97.459	97.99	97.74	97.87	98.37	97.989			
23 oxygens															
Si	6.313	6.277	6.301	6.254	6.269	6.321	6.2890	6.259	6.249	6.294	6.261	6.2654			
Al	1.688	1.723	1.699	1.746	1.731	1.680	1.7110	1.741	1.752	1.707	1.740	1.7346			
	8	8	8	8	8	8	8	8	8	8	8	8			
Al	0.546	0.558	0.549	0.579	0.546	0.547	0.5539	0.512	0.542	0.494	0.548	0.5236			
Ti	0.092	0.094	0.093	0.100	0.108	0.103	0.0980	0.105	0.105	0.104	0.103	0.1038			
Fe	2.524	2.406	2.449	2.485	2.421	2.425	2.4515	2.454	2.463	2.397	2.433	2.4365			
Mn	0.054	0.054	0.049	0.051	0.051	0.055	0.0523	0.056	0.050	0.042	0.047	0.0486			
Cr	0.002	0.000	0.000	0.000	0.002	0.005	0.0013	0.003	0.000	0.000	0.002	0.0011			
Mg	1.955	2.078	2.059	1.979	2.091	2.060	2.0368	2.106	2.118	2.191	2.101	2.1290			
	5.171	5.188	5.198	5.194	5.219	5.195	5.1938	5.235	5.277	5.227	5.233	5.2426			
Ca	1.929	1.918	1.913	1.933	1.918	1.955	1.9273	1.927	1.930	1.920	1.913	1.9224			
K	0.262	0.259	0.274	0.281	0.282	0.272	0.2716	0.282	0.276	0.273	0.278	0.2773			
Na	0.496	0.508	0.471	0.435	0.415	0.353	0.4460	0.412	0.311	0.438	0.417	0.3945			
	2.686	2.685	2.657	2.648	2.614	2.580	2.6448	2.621	2.517	2.631	2.608	2.5941			

Sample 87-96-1		Homblende (end)			
		C rim HB.26	D core HB.27	E core HB.28	F core HB.30
SiO ₂		41.00	41.23	41.22	42.31
Al ₂ O ₃		12.24	11.84	12.38	11.42
TiO ₂		0.86	0.90	0.89	0.84
FeO		18.99	18.61	18.76	18.37
MnO		0.40	0.31	0.42	0.35
Cr ₂ O ₃		0.00	0.01	0.00	0.00
MgO		9.12	8.96	9.50	9.72
CaO		11.75	11.78	11.71	11.71
K ₂ O		1.39	1.39	1.40	1.22
Na ₂ O		1.06	0.69	1.39	1.38
TOTAL		96.81	95.69	97.64	97.30
23 oxygens					
Si		6.318	6.403	6.293	6.450
Al		1.683	1.598	1.707	1.551
		8	8	8	8
Al		0.542	0.569	0.521	0.501
Ti		0.100	0.105	0.102	0.097
Fe		2.448	2.418	2.396	2.342
Mn		0.053	0.041	0.054	0.046
Cr		0.000	0.002	0.000	0.000
Mg		2.095	2.075	2.161	2.208
		5.236	5.208	5.234	5.193
Ca		1.941	1.961	1.916	1.913
K		0.274	0.275	0.272	0.236
Na		0.315	0.208	0.410	0.407
		2.529	2.443	2.598	2.556

Sample 89-139		Hornblende compositions for Al-in-hornblende geobarometry										Tables 2-4, 2-5 and 2-6			
		A rim					A core								
		HB.31	HB.32	HB.33	HB.34	HB.35	HB.36 Average (6)	HB.37	HB.38	HB.39	HB.40 Average (4)				
SiO ₂		40.34	40.22	40.52	40.27	40.85	40.22	41.67	41.35	41.20	41.28	41.371			
Al ₂ O ₃		12.78	12.62	12.85	12.49	13.09	12.53	12.06	12.13	12.09	12.14	12.101			
TiO ₂		0.86	0.82	0.85	0.90	0.82	0.85	1.08	1.04	1.07	1.04	1.058			
FeO		20.82	20.56	20.32	19.79	20.28	20.07	19.55	19.75	19.76	19.64	19.673			
MnO		0.36	0.39	0.37	0.41	0.35	0.40	0.34	0.35	0.35	0.39	0.358			
Cr ₂ O ₃		0.00	0.01	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.003			
MgO		7.66	7.66	8.07	8.05	7.61	8.02	8.42	8.57	8.35	8.40	8.431			
CaO		11.48	11.40	11.41	11.44	11.30	11.46	11.41	11.60	11.67	11.51	11.548			
K ₂ O		1.47	1.52	1.59	1.56	1.55	1.52	1.41	1.43	1.39	1.43	1.411			
Na ₂ O		1.57	1.18	1.21	1.29	2.18	1.36	1.70	1.41	1.73	1.41	1.559			
TOTAL		97.32	96.36	97.21	96.21	98.02	96.41	97.62	97.61	97.59	97.23	97.511			
23 oxygens															
Si		6.249	6.282	6.262	6.283	6.269	6.272	6.379	6.340	6.329	6.352	6.3496			
Al		1.751	1.718	1.739	1.717	1.731	1.729	1.622	1.660	1.672	1.649	1.6504			
		8	8	8	8	8	8	8	8	8	8	8			
Al		0.583	0.605	0.603	0.580	0.637	0.574	0.555	0.533	0.518	0.553	0.5394			
Ti		0.101	0.097	0.099	0.106	0.095	0.100	0.125	0.121	0.124	0.121	0.1224			
Fe		2.699	2.687	2.626	2.584	2.602	2.618	2.504	2.533	2.539	2.529	2.5259			
Mn		0.048	0.051	0.048	0.054	0.046	0.053	0.044	0.045	0.046	0.051	0.0463			
Cr		0.000	0.001	0.004	0.004	0.000	0.000	0.000	0.000	0.000	0.001	0.0003			
Mg		1.768	1.782	1.860	1.874	1.741	1.864	1.921	1.958	1.912	1.926	1.9289			
		5.197	5.222	5.239	5.200	5.120	5.208	5.147	5.189	5.137	5.180	5.1630			
Ca		1.906	1.909	1.889	1.913	1.858	1.915	1.873	1.906	1.922	1.899	1.8998			
K		0.289	0.303	0.314	0.309	0.302	0.302	0.275	0.280	0.273	0.280	0.2769			
Na		0.471	0.358	0.364	0.339	0.647	0.410	0.503	0.420	0.515	0.422	0.4646			
		2.666	2.569	2.566	2.611	2.807	2.626	2.650	2.605	2.710	2.600	2.6413			

