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THE DEVONIAN-CARBONIFEROUS NORTH RIVER AND GILBERT MOUNTAIN PLUTONS, COBEQUID HIGHLANDS, NOVA SCOTIA

by

Georgia Pe-Piper

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THE DEVONIAN-CARBONIFEROUS NORTH RIVER AND GILBERT MOUNTAIN PLUTONS, COBEQUID HIGHLANDS, NOVA SCOTIA

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Abstract

This open file reports on field mapping and laboratory investigation of the latest Devonian - earliest Carboniferous North River and Gilbert Mountain plutons of the Cobequid Highlands of Nova Scotia. The report complements a 1:10 000 map of the North River pluton and 1:20 000 maps showing the sparse outcrops of the Gilbert Mountain pluton.

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Note: the eastern end of the "Gilbert Mountain" pluton is reported by Pe-Piper et al., 1994, Geological Survey of Canada Open File 2887.

PART I: NORTH RIVER PLUTON

INTRODUCTION

Geological setting of the Devonian-Carboniferous plutons of the Cobequid Highlands

In the Cobequid Highlands of northern Nova Scotia, granite and diorite plutons of latest Devonian age occupy a 160-km-long, 10 - 20-km-wide belt (Fig. 1), bounded to the south by the Cobequid fault zone (CFZ). This fault zone is part of a major tectonic element, the Cobequid-Chedabucto fault zone, which marked the northern limit of the Carboniferous Minas sub-basin and was reactivated in the Triassic. This fault zone was a Devonian-Carboniferous dextral strike slip system (Mawer & White 1987), interpreted as the suture between the Avalon and Meguma terranes (Eisbacher 1969, 1970; Williams 1979; Keppie 1989) which converged in the early to middle Devonian (405 - 390 Ma: Keppie & Dallmeyer 1987; Muecke *et al.* 1988). Other authors (Keen *et al.* 1991) have interpreted the terrane suture zone as lying further south, with the Cobequid-Chedabucto fault zone resulting from late Devonian - Carboniferous transcurrent motion.

The Cobequid fault zone includes a complex system of faults parallel to the main fault (including the Kirkhill and Rockland Brook (RBF) faults: Fig. 1) and second order shear zones forming splays. Strain variation, observed in areas of releasing and restraining bends, is inferred throughout the period of strike-slip motion on the CFZ. The amount of strike-slip motion on the fault is poorly constrained. Early to mid-Devonian motion may have been sinistral (Keppie & Dallmeyer 1987), during the main phase of collision of the Meguma and Avalon terranes (Muecke *et al.* 1988) (the "Acadian orogeny"), but in eastern Nova Scotia dextral shear on the Chedabucto fault has been dated from 359 - 372 $\pm$2 Ma using $^{39}Ar/^{40}Ar$ dating of micas (Keppie & Dallmeyer 1987). This deformation immediately preceded or overlapped the period of pluton emplacement in the Cobequid Highlands. The plutons of the Cobequid Highlands are geochemically and structurally similar (Pe-Piper et al., 1991). From various granitic bodies (including the Pleasant Hills and Cape Chignecto plutons described here), six U/Pb zircon ages from 361 - 365 Ma have been determined (Doig *et al.* 1991a,b; 1993). Diorite has been dated at 357 Ma by K/Ar on hornblende (Piper *et al.* 1993). The youngest igneous phase in the plutons comprises diabase dykes associated with E-W extension. Similar dykes cut Tournaisian, but not Visean, sediments south of the plutons and probably correlate with abundant gabbro intrusions in southeastern Nova Scotia dated at 339$\pm$2 Ma by U/Pb on zircon and baddelyite (Barr *et al.*, 1994). Secondary biotite and hornblende from mylonite in the Cape Chignecto pluton yielded K/Ar ages of 329 and 327 Ma that have been recently redated by $^{39}Ar/^{40}Ar$ dating at about 340 Ma (J. Nearing, pers. comm. 1994). No undeformed igneous phases cut these mylonite zones. Thus most pluton emplacement appears to be restricted to a few million years in the latest Devonian - Tournaisian. It was followed by a phase of diabase dyke emplacement associated with E-W extension and by ductile deformation on E-W faults. Post-Visean dextral slip of about 100 km is interpreted from offset of the Antigonish and Shubenacadie basins and the opening of the Stellarton basin (Yeo & Gao, 1987). Triassic graben formation immediately south of the Cobequid Fault zone means that any correlative plutons south of the Cobequid Fault have a thick Carboniferous and Triassic sediment cover. Diorite blocks in fault breccia at Clarke Head (Fig. 1: Donohoe & Wallace, 1985) and the continuation of magnetic anomalies associated with diorite from the central Cobequid Highlands to south of the CFZ (Piper *et al.* 1993) suggest that plutons similar to those in the Cobequid Highlands may occur immediately south of the CFZ. The CFZ thus appears to be a broad zone of pluton emplacement that has been truncated by later movement on the Cobequid Fault.