Sample 89-139		Hornblende compositions for Al-in-hornblende geobarometry (continued)										Tables 2-4, 2-5 and 2-6			
	B rim	HB.50	HB.51	HB.52	HB.53	HB.54	HB.55 Average (6)	B core	HB.56	HB.57	HB.58	HB.59 Average (4)			
SiO ₂	40.56	39.79	40.39	40.38	39.18	39.54	39.973	40.50	41.19	41.59	41.61	41.221			
Al ₂ O ₃	12.07	12.18	12.26	11.63	12.79	12.39	12.220	11.67	11.39	11.24	11.49	11.445			
TiO ₂	1.12	1.07	0.89	1.02	0.81	0.88	0.965	1.08	1.12	1.08	1.07	1.086			
FeO	19.88	19.61	20.11	19.77	20.36	20.30	20.005	19.60	19.57	19.57	19.60	19.585			
MnO	0.35	0.40	0.32	0.38	0.36	0.29	0.350	0.31	0.35	0.41	0.32	0.345			
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.08	0.00	0.020			
MgO	8.45	8.08	8.26	7.86	7.66	7.49	7.967	8.57	8.53	8.77	8.72	8.645			
CaO	11.56	11.42	11.60	11.58	11.41	11.35	11.487	11.41	11.48	11.43	11.46	11.444			
K ₂ O	1.43	1.44	1.49	1.29	1.47	1.51	1.438	1.40	1.30	1.31	1.35	1.338			
Na ₂ O	1.80	1.51	1.80	1.31	1.70	1.35	1.578	1.79	1.39	1.45	1.51	1.535			
TOTAL	97.22	95.50	97.12	95.22	95.74	95.10	95.983	96.33	96.31	96.92	97.11	96.664			
23 oxygens															
Si	6.274	6.263	6.263	6.364	6.182	6.266	6.2687	6.313	6.399	6.419	6.406	6.3843			
Al	1.726	1.737	1.737	1.636	1.818	1.734	1.7313	1.687	1.601	1.581	1.594	1.6158			
	8	8	8	8	8	8	8	8	8	8	8	8			
Al	0.474	0.523	0.504	0.525	0.561	0.581	0.5280	0.457	0.484	0.464	0.490	0.4736			
Ti	0.130	0.127	0.103	0.121	0.096	0.105	0.1137	0.126	0.131	0.126	0.124	0.1264			
Fe	2.571	2.581	2.608	2.606	2.687	2.690	2.6238	2.555	2.543	2.527	2.524	2.5371			
Mn	0.046	0.053	0.042	0.050	0.048	0.039	0.0463	0.041	0.046	0.053	0.041	0.0451			
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.0000	0.000	0.000	0.010	0.000	0.0024			
Mg	1.948	1.895	1.910	1.846	1.802	1.769	1.8617	1.992	1.977	2.016	2.001	1.9963			
	5.169	5.179	5.167	5.148	5.194	5.184	5.1735	5.171	5.180	5.194	5.180	5.1809			
Ca	1.916	1.926	1.927	1.955	1.929	1.927	1.9300	1.906	1.911	1.890	1.891	1.8993			
K	0.283	0.290	0.294	0.259	0.295	0.306	0.2878	0.279	0.258	0.258	0.265	0.2650			
Na	0.539	0.461	0.542	0.401	0.521	0.416	0.4800	0.542	0.418	0.434	0.451	0.4611			
	2.738	2.677	2.763	2.615	2.745	2.649	2.6978	2.727	2.587	2.582	2.606	2.6254			

Sample 89-139

Hornblende compositions for Al-in-hornblende geobarometry (end)

Tables 2-4, 2-5 and 2-6

	C rim	C core	D core	E core	F core	G core	H core	I core	J core
SiO ₂	HB.45	HB.46	HB.41	HB.42	HB.43	HB.44	HB.47	HB.48	HB.49
Al ₂ O ₃	40.42	41.44	41.07	40.19	41.58	41.06	41.16	41.38	41.15
TiO ₂	12.73	11.60	12.26	12.93	11.94	11.93	12.29	12.33	12.70
FeO	1.05	1.01	0.91	0.74	1.17	0.89	0.72	0.74	1.01
MnO	19.77	19.58	20.34	20.46	19.86	19.81	19.76	19.76	20.20
Cr ₂ O ₃	0.38	0.40	0.37	0.37	0.34	0.39	0.37	0.37	0.34
MgO	0.00	0.04	0.02	0.00	0.00	0.00	0.00	0.04	0.03
CaO	7.91	8.69	8.17	7.71	8.68	8.39	8.15	8.48	8.18
K ₂ O	11.50	11.45	11.38	11.38	11.65	11.33	11.30	11.50	11.45
Na ₂ O	1.46	1.29	1.40	1.59	1.41	1.35	1.37	1.45	1.44
TOTAL	1.25	1.70	2.05	1.74	2.08	1.40	0.92	1.28	1.55
	96.46	97.18	97.95	97.07	98.69	96.53	96.04	97.31	98.03
23 oxygens									
Si	6.280	6.383	6.307	6.240	6.322	6.367	6.397	6.358	6.295
Al	1.720	1.618	1.694	1.761	1.678	1.633	1.603	1.642	1.705
	8	8	8	8	8	8	8	8	8
Al	0.610	0.488	0.525	0.605	0.462	0.548	0.648	0.592	0.584
Ti	0.123	0.117	0.106	0.086	0.134	0.104	0.084	0.085	0.116
Fe	2.570	2.522	2.612	2.657	2.526	2.570	2.569	2.540	2.585
Mn	0.049	0.052	0.048	0.048	0.044	0.052	0.049	0.048	0.044
Cr	0.000	0.006	0.003	0.000	0.000	0.000	0.000	0.006	0.003
Mg	1.833	1.995	1.870	1.785	1.968	1.939	1.888	1.942	1.866
	5.184	5.178	5.163	5.180	5.134	5.212	5.238	5.211	5.197
Ca	1.915	1.889	1.873	1.893	1.898	1.883	1.881	1.894	1.876
K	0.290	0.252	0.273	0.315	0.273	0.267	0.271	0.284	0.280
Na	0.379	0.506	0.610	0.523	0.613	0.421	0.277	0.381	0.461
	2.583	2.647	2.756	2.730	2.784	2.571	2.429	2.559	2.617

Énergie, Mines et
Ressources Canada

Energy, Mines and
Resources Canada

GEOLOGICAL SURVEY OF CANADA

COMMISSION GÉOLOGIQUE DU CANADA

This legend is on the back of the map.
Blank boxes indicate areas of unknown age.

Area between the heavy dotted lines

QUATERNARY

PLEISTOCENE AND RECENT

Gravel, sand, silt, and clay

TERTIARY

EOCENE

Garnet-biotite quartz diorite dykes; unfoliated and crosscutting

LATE PALEOCENE-(?)EARLY EOCENE

Quotzon pluton: hornblende ± biotite quartz diorite and tonalite; in 1031/4 includes felsic biotite ± garnet-bearing tonalite; medium to coarse grained; strongly foliated and locally lineated

CRETACEOUS

ALBIAN-CENOMANIAN (?)

Dyk complex adjacent to and probably partly comagmatic with Ecstall pluton; dykes constitute 40-80% of area, country rock forms the remainder. Dyke lithologies include straight, crosscutting garnet apfite and leucocratic pegmatite; fine grained leucocratic garnet-biotite quartz monzonite and granodiorite; titanite-epidote-biotite quartz diorite and granodiorite; and amphibolite

ALBIAN-CENOMANIAN

Ecstall pluton: epidote-hornblende-biotite quartz diorite to granodiorite; unfoliated except within 1 km (generally less than 300 m) of its margin; in 1034/11 includes foliated, fine grained, epidote-free, leucocratic garnet-biotite quartz diorite

JURASSIC-EARLY CRETACEOUS (?)

Mafic and ultramafic plutonic rocks; coarse grained, locally weakly lineated hornblende diorite, and rusty weathering coarse hornblende

JURASSIC

EARLY JURASSIC

Foch Lake orthogneiss: titanite-epidote-biotite tonalite gneiss; medium grained; typically contains plagioclase megacrysts; weakly to strongly foliated

Johnson Lake orthogneiss: epidote-biotite-hornblende tonalite gneiss; medium grained; strongly lineated and weakly to strongly foliated

DEVONIAN

MIDDLE DEVONIAN

Sig Falls orthogneiss: muscovite-biotite-hornblende tonalite augen gneiss; locally garnet- and epidote-bearing; medium grained; well foliated

LEGEND

This legend is common to all four maps in this open file
 X boxes indicate units that are not present on this map

nes

Areas outside the heavy dotted lines

QUATERNARY

PLEISTOCENE AND RECENT

Gravel, sand, silt, and clay

utting

TERTIARY

LATE PALEOCENE-(?)EARLY EOCENE

Quotzon pluton: TQgd: hornblende-biotite granodiorite; TQgd [103H/11, 14]:
 biotite-hornblende quartz diorite; TQqgn: quartz diorite and abundant gneiss; TQgd
 [103I/4]: quartz diorite, minor diorite and granodiorite; TQm: migmatitic plutonic rock

ic with Ecstall pluton; dykes
 nder. Dyke lithologies
 ic pegmatite; fine grained,
 rite; titanite-epidote-biotite

CRETACEOUS

ALBIAN-CENOMANIAN

Ecstall pluton [104H/11, 13]: KEqm: hornblende-biotite quartz monzonite; KEqd:
 biotite-hornblende granodiorite, hornblende-biotite granodiorite; KEqd: biotite-
 hornblende quartz diorite. Ecstall pluton [103I/4]: KEqm: quartz monzonite, minor
 granodiorite; KEqd: granodiorite, minor quartz diorite and quartz monzonite; KEqd:
 quartz diorite, minor diorite and granodiorite; KEq: diorite, minor quartz diorite

ly weakly lineated
 hornblende

JURASSIC-CRETACEOUS(?)

Gneissic diorite-migmatite complex

gneiss; medium grained,
 ngly foliated

Aplitic, garnetiferous quartz monzonite (may in part or whole be Palaeozoic)

tonalite gneiss; medium

tonalite augen gneiss; locally
 ated

This legend is common to
Blank boxes indicate units

Area west of the heavy dotted line

QUATERNARY

PLEISTOCENE AND RECENT

Gravel, sand, silt, and clay

TERTIARY

EOCENE

Garnet-biotite quartz diorite dykes; unfoliated and crosscutting

LATE PALEOCENE(?)EARLY EOCENE

Quotoon pluton: hornblende $\pm$ biotite quartz diorite and tonalite; in 1031/4 includes felsic biotite $\pm$ garnet-bearing tonalite; medium to coarse grained; strongly foliated and locally lineated

CRETACEOUS

ALBIAN-CENOMANIAN (?)

Dyke complex adjacent to and probably partly comagmatic with Ecstall pluton; dykes constitute 40-80% of area, country rock forms the remainder. Dyke lithologies include straight, crosscutting garnet apilite and leucocratic pegmatite; fine grained, leucocratic garnet-biotite quartz monzonite and granodiorite; titanite-epidote-biotite quartz diorite and granodiorite; and amphibolite

ALBIAN-CENOMANIAN

Ecstall pluton: epidote-hornblende-biotite quartz diorite to granodiorite; unfoliated except within 1 km (generally less than 300 m) of its margin; in 103H/11 includes foliated, fine grained, epidote-free, leucocratic garnet-biotite quartz diorite

JURASSIC-EARLY CRETACEOUS (?)