The granitic magmas in the Cobequid Highlands have been interpreted to be derived from melting of lower crust by mafic magma resulting from mid to late Devonian extension of the Magdalen basin (Piper *et al.* 1993). The major extensional detachment fault in the Magdalen basin, the Margaree detachment, cross-cuts late Devonian volcanic rocks but does not deform early Carboniferous sediments in Cape Breton Island (Lynch and Tremblay 1994) and thus immediately precedes magma emplacement. The rapid extension associated with this detachment may have been the trigger for voluminous extensional melting. The widespread unconformity between the Horton and Windsor Groups, marking a change in structural style in the adjacent basins (Durling & Marillier 1990), followed pluton emplacement by some 8-10 Ma.

The plutons were emplaced into Neoproterozoic metasedimentary and metavolcanic rocks and were associated with basaltic and rhyolitic volcanism. The country rock nowhere has a metamorphic grade higher than low greenschist facies.

Purpose of this study

The purpose of this study was to map the North River pluton at a scale of 1:10 000. This report provides a general description of the pluton.

GEOLOGY OF THE NORTH RIVER PLUTON

The North River pluton has an asymmetrical tear-drop shape with its long axis (ca. 8 km) parallel to the CFZ (Fig. 2). The southern margin of the pluton is subparallel to and 1-2 km N of the CFZ and includes several small gabbro/ diorite intrusions (locally with the development of intermediate hybrid rocks). Much of this southern margin appears to be a steeply dipping brittle fault, that is cross-cut by fine-grained granite at the southwestern end of the pluton. North of this fault, the pluton comprises an outer zone of fine-grained granite and an inner core of coarse-grained granophyric granite and alkali-feldspar granite, with minor quartz syenite. Several large gabbro bodies outcrop at the eastern end of the pluton. Numerous mafic dykes cut the pluton, with varying degrees of deformation (Pe-Piper 1991; Piper *et al.* 1993). The western end of the North River pluton, at a map scale, cross-cuts E-W trending structures in the Neoproterozoic country rock. The eastern end of the pluton appears to be a N-S normal fault.

No reliable radiometric ages have been determined for the North River pluton. Pe-Piper et al. (1989) obtained a Rb-Sr "errorchron" of 356±17 Ma. The structural, petrographic and geochemical similarity of the North River pluton to dated plutons such as the Cape Chignecto and Pleasant Hills plutons (Doig et al., 1996) suggests that it is of latest Devonian to earliest Carboniferous age.