JKum Mafic and ultramafic plutonic rocks; coarse grained, locally weakly lineated hornblende diorite, gabbro and rusty weathering coarse hornblende

JURASSIC

EARLY JURASSIC

JFo Foch Lake orthogneiss: titanite-epidote-biotite tonalite gneiss; medium grained, typically contains plagioclase megacrysts; weakly to strongly foliated

JJo Johnson Lake orthogneiss: epidote-biotite-hornblende tonalite gneiss; medium grained; strongly lineated and weakly to strongly foliated

DEVONIAN

MIDDLE DEVONIAN

DBo Big Falls orthogneiss: muscovite-biotite-hornblende tonalite augen gneiss; locally garnet- and epidote-bearing; medium grained; well foliated

PROTEROZOIC(?)PALEOZOIC

LEGEND

Common to all four maps in this open file
The units that are not present on this map

Area east of the heavy dotted lines

QUATERNARY

PLEISTOCENE AND RECENT

Gravel, sand, silt, and clay

TERTIARY

LATE PALEOCENE-(?)EARLY EOCENE

Quotston pluton: TQgd: hornblende-biotite granodiorite; TQgd (103H/11, 14):
biotite-hornblende quartz diorite; TQgdh: quartz diorite and abundant gneiss; TQgd
(103H/4): quartz diorite, minor diorite and granodiorite; TQml: migmatitic plutonic rock

CRETACEOUS

ALBIAN-CENOMANIAN

Ecstall pluton (104H/11, 13): KEqm: hornblende-biotite quartz monzonite; KEgd:
biotite-hornblende granodiorite, hornblende-biotite granodiorite; KEgd: biotite-
hornblende quartz diorite. Ecstall pluton (103H/4): KEqm: quartz monzonite, minor
granodiorite; KEgd: granodiorite, minor quartz diorite and quartz monzonite; KEgd:
quartz diorite, minor diorite and granodiorite; KEd: diorite, minor quartz diorite

JURASSIC-CRETACEOUS(?)

Gneissic diorite-migmatite complex

Aplitic, garnetiferous quartz monzonite (may in part or whole be Paleozoic)

zu 94-110
(3)

Johnson Lake orthogneiss: epidote-biotite-hornblende tonalite gneiss, medium grained; strongly lineated and weakly to strongly foliated

DEVONIAN
MIDDLE DEVONIAN

DBo **Big Falls orthogneiss:** muscovite-biotite-hornblende tonalite augen gneiss; locally garnet- and epidote-bearing; medium grained; well foliated

PROTEROZOIC(?) PALEOZOIC
MIDDLE DEVONIAN AND/OR OLDER

Pv **Metavolcanic unit:** Pv: mafic and intermediate metavolcanic rock with minor metasedimentary and felsic metavolcanic interlayers; locally pyritic; strongly foliated and lineated; mafic component is fine grained amphibole ± chlorite schist, locally with relict clastic texture; intermediate component is biotite quartzofeldspathic semi-schist; minor quartzite, semi-pelitic to pelitic schist, and quartz-rich semi-schist of probable volcanic protolith. **Pvm:** marble (103H/13)

Psc **Metasedimentary clastic unit:** epidote-rich, hornblende-biotite gneiss; fine to medium grained; locally contains epidote-rich and granitoid clasts; well developed foliation and lineation

Psq **Quartzite unit:** Psq: white to grey, locally pyritic quartzite interlayered with lesser amounts of biotite-hornblende gneiss, fissile mica schist, black phyllite to meta-argillite, semi-pelitic to pelitic schist; well foliated. **Psqa:** amphibolite bands, probably dykes (103H/14). **Psqm:** marble (103H/13, 14)

Pn **Layered gneiss unit:** epidote-hornblende-biotite quartz diorite and granodiorite gneiss and garnet amphibolite; some epidote-garnet pods; medium grained; well defined compositional layering on a scale of tens of centimetres; strongly foliated and locally lineated

SYMBOLS

- Limit of detailed mapping by Gareau
- Geological contact (defined, approximate, assumed)
- Fault (assumed)
- Foliation (inclined, vertical, absent)
- Lineation (inclined mineral, inclined stretching, vertical)
- Dominant or average axial surface in area of intense small-scale folding (inclined, vertical)
- Dominant or average hinge line in area of intense small-scale folding (unspecified vergence, s-fold, z-fold, vertical)
- Axial trace of synform (arrow indicates plunge)
- Axial trace of antiform (arrow indicates plunge)
- Dominant fracture set
- Plagioclase megacrysts
- K-feldspar megacrysts

PROTEROZOIC(?) - PALEOZOIC

PMsa Mainly metasediments: hornblende-biotite-plagioclase amphibolite and schist; biotite schist (locally garnetiferous); sericite-epidote schist; graphitic schist; quartzite; crystalline limestone; conglomerate; minor lit-par-lit gneiss, agmatite, and granitic rocks; may in part be equivalent to **Psc**, **Psq** and **Pn**

In 103/14: grey biotite ± hornblende gneiss and amphibolite; minor sillimanite ± garnet gneiss. In 103H/14: granitoid gneiss, gneissic quartz diorite, rusty fine grained gneiss and schist, migmatite; minor garnet-sillimanite-biotite schist and crystalline limestone. May be equivalent to **Psq** and **Pn**

Massive to thickly layered crystalline limestone

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- van der Heyden, P. 1989: U-Pb and K-Ar geochronometry of the Coast Plutonic Complex, 53°N to 54°N, British Columbia, and implications for the Insular-Intermontane superterrane boundary; Ph.D. thesis, University of British Columbia, Vancouver, 392 p.
- Woodsworth, G.J., Loveridge, W.D., Parrish, R.R., and Sullivan, R.W. 1983: Uranium-lead dates from the Central Gneiss Complex and Ecstall pluton, Prince Rupert map area, British Columbia; *Canadian Journal of Earth Sciences*, v. 20, p. 1475-1483.

JJo Johnson Lake orthogneiss: epidote-biotite-hornblende tonalite gneiss; medium grained; strongly lineated and weakly to strongly foliated

DEVONIAN

MIDDLE DEVONIAN

DBo Big Falls orthogneiss: muscovite-biotite-hornblende tonalite augen gneiss; locally garnet- and epidote-bearing; medium grained; well foliated

PROTEROZOIC(?) - PALEOZOIC

MIDDLE DEVONIAN AND/OR OLDER

Pv Metavolcanic unit: **Pv**: mafic and intermediate metavolcanic rock with minor metasedimentary and felsic metavolcanic interlayers; locally pyritiferous; strongly foliated and lineated; mafic component is fine grained amphibole $\pm$ chlorite schist, locally with relict clastic texture; intermediate component is biotite quartzfeldspathic semi-schist; minor quartzite, semi-pelitic to pelitic schist, and quartz-rich semi-schist of probable volcanic protolith. **Pvm**: marble [103H/13]

Psc Metasedimentary clastic unit: epidote-rich, hornblende-biotite gneiss; fine to medium grained; locally contains epidote-rich and granitoid clasts; well developed foliation and lineation

Psq, sq, sqm Quartzite unit: **Psq**: white to grey, locally pyritiferous quartzite interlayered with lesser amounts of biotite-hornblende gneiss, fissile mica schist, black phyllite to meta-argillite, semi-pelitic to pelitic schist; well foliated. **Psqg**: amphibolite bands, probably dykes. **Psqm**: marble