South of the North River pluton, sedimentary rocks similar to the Greville River and Rapid Brook formations (Piper, 1994) of the Horton Group are exposed in the East, Bass North and Harrington rivers and on Lynn road (immediately east of the Harrington River, Fig. 2). As in the type section south of the Cape Chignecto pluton, the sequence is folded and outcrops discontinuously. Lithologies include quartz wacke, greenish and purplish siltstone and fine wacke, dark argillite, and rare granule conglomerates, the clasts of which are mostly vein quartz and rhyolite. Two samples of dark argillite submitted for palynology were barren. Donohoe and Wallace (1982) recorded granite clast conglomerate on the East River. The structural setting of this unit is similar to that of the type sections Rapid Brook - Greville River formations near the Cape Chignecto pluton, lying between the Cobequid and Kirkhill faults immediately south of a granitoid pluton and including tectonic intercalations of granite. The sequence is therefore regarded as correlative with the type Greville River and Rapid Brook formations, rather than being "undivided Silurian-Devonian" as mapped by Donohoe and Wallace (1982, 1985). In the lower Harrington River, this unit is intruded by a sill of microgranite; small granite intrusions also cut the unit in the Bass River.

STRUCTURE

Northern contact

At the northern contact of the pluton (Fig. 3), the Neoproterozoic metasediments are intruded by millimetre-thick granitic dykes, which are isoclinally folded under ductile solid-state conditions with axial planes dipping steeply to the south indicating northward thrusting at the margin.

In the 0.8-km-wide zone north of the contact in the East River section, Neoproterozoic country rock is intruded by eight foliated igneous sheets (sills). Five are granites, two are mafic rocks and one diorite. The distance between adjacent sheets decreases nearer the pluton. These sheets die out upward in the sequence and away from the pluton. The thickness for these igneous intrusions vary from 0.5 to 30 m. These igneous intrusions typically show two segments: one dyke-like and the other sill-like, thus forming a typical ramp and flat geometry. The ramp part is typically subvertical and varies in thickness from 10 - 30 m. The flat part is inclined southward at moderate to low angles with thickness varying from 0.5 - 10 m and may thin to a tip point (see Fig. 4). Two sheets, with thickness 1 and 1.5 m, thin out updip over a distance of 10 and 15 m respectively, suggesting an up-section elimination ratio of 1:10 from the ramp-flat transition to the tip. As these sheets are foliated, a minimum offset, in the absence of other markers, for each thrust plane hosted by igneous material is equal to the length of the igneous material (assuming that the vertical expansion in these sheets is practically equal to zero as the lithostatic pressure would have been very high and these sheets are relatively thin). Based on such estimates for all eight sheets, we estimate the total shortening to be 227 m in the 851-m-wide structural aureole, corresponding to a 25% shortening.

Within the granite sheets, both the sigmoidal foliation planes at an angle with the host rock foliation and flame structures on the rim of mafic xenoliths show top-to NW thrust movement (a in Fig. 4), thus including a sinistral sense of shear on the E-W striking contact. Tension gashes in the granite that formed during this NW movement are occupied by epidote and quartz. The epidote veins were ductilely folded by asymmetric open folds that indicate a sense of movement top-to-S (b in Fig. 4). The quartz veins were deformed under ductile-brittle conditions, again indicating southward movement that is accompanied by a dextral sense of shear (c in Fig. 4).

In summary, north of the North River pluton, a 0.8-km-wide zone of country rock is intruded by sills of granite or gabbro up to 30 m thick that show both magmatic and post-crystallization ductile deformation produced by NW-directed oblique thrusting. These sheets and the deformation produced strain softening in country rock near the pluton, which could have created some of the space required for the emplacement of the pluton.

Main body of the pluton

Syn-magmatic deformation within the pluton, interpreted principally from the distribution and deformation of mafic sheets, has been described in detail by Pe-Piper (1991).

Solid-state deformation within the pluton is defined by flat-lying shear zones that strike E-W and mostly dip 10 - 40°N. Some dip at low angles to the south and are characterized by cataclastic zones. Many of these shear zones have planar or gently curved floor and roof thrusts integrated as duplex structures (Fig. 5E). Kinematic analysis in these zones (cf. Tanner 1992) indicates a complex pattern of material escape both parallel and perpendicular to the axis of duplex development. Displacement analysis where these zones cut diabase or aplite dykes indicates displacements of hundreds of metres top-to-south.