Pn Layered gneiss unit: epidote-hornblende-biotite quartz diorite and granodiorite gneiss and garnet amphibolite; some epidote-garnet pods; medium grained; well defined compositional layering on a scale of tens of centimetres; strongly foliated and locally lineated

SYMBOLS

..... Limit of detailed mapping by Gareau

----- Geological contact (defined, approximate, assumed)

----- Fault (assumed)

+ Foliation (inclined, vertical, absent)

Lineation (inclined mineral, inclined stretching, vertical)

Dominant or average axial surface in area of intense small-scale folding (inclined, vertical)

Dominant or average hinge line in area of intense small-scale folding; (unspecified vergence, s-fold, z-fold, vertical)

Axial trace of synform (arrow indicates plunge)

Axial trace of antiform (arrow indicates plunge)

Dominant fracture set

Plagioclase megacrysts

K-feldspar megacrysts

PROTEROZOIC(?) - PALEOZOIC

Mainly metasediments: hornblende-biotite-plagioclase amphibolite and schist; biotite schist (locally garnetiferous); sericite-epidote schist; graphitic schist; quartzite; crystalline limestone; conglomerate; minor lit-par-lit gneiss, agmatite, and granitic rocks; may in part be equivalent to **Psc**, **Psq** and **Pn**

PMn In 103H/4: grey biotite ± hornblende gneiss and amphibolite; minor sillimanite ± garnet gneiss. In 103H/14: granitoid gneiss, gneissic quartz diorite, rusty fine grained gneiss and schist, migmatite; minor garnet-sillimanite-biotite schist and crystalline limestone. May be equivalent to **Psq** and **Pn**

Massive to thickly layered crystalline limestone

Area between the lines is the approximate extent of the Scotia-Ouzal metamorphic belt and of the area mapped in detail during this study

METALLIC MINERAL DEPOSITS

(Minfile number, name, commodities)

103H/11

15 Kiskosh Inlet (Cu)

16 Decaire (Zn, Pb)

17 Abruzzi (Cu, Ag)

103H/13

11 Ecstall (Cu, Zn, Pb, Ag, Fe, S)

GEOLOGY OF THE SCOTIA-QUAAL METAMORPHIC BELT, COAST PLUT KITKIATA INLET

O.F. 2337

(unspecified vergence, s-fold, z-fold, vertical)

- Axial trace of synform (arrow indicates plunge)
- Axial trace of antiform (arrow indicates plunge)
- Dominant fracture set
- Plagioclase megacrysts
- K-feldspar megacrysts

Radiometric dates (Ma):

hk = K-Ar date on hornblende

bk = K-Ar date on biotite

zu = U-Pb date on zircon

Sources of data: (1) this study; (2) Woodsworth et al. (1983); (3) van der Heyden (1989)

Mineral deposit (number is MINFILE number; see sheet 2 for list)

SOURCES OF INFORMATION

Present work: S.A. Gareau, 1987-1989

Previous work:

Hutchison (1982) [103I/4]

Roddick (1970) [103H/11, 103H/13, 103H/14]

Padgham (1958) [103H/11, 103H/13, 103H/14]

Money (1959) [103H/11]

Kenah (1979) [103I/4]

Runkle (1979) [103H/11]

Compilation: S.A. Gareau, 1990

AST PLUTONIC COMPLEX, BRITISH COLUMBIA

o.d., vertical)

unge)

unge)

Douglas, Sue and Loretta channels, British Columbia; M.Sc. thesis, University of British Columbia, Vancouver, 96 p.

van der Heyden, P. 1989: U-Pb and K-Ar geochronometry of the Coast Plutonic Complex, 53°N to 54°N, British Columbia, and implications for the Insular-Intermontane superterrane boundary; Ph.D. thesis, University of British Columbia, Vancouver, 392 p.

Woodsworth, G.J., Loveridge, W.D., Parrish, R.R., and Sullivan, R.W. 1983: Uranium-lead dates from the Central Gneiss Complex and Ecstall pluton, Prince Rupert map area, British Columbia; Canadian Journal of Earth Sciences, v. 20, p. 1475-1483.

Woodsworth et al.
(1989)

sheet 2 for list)

TION

Appendix 1, part A

Sheet 1 of 4

121

FOCH LAGOON BRITISH COLUMBIA

Scale 1:50 000 Échelle

O.F. 2337

(unspecified vergence, s-fold, z-fold, vertical)

Axial trace of synform (arrow indicates plunge)

Axial trace of antiform (arrow indicates plunge)

Dominant fracture set

Plagioclase megacrysts

K-feldspar megacrysts

Radiometric dates (Ma):

hk = K-Ar date on hornblende

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Mineral deposit (number is MINFILE number)

METALLIC MINERAL DEPOSITS

(Minile number, name, commodities)

103H/11

- 15 Kiskosh Inlet (Cu)
- 16 Decaire (Zn, Pb)
- 17 Abruzzi (Cu, Ag)

103H/13

- 11 Ecstall (Cu, Zn, Pb, Ag, Fe, S)
- 12 Third Outcrop (Cu, Zn)
- 50 East Plateau (Zn, Cu)
- 51 Trench (Cu, Zn, Ag)
- 52 Mariposite (Zn)
- 53 West Grid (Cu, Zn, Ag, Au)
- 54 Thirteen Creek Cirque (Cu, Zn, Ag, Au)
- 55 South Creek Grid (Cu, Zn)
- 56 Bear (Cu, Zn, Ag)
- 69 Phoebe Creek (Cu, Zn, Ag, Au)
- 71 El Amino (Cu, Zn, Ag)

103H/14

- 13 Packsack (Cu, Zn, Ag, Au, Pb)
- 14 Horesfly (Zn, Cu, Pb, Ag, Au)
- 18 Drum Lummon (Cu, Ag, Au)
- 36 Steelhead (Cu, Zn, Ag)

103I/4

- 7 Scotia (Zn, Pb, Ag, Cu, Cd, Au, Fe)
- 6 Lat Porte (Au, Ag, Cu)

Appendix 1, part A
Sheet 2 of 4

6

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

LEGEND

This legend is common to all four maps in this open file
Blank boxes indicate units that are not present on this map

Area east of the heavy dotted line

Area west of the heavy dotted lines

QUATERNARY

PLEISTOCENE AND RECENT

Gravel, sand, silt, and clay

TERTIARY

EOCENE

Garnet-biotite quartz diorite dykes; unfoliated and crosscutting

LATE PALEOCENE-(?)EARLY EOCENE

Quotatoon pluton: hornblende ± biotite quartz diorite and tonalite; in 1031/4 includes felsic biotite ± garnet-bearing tonalite; medium to coarse grained; strongly foliated and locally lineated

CRETACEOUS

ALBIAN-CENOMANIAN (?)