Summary: structural evolution of the pluton

The structural evolution of the North River pluton and other plutons in the western Cobequid Highlands has been recently interpreted by Koukouvelas *et al.* (1996). This section briefly summarises their findings. The North River pluton is one of a series of A-type granite-gabbro plutons, in part ductilely deformed, that are spatially associated with the strike-slip Cobequid fault zone. Two phases of deformation accompanying magma emplacement are recognised. Early magmas intruded ductile country rock during left-lateral oblique thrust movements, as shown at the northern margin of the North River pluton. A second stage of right-lateral oblique slip faulting accommodated increasing uplift of the plutons. At this time coarse granite was emplaced in the most elevated region through a process of roof lifting. Cross-cutting late stage porphyries, granitic clasts in marginal basins cut by granitic dykes, and superposition of brittle on ductile structures all indicate rapid uplift of the plutons. Pluton emplacement was not the result of extension in releasing bends during transcurrent shear. Rather, flower-structure high-angle faults acted as magma conduits and space was created by wall-rock deformation and hanging wall expansion on thrust faults at depth, and by roof lifting as the plutons were uplifted to higher structural levels (Koukouvelas *et al.* 1996).

Several lines of evidence suggest that the Cobequid fault zone in the west and the Rockland Brook fault zone in the east were the main path for magma ascent (Piper *et al.* 1993; Koukouvelas & Pe-Piper 1995). In places, the granitic magmas have intruded along older gabbro-argillite thrust contacts (e.g. Pleasant Hills pluton, Koukouvelas *et al.* 1996). Gabbro-diorite outcrops throughout the western Cobequid Highlands (Fig. 1) demonstrate a spatial association of mafic magmas with the major faults: the CFZ, the Kirkhill and the Rockland Brook faults. These south-dipping faults that acted as magma pathways and are characterized by mylonites appear to be mappable splays of a major strike slip fault (the CFZ) defining a positive flower structure, with a median elevated block along the southern part of the Cobequid highlands.

The less-deformed later coarse granite phases, well developed in the North River pluton, record development of a magma chamber without significant ductile tectonic strain and were not severely deformed by later strike-slip related solid-state deformation. The south-directed flat-lying shear zones and duplex structures seen in an area at least 5 km north of the CFZ may have played a further role in creating space for these late magmas by low-angle extensional translation.

PETROGRAPHY

The rock lithologies identified in the field and mapped include granitoid rocks, gabbros, gabbro/diabase dykes and sheets, and rocks of intermediate composition that are considered to be of hybrid origin.

Granitoid Rocks

The predominant coarse-grained granite of the North River pluton has a granophyric texture and consists of microperthite, quartz and plagioclase. Modal analyses of representative lithologies are given in Table 1. In the I.U.G.S classification system (Fig. 6) these rocks classify as granites, alkali-feldspar granites, and quartz syenites (Table 1). Plagioclase occurs as subhedral to anhedral grains and all those analyzed by electron microprobe consist of albite. Microperthite in places appears to have replaced plagioclase and elsewhere is intergrown with cuneiform or rod-shaped quartz. Some microperthite is rimmed by albite. Large quartz crystals are mostly subhedral and rounded; texturally they appear earlier than feldspar and granophyric intergrowths. The granophyric texture commonly occurs as pod-like growths within the rock, in places nucleated around a smaller crystal of plagioclase, perthite or quartz. Most rocks contain less than 3% mafic minerals, principally opaque oxides. The granites are ubiquitously fractured on a cm scale; green secondary biotite occurs along the fractures, together with muscovite, chlorite and epidote in some rocks. The marginal fine-grained granites are texturally similar, except for a finer grain size. Accessory minerals in these rocks include brown primary biotite, clots of green secondary biotite and titanite. In places, the pluton is cut by veins of white granite in which microperthite is completely albitized.

Well-formed albite crystals occur in the freshest granites that contain no epidote. Highly albitized rocks appear petrographically and geochemically quite distinct, and plagioclase in most early gabbros and associated hybrid rocks is not albitized. Thus, much of the albite in the North River granite appears primary.

Gabbro and Diabase

The marginal gabbro bodies are medium grained and sub-ophitic in texture. The primary mafic mineral is clinopyroxene, which has been replaced to varying extent by dusty amphibole or fine grained clots of chlorite, amphibole and secondary biotite. Some samples contain anhedral brown biotite with oriented rutile inclusions. Fine grained opaque minerals are dispersed throughout the rock. Plagioclase shows alteration to sericite. The fine grained gabbro/diabase dykes and sheets are similar to the marginal gabbros, but are finer grained and lack brown biotite. Some samples contain diamond-shaped clusters of chlorite/serpentine that may be pseudomorphs after olivine.

Intermediate hybrid rocks

Most rocks of intermediate composition are texturally and mineralogically inhomogeneous at hand specimen and thin section scale. They occur at the margins of gabbro bodies and in some dykes and sills. The presence of mafic clots, wisps and stringers in the granitic hybrid rocks, and of granitic stringers, lenses and large subhedral K-feldspar phenocrysts in the more mafic hybrid rocks, are consistent with the mingling of two penecontemporaneous magmas, a mafic and a felsic one. The occurrence of geochemically analogous felsic and mafic lavas interbedded in the Fountain Lake Group is consistent with this interpretation. The principal minerals in the hybrid rocks are plagioclase, K-feldspar, quartz, amphibole, green and brown biotite and opaque oxides (Table 1). The alteration minerals also include chlorite and epidote. In some hybrid rocks plagioclase has rims or patches of perthite.

Petrography of secondary minerals

To study the secondary petrography of the North River pluton we have collected samples from six localities: 1) North River; 2) Bass River; 3) East River; 4) Gundalow Brook; 5) Boyd Brook woods road; 6) Lynn road. The lithologies present in these rocks are medium-fine grained diorites, medium-fine grained granites, porphyritic microgranite sheets and fine grained mafic sheets. All lithologies are characterized by greenschist facies metamorphism.

Hydrothermal alteration present in the seven locations is recorded in three modes: 1) clots and stringers along features; 2) replacement of primary mineralogy; 3) monomineralic and polymineralic veins >0.1 mm wide.

Clots and stringers of hydrothermal materials are confined to discrete fractures in the granite and microgranite sheets, consisting of green-brown biotite, chlorite, rutile, magnetite and hematite. The dominant paragenetic assemblages are: 1) brown-green biotite + chlorite + magnetite; 2) chlorite + rutile + hematite.

Hematite observed in clots and stringers is an alteration product of magnetite. Rutile is also confined to clots and stringers and along later stage fractures overprinting the primary mineralogy of granite, diorite and mafic-felsic sheets.

The second mode of occurrence for hydrothermal related phases is the full or partial replacement of primary hornblende by secondary biotite in diorite. This replacement alteration is accompanied by reticulation {001} and kinked cleavages {010} of primary biotite. Primary biotite is also observed to have large embayment structures coupled with strong alteration to clays and epidote. Primary hornblende is also observed to have actinolite coronas.

The third mode of occurrence is veins >0.1 mm in width. Monomineralic veins of chlorite, rutile or quartz are present in all lithologies. Polymineralic veins of brown biotite + quartz + chlorite + K-feldspar are confined to granite. Veins containing albite are also present in granites and are characterized by albite + quartz + K-feldspar.