Dyke complex adjacent to and probably partly comagmatic with Ecstall pluton; dykes constitute 40-80% of area, country rock forms the remainder. Dyke lithologies include straight, crosscutting garnet aplite and leucocratic pegmatite; fine grained, leucocratic garnet-biotite quartz monzonite and granodiorite; titanite-epidote-biotite quartz diorite and granodiorite; and amphibolite

ALBIAN-CENOMANIAN

Ecstall pluton: epidote-hornblende-biotite quartz diorite to granodiorite; unfoliated except within 1 km (generally less than 300 m) of its margin; in 103H/11 includes foliated, fine grained, epidote-free, leucocratic garnet-biotite quartz diorite

JURASSIC-EARLY CRETACEOUS (?)

Mafic and ultramafic plutonic rocks; coarse grained, locally weakly lineated hornblende diorite, gabbro and rusty weathering coarse hornblende

JURASSIC

EARLY JURASSIC

Foch Lake orthogneiss: titanite-epidote-biotite tonalite gneiss; medium grained, typically contains plagioclase megacrysts; weakly to strongly foliated

Johnson Lake orthogneiss: epidote-biotite-hornblende tonalite gneiss; medium grained; strongly lineated and weakly to strongly foliated

DEVONIAN

MIDDLE DEVONIAN

Big Falls orthogneiss: muscovite-biotite-hornblende tonalite augen gneiss; locally garnet- and epidote-bearing; medium grained; well foliated

PROTEROZOIC(?) - PALEOZOIC

MIDDLE DEVONIAN AND/OR OLDER

QUATERNARY

PLEISTOCENE AND RECENT

Gravel, sand, silt, and clay

TERTIARY

LATE PALEOCENE-(?)EARLY EOCENE

Quotatoon pluton: TQgd: hornblende-biotite granodiorite; TQqd [103H/11, 14]: biotite-hornblende quartz diorite; TQqdn: quartz diorite and abundant gneiss; TQqd [1031/4]: quartz diorite, minor diorite and granodiorite; TQmt: migmatitic plutonic rock

CRETACEOUS

ALBIAN-CENOMANIAN

Ecstall pluton [104H/11, 13]: KEqm: hornblende-biotite quartz monzonite; KEgd: biotite-hornblende granodiorite, hornblende-biotite granodiorite; KEgd: biotite-hornblende quartz diorite. Ecstall pluton [1031/4]: KEqm: quartz monzonite, minor granodiorite; KEgd: granodiorite, minor quartz diorite and quartz monzonite; KEgd: quartz diorite, minor diorite and granodiorite; KEd: diorite, minor quartz diorite

JURASSIC-CRETACEOUS(?)

Gneissic diorite-migmatite complex

Aplitic, garnetiferous quartz monzonite (may in part or whole be Paleozoic)

PROTEROZOIC(?) - PALEOZOIC

[illegible]

LEGEND.

This legend is common to all four maps in this open file
Blank boxes indicate units that are not present on this map

Area between the heavy dotted lines

Areas outside the heavy dotted lines

QUATERNARY

PLEISTOCENE AND RECENT

Qa Gravel, sand, silt, and clay

TERTIARY

EOCENE

Tg Garnet-biotite quartz diorite dykes; unfoliated and crosscutting

LATE PALEOCENE-(?)EARLY EOCENE

TQg Quotatoon pluton: hornblende ± biotite quartz diorite and tonalite; in 1031/4 includes felsic biotite ± garnet-bearing tonalite; medium to coarse grained; strongly foliated and locally lineated

CRETACEOUS

ALBIAN-CENOMANIAN (?)

Dyke complex adjacent to and probably partly comagmatic with Ecstall pluton; dykes constitute 40-80% of area, country rock forms the remainder. Dyke lithologies include straight, crosscutting garnet aplite and leucocratic pegmatite; fine grained, leucocratic garnet-biotite quartz monzonite and granodiorite; titanite-epidote-biotite quartz diorite and granodiorite; and amphibolite

ALBIAN-CENOMANIAN

KEg Ecstall pluton: epidote-hornblende-biotite quartz diorite to granodiorite; unfoliated except within 1 km (generally less than 300 m) of its margin; in 103H/11 includes foliated, fine grained, epidote-free, leucocratic garnet-biotite quartz diorite

JURASSIC-EARLY CRETACEOUS (?)

Mafic and ultramafic plutonic rocks; coarse grained, locally weakly lineated hornblende diorite, gabbro and rusty weathering coarse hornblende

JURASSIC

EARLY JURASSIC

Foch Lake orthogneiss: titanite-epidote-biotite tonalite gneiss; medium grained, typically contains plagioclase megacrysts; weakly to strongly foliated

Johnson Lake orthogneiss: epidote-biotite-hornblende tonalite gneiss; medium grained; strongly lineated and weakly to strongly foliated

DEVONIAN

MIDDLE DEVONIAN

DBo Big Falls orthogneiss: muscovite-biotite-hornblende tonalite augen gneiss; locally garnet- and epidote-bearing; medium grained; well foliated

QUATERNARY

PLEISTOCENE AND RECENT

Qa Gravel, sand, silt, and clay

TERTIARY

LATE PALEOCENE-(?)EARLY EOCENE

TQgd, ml Quotatoon pluton: **TQgd**: hornblende-biotite granodiorite; **TQgd** [103H/11, 14]: biotite-hornblende quartz diorite; **TQgdq**: quartz diorite and abundant gneiss; **TQgd** [1031/4]: quartz diorite, minor diorite and granodiorite; **TQmt**: migmatitic plutonic rock

CRETACEOUS

ALBIAN-CENOMANIAN

KEqd, gd,qm Ecstall pluton [104H/11, 13]: **KEqm**: hornblende-biotite quartz monzonite; **KEqd**: biotite-hornblende granodiorite, hornblende-biotite granodiorite; **KEqd**: biotite-hornblende quartz diorite. Ecstall pluton [1031/4]: **KEqm**: quartz monzonite, minor granodiorite; **KEgd**: granodiorite, minor quartz diorite and quartz monzonite; **KEqd**: quartz diorite, minor diorite and granodiorite; **KEd**: diorite, minor quartz diorite

JURASSIC-CRETACEOUS(?)