MINERALISATION OF CARBONATES ADJACENT TO THE NORTH RIVER PLUTON

The North River pluton is adjacent to, and may have thermally metamorphosed, a sliver of carbonate rocks within the Horton Group south of the pluton that outcrop in the North River valley. Possibly similar limestones that host mineralisation in the New Britain prospect on the East River have been interpreted as Windsor Group by A. Hudgins (pers. comm. 1993). The mineralisation at both localities is probably genetically related to the North River pluton. This summary of the outcrops in the North River south of the pluton is based on an honours thesis by F. Boner (1985). It should be noted that at the time Boner did his work, these rocks were interpreted as part of the Jeffers Group.

The carbonate rocks are associated with slaty argillite and quartzite that have been isoclinally folded. Figure 7 illustrates one outcrop that has several lithologies present. Almost pure white marble alternates with yellow and green mineralized marble, white quartzite (? or chert), and thin silty slate (Fig. 7). A strong penetrative cleavage is associated with flat-lying isoclinal folds. This penetrative cleavage has been refolded into open, upright folds, with an associated crenulation cleavage.

The white marbles contain rare quartz and opaque minerals including pyrite and malachite. The green marble consists of calcite and chlorite. The chlorite is developed along the penetrative cleavage, and displays the later crenulation cleavage well. The yellow marble appears banded in hand specimen, with bands picked out by alternation of minerals including calcite, quartz, garnet, epidote, and actinolite. Minor clinopyroxene (hedenbergite in some rocks, diopside in others) and opaque minerals including sphalerite and magnetite are also present (Table 2). The garnets show interesting zoning and cleavage relationships that are described in detail below. The quartzites consist predominantly of quartz, with some calcite, and trace minerals similar to those in the yellow marble.

The silty shale contains chlorite and biotite (with minor quartz and epidote) that appear folded and fractured, and may have developed synchronously with the axial planar cleavage. Large mica flakes lie in the cleavage, but are not in any way folded.

Garnets in the yellow marble have formed in massive bands. The garnets show a strong cleavage or parallel fracturing (Fig. 8) that is parallel to the flat-lying penetrative cleavage in the surrounding incompetent rocks (Fig. 7). We interpret this structural relationship to mean that these garnets pre-date the formation of the penetrative cleavage.

The garnets in the massive bands show optical zoning (Fig. 9). Particularly at the edge of the bands, they are overgrown by euhedral garnets (Fig. 9) that lack the strong cleavage of parallel fracture. These euhedral garnets appear associated with sphalerite and magnetite bands in which the minerals likewise appear euhedral.

Electron microprobe analysis (Boner, 1985) showed that grossular garnet occurs in the more siliceous lithologies (along with diopside, e.g. sample 1017b: Table 3, Analyses 7 & 8) whereas andradite occurs in the more calcareous lithologies (along with hedenbergite e.g. sample 1014: Table 3, Analyses 1-6). The optically zoned fractured garnets show little chemical change corresponding to the optical zones (e.g. Analyses 5 & 6, Fig. 9 and Table 3). Andradite locally contains irregular patches of more grossular composition, presumably representing a failure to achieve equilibrium. The unfractured euhedral rims contain a high proportion of spessartine molecule (e.g. Analysis 6, Table 3).

The occurrence of andradite rather than grossular in the more carbonate rich lithologies is consistent with the work of Taylor and Liou (1978), who showed that andradite is more stable than grossular in the CO_2 rich fluids. The coexistence of hedenbergite + andradite + quartz + magnetite indicates a narrow range of oxygen fugacity in the range of 10^{-30} to 10^{-20} over a temperature range of 400 to 600 °C (Liou, 1974).

The occurrence of unfractured euhedral overgrowths over the strongly fractured garnets suggest that there were two phases of garnet growth. The first preceded the formation of the regional penetrative cleavage, and consists of grossular or andradite, dependant on bulk rock composition. The second phase followed the development of this cleavage, and the garnet that formed was chemically similar to that in the first phase, except for a higher Mn content. This second phase appears to be associated with the growth of clinopyroxene, sphalerite and magnetite.

Although grossular occurs both in thermally and regionally metamorphosed impure carbonate rocks, andradite is characteristic only of thermal metamorphism and skarns (Deer et al., 1978, pp. 614-616, 636-638; Einaudi et al., 1981). Likewise, whereas diopside is known from both thermally and regionally metamorphosed rocks, hedenbergite occurs as a regional metamorphic mineral only in banded ironstones; it is, however, common in skarns and thermally metamorphosed carbonates (Deer et al., 1978, pp. 270-276). The mineralogical data from the metacarbonate unit thus suggests that garnets developed at two separate times, both under conditions of thermal metamorphism. The second metamorphic event was associated with metasomatism, leading to a spessartine component of the garnet and the development of sphalerite and magnetite.

The oldest garnets in the Carbonate Unit developed during thermal metamorphism, presumably related to the intrusion of the North River pluton. These garnets subsequently acquired a parallel fracture or cleavage when their host rock was isoclinally folded and cleaved. The unfractured garnet overgrowths represent a second thermal metamorphic event that was associated with sphalerite and magnetite mineralization, also associated with the North River pluton. The garnets thus provide evidence that the deformation of the Horton Group was synchronous with igneous events to the north.

GEOCHEMISTRY

Pe-Piper (1991) gave a geochemical account of both the granitoid and mafic phases of the North River pluton. In this study we did some extra analytical work to establish the character of new mapped areas. All analytical data available at present are given in Table 4, using analytical methods described by Pe-Piper and Piper (1989). The geochemical conclusions presented by Pe-Piper (1991) have not been changed significantly and in summary are as follows:

This pluton is geochemically similar to other Devonian-Carboniferous plutons in the Cobequid Highlands, although it represents a deeper structural level than most of the other plutons. The granite is a subalkalic A-type granite. The mafic rocks show "within plate" geochemical characteristics; early intrusions resemble olivine-normative continental tholeiites, but later dykes are highly fractionated and show strong enrichment in incompatible elements. Enrichment in Rb and K in the northeastern part of the pluton reflects a late metasomatic event associated with the growth of secondary biotite.

Table 1: Modal compositions of representative granitoid samples from the North River pluton

Sample No	C856	C1641	C1642	C1666	C1672	C1673	C1674	C1675	C2388	C2406	C2465	C2577
Plag.[1]	2.9	36.8	27.2	51.1	28.8	14	4.6	13.6	29.3	13.5	11.2	3
Ab/perth	5.3	-	18.1	-	-	-	18.1	14.1	2.9	-	5.3	5.3
K-Feldspar	48	-	29.6	-	-	34	52.3	30.4	30	54.9	40.6	60.3
Quartz	28.6	-	17.9	44.1	0.3	27.0	19.3	37.6	17.9	6.6	32.1	23.5
Amphibole[2]	0.3	29.2	-	-	49.2	-	-	-	-	-	0.1	-
Biotite[3]	0.1	14.7	4.6	-	10.6	20	1.6	1.6	17.6	22.2	-	-
Opaques	2	0.9	2.0	1.7	2.1	-	3.9	2.7	1.8	0.3	0.9	0.2
Epidote	2.5	-	-	-	-	-	-	-	-	-	2.8	4.4
Alteration	7	-	-	-	-	-	-	-	-	-	0.9	0.5
Others[4]	3.3	11.4	0.6	3.1	10.0	5.0	-	-	0.5	2.4	6.1	2.8
Veins	-	6.7	-	-	-	-	-	-	-	-	-	-
Total	100	99.7	100	100	101	100	99.8	100	100	99.9	100	100
Colour Index	11.9	63.2	7.2	4.8	71.9	25	5.5	4.3	19.4	22.5	4.7	5.1
IUGS Nomenclature components												
Plag.	3.42	100	4.8	53.68	98.97	18.67	24.07	28.94	40.2	18	12.56	3.26
K-feldspar	62.85	-	31.9	-	-	45.33	55.46	31.77	37.45	73.2	51.46	71.23
Quartz	33.73	-	19.29	46.32	1.03	36	20.47	39.29	22.34	8.8	35.99	25.52
Name[5]	AFG	GA	QSY	GR	GR	GR hybr	AFG	GR	GR hybr	QSY hybr	GR	AFG