Gneissic diorite-migmatite complex

Aplitic, garnetiferous quartz monzonite (may in part or whole be Paleozoic)

Energie, Mines et
Ressources Canada

Energy, Mines and
Resources Canada

GEOLOGICAL SURVEY OF CANADA

COMMISSION GEOLOGIQUE DU CANADA

typically contains plagioclase megacrysts; weakly to strongly foliated

Johnson Lake orthogneiss: epidote-biotite-hornblende tonalite gneiss; medium grained; strongly lineated and weakly to strongly foliated

DEVONIAN

MIDDLE DEVONIAN

Dbo

Big Falls orthogneiss: muscovite-biotite-hornblende tonalite augen gneiss; locally garnet- and epidote-bearing; medium grained; well foliated

PROTEROZOIC(?) - PALEOZOIC

MIDDLE DEVONIAN AND/OR OLDER

Pvym

Metavolcanic unit: Pv: mafic and intermediate metavolcanic rock with minor metasedimentary and felsic metavolcanic interlayers; locally pyritic; strongly foliated and lineated; mafic component is fine grained amphibole ± chlorite schist, locally with relict clastic texture; intermediate component is biotite quartzofeldspathic semi-schist; minor quartzite, semi-pelitic to pelitic schist, and quartz-rich semi-schist of probable volcanic protolith. Pvm: marble [103H/13]

Psc

Metasedimentary clastic unit: epidote-rich, hornblende-biotite gneiss; fine to medium grained; locally contains epidote-rich and granitoid clasts; well developed foliation and lineation

Psq, sqm

Quartzite unit: Psq: white to grey, locally pyritic quartzite interlayered with lesser amounts of biotite-hornblende gneiss, fissile mica schist, black phyllite to meta-argillite, semi-pelitic to pelitic schist; well foliated. Psqm: amphibolite bands, probably dykes [103H/14]. Psqm: marble [103H/13, 14]

Pn

Layered gneiss unit: epidote-hornblende-biotite quartz diorite and granodiorite gneiss and garnet amphibolite; some epidote+garnet pods; medium grained; well defined compositional layering on a scale of tens of centimetres; strongly foliated and locally lineated

Jkqm

Mainly metasediments: hornblende-biotite-plagioclase amphibolite and schist; biotite schist (locally garnetiferous); sericite-epidote schist; graphitic schist; quartzite; crystalline limestone; conglomerate; minor ill-par-ill gneiss, agmatite, and granitic rocks; may in part be equivalent to Psc, Psq and Pn

PMsa

Mainly metasediments: hornblende-biotite-plagioclase amphibolite and schist; biotite schist (locally garnetiferous); sericite-epidote schist; graphitic schist; quartzite; crystalline limestone; conglomerate; minor ill-par-ill gneiss, agmatite, and granitic rocks; may in part be equivalent to Psc, Psq and Pn

PMsc

In 103H/4: grey biotite ± hornblende gneiss and amphibolite; minor sillimanite ± garnet gneiss. In 103H/14: granitoid gneiss, gneissic quartz diorite, rusty fine grained gneiss and schist, migmatite; minor garnet-sillimanite-biotite schist and crystalline limestone. May be equivalent to Psq and Pn

PMsc

Massive to thickly layered crystalline limestone

SYMBOLS

..... Limit of detailed mapping by Gareau

----- Geological contact (defined, approximate, assumed)

----- Fault (assumed)

+/ Folia (inclined, vertical, absent)

+/ Lineation (inclined mineral, inclined stretching, vertical)

+/ Dominant or average axial surface in area of intense small-scale folding (inclined, vertical)

+/ Dominant or average hinge line in area of intense small-scale folding (unspecified vergence, s-fold, z-fold, vertical)

+/ Axial trace of synform (arrow indicates plunge)

+/ Axial trace of antiform (arrow indicates plunge)

+/ Dominant fracture set

PMsa

JURASSIC

EARLY JURASSIC

Foch Lake orthogneiss: titanite-epidote-biotite tonalite gneiss; medium grained, typically contains plagioclase megacrysts; weakly to strongly foliated

Johnson Lake orthogneiss: epidote-biotite-hornblende tonalite gneiss; medium grained; strongly lineated and weakly to strongly foliated

DEVONIAN

MIDDLE DEVONIAN

DBo **Big Falls orthogneiss:** muscovite-biotite-hornblende augen gneiss; locally garnet- and epidote-bearing; medium grained; well foliated

PROTEROZOIC(?) - PALEOZOIC

MIDDLE DEVONIAN AND/OR OLDER

Pv **Metavolcanic unit:** **Pv:** mafic and intermediate metavolcanic rock with minor metasedimentary and felsic metavolcanic interlayers; locally pyritiferous; strongly foliated and lineated; mafic component is fine grained amphibole $\pm$ chlorite schist, locally with relict clastic texture; intermediate component is biotite quartzofeldspathic semi-schist; minor quartzite, semi-pelitic to pelitic schist, and quartz-rich semi-schist of probable volcanic protolith. **Pvm:** marble [103H/13]

Psc **Metasedimentary clastic unit:** epidote-rich, hornblende-biotite gneiss; fine to medium grained; locally contains epidote-rich and granitoid clasts; well developed foliation and lineation

Psq **Quartzite unit:** **Psq:** white to grey, locally pyritiferous quartzite interlayered with lesser amounts of biotite-hornblende gneiss, fissile mica schist, black phyllite to meta-argillite, semi-pelitic to pelitic schist; well foliated. **Psqg:** amphibolite bands, probably dykes [103H/14]. **Psqm:** marble [103H/13, 14]

Pn **Layered gneiss unit:** epidote-hornblende-biotite quartz diorite and granodiorite gneiss and garnet amphibolite; some epidote+garnet pods; medium grained; well defined compositional layering on a scale of tens of centimetres; strongly foliated and locally lineated

PROTEROZOIC(?) - PALEOZOIC

Mainly metasediments: hornblende-biotite-plagioclase amphibolite and schist; biotite schist (locally garnetiferous); sericite-epidote schist; graphitic schist; quartzite; crystalline limestone; conglomerate; minor lit-par-lit gneiss, agmatite, and granitic rocks; may in part be equivalent to **Psc**, **Psq** and **Pn**

PMn **In 103H/4:** grey biotite $\pm$ hornblende gneiss and amphibolite; minor sillimanite $\pm$ garnet gneiss. **In 103H/14:** granitoid gneiss, gneissic quartz diorite, rusty fine grained gneiss and schist, migmatite; minor garnet-sillimanite-biotite schist and crystalline limestone. May be equivalent to **Psq** and **Pn**

Massive to thickly layered crystalline limestone

SYMBOLS

..... Limit of detailed mapping by Gareau

— — — — — Geological contact (defined, approximate, assumed)

— — — — — Fault (assumed)

+ Foliation (inclined, vertical, absent)

Lineation (inclined mineral, inclined stretching, vertical)

Dominant or average axial surface in area of intense small-scale folding (Inclined, vertical)

Dominant or average hinge line in area of intense small-scale folding (unspecified vergence, s-fold, z-fold, vertical)

Axial trace of synform (arrow indicates plunge)

Axial trace of antiform (arrow indicates plunge)

Dominant fracture set

Dominant or average axial surface in area of intense small-scale folding (inclined, vertical)

Dominant or average hinge line in area of intense small-scale folding (unspecified vergence, s-fold, z-fold, vertical)

Axial trace of synform (arrow indicates plunge)

Axial trace of antiform (arrow indicates plunge)

Dominant fracture set

Plagioclase megacrysts

K-feldspar megacrysts

Radiometric dates (Ma):

hk = K-Ar date on hornblende

bk = K-Ar date on biotite

zu = U-Pb date on zircon

Sources of data: (1) this study; (2) Woodsworth et al. (1983); (3) van der Heyden (1989)

Mineral deposit (number is MINFILE number; see sheet 2 for list)

Area between the lines is the approximate extent of the Scotia-Quaal metamorphic belt and of the area mapped in detail during this study

O.F. 2337

KUMEALON LAKE

COAST LAND DISTRICT RANGE 4

BRITISH COLUMBIA

Scale 1:50 000 Echelle

Appendix 1, part A
Sheet 3 of 4

2
19
10

Dominant or average axial surface in area of intense small-scale folding (Inclined, vertical)

Dominant or average hinge line in area of intense small-scale folding (unspecified vergence, s-fold, z-fold, vertical)

Axial trace of synform (arrow indicates plunge)

Axial trace of antiform (arrow indicates plunge)

Dominant fracture set

Plagioclase megacrysts

K-feldspar megacrysts

Radiometric dates (Ma):

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Sources of data: (1) this study; (2) Woodsworth et al. (1983); (3) van der Heyden (1989)

Mineral deposit (number is MINFILE number; see sheet 2 for list)

O.F. 2337

KEd

KEqd

KEqd

KEqd

PORT ESSINGTON BRITISH COLUMBIA

Scale 1:50 000 Échelle

Appendix 1, part A
Sheet 4 of 4

4
8
7

7

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

K I T I M A T R

/K

KITIMAT INLET

COAST MOUNTAINS

A
L
G
U
O
D

Alty
Lake

Mear
Lake

Nqospi
Lake

COUNTY OF D

D A N B L E

*88-63
*88-64
88-40

*88-42
*88-38

89-16

*88-42
*88-43

*89-10
*89-11

*88-44

*89-10
*89-11

*89-17

*88-45

*89-12
*89-13

89-14

*88-46
*88-48

*88-49
*88-50

*88-51

*88-52

*89-8

*88-62

RANGES

*88-63

VK

**88-64

HAWKESBURY

86 87 88 89 90 91 92 93 94 95 96 97 98 99

*89-148
*89-149

*89-146

*89-145 *89-144

*89-143

*89-142

*89-141

*89-140

*89-135

*89-136

*89-137

*89-138

*89-139

*89-37

*89-36

PASSAGE

Atty. Prison

WATER RESERVOIR
LAKESIDE CHURCH

UNTAINS)

D O U G L A S

KITKIATA INLET

COAST LAND DISTRICT RANGE 4

BRITISH COLUMBIA

Scale 1:50 000 Echelle

UNITED STATES GEOLOGICAL SURVEY
 WATER RESOURCES DIVISION

WATER RESOURCES DIVISION
 WATER RESOURCES DIVISION

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 WATER RESOURCES DIVISION

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WATER RESOURCES DIVISION
 WATER RESOURCES DIVISION

Station map
 Appendix 1, part B
 Sheet 1 of 4

3 Miles
 4000 Feet
 6000 Feet

RANGE 36 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 129.00

ND DISTRICT RANGE 54 55 56 40 57 58 59 60 61 35 62 63 64 65 466000m E 128°30'

VK

COAST MOUNTAIN

R A N G E S

VK

U N T A I N S

Waterfall
Ranch

KITIMAT RAN

Ref

Kameelon
Lagoon

VK

30 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53

Kameelon

Kameelon

CONST MOUNTA

Kameelon

HARPER

VALLEY

GREVILLE

Alton Lake

1000

Rae Lake

STAIN S

FOCH LAGOON

BRITISH COLUMBIA

Scale 1:50,000 (1:50,000)

100	200	300	400	500	600	700	800	900	1000
100	200	300	400	500	600	700	800	900	1000

Station map
 Appendix 1, part B
 Sheet 2 of 4

KUMEALON LAKE

MAP LAND DISTRICT RANGE 1

BRITISH COLUMBIA

Scale 1:50,000 Echelle

Station map
Appendix 1, part B
Sheet 3 of 4

8 of/de 8

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

VL

VK

00

89.52
89.51

89

89.49

89.48

89.47

89.46

89.5

89.58

89.57

89.4

89.45

89.44

87.2

87.25

87.24

89.43

87.251

89.41

35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55

C O A S T M O U N T

B E C K H A M

Mount Morrison

Spokane Mountain

Colony

Hayward

R I V E R

Creek

Rocky

90

89

88

87

86

85

84

83

82

PORT ESSINGTON BRITISH COLUMBIA

Scale 1:50,000 Échelle

Station map
Appendix 1, part B
Sheet 4 of 4

Appendix 1, part C
Cross-sectional sketches across the Scotia-Quaal metamorphic belt.

END

29.05.92