NOTES:

1: Includes albite
2: Includes hornblende and actinolite
3: Includes both primary and secondary biotite
4: Includes chlorite, muscovite, sericite, calcite and sometimes epidote and dusty altered minerals (if not otherwise indicated)
5: GA=gabbro; GR=granite; AFG=alkali-feldspar granite; QSY=quartz syenite; hybr=hybrid
6: **T**: tonalite; **QZD**: Quartz diorite; **GR**: Granite

Modes are based on counting 1000 to 1500 points in one or two thin sections (depending on grain size of rock) stained using a modification of the method of Bailey and Stevens (1960).

Table 2: Representative electron microprobe analyses on the main metamorphic phases associated with the Carbonate Unit1

Mineral	Hed	Di		Act		Ep	Chl
Sample No.	C1222	C1235	C1017b	C1229	C1017b	C1017b	C1235
SiO_2	49.46	54.51	53.17	53.78	49.93	37.66	28.31
TiO_2	-	-	-	-	-	-	-
Al_2O_3	-	0.06	-	1.20	3.60	26.89	19.69
FeO_t	22.77	5.78	6.47	16.55	19.07	6.64	16.63
MnO	2.46	0.70	2.37	-	0.24	-	0.4
MgO	1.75	14.57	13.23	13.11	10.93	-	23.02
CaO	22.84	24.95	24.70	12.71	12.32	23.59	0.20
Na_2O	0.14	-	-	-	0.42	-	-
K_2O	-	-	-	-	0.44	-	-
Total	99.42	100.27	99.94	97.35	96.95	94.78	88.25
No of Analyses	2	5	2	1	3	1	2

Hed=hedenbergite; Di=diopside; Act=actinolite; Ep=epidote; Chl=chlorite

1: The analyses in this and table 3 are from Boner (1985)

Table 3: Representative electron microprobe garnet analyses associated with the Carbonate Unit

	C1014[+]						C 1017b	
							CORE	RIM
	1	2	3	4	5	6	7	8
SiO_2	35.74	35.91	34.88	36.04	35.51	34.94	37.92	37.37
TiO_2	-	-	-	-	-	-	0.49	0.25
Al_2O_3	1.10	0.18	0.20	18.22	0.31	0.12	18.83	20.27
FeO_t	26.18	27.10	27.74	5.63	27.59	27.95	3.83	1.67
MnO	1.81	1.72	1.80	10.19	1.33	1.84	1.75	-
MgO	0.34	0.52	-	-	0.23	-	-	-
CaO	32.92	32.72	32.84	29.52	32.92	32.02	35.27	38.37
Na_2O	-	0.06	-	-	-	-	-	-
K_2O	-	-	-	-	-	0.04	-	-
Total	98.09	97.81	97.46	99.60	97.89	96.91	98.09	97.93
ATOMIC FORMULAE BASED ON 24 [O]								
Si	6.467	6.539	6.438	5.795	6.487	6.483	5.974	5.844
^{IV}Al	-	-	-	0.205	-	-	0.026	0.156
^{VI}Al	0.235	0.039	0.044	3.247	0.067	0.026	3.469	3.580
Ti	-	-	-	-	-	-	0.058	0.029
Fe_t	3.962	4.126	4.282	0.757	4.215	4.337	0.505	0.218
Mn	0.277	0.204	0.281	1.388	0.206	0.289	0.234	-
Mg	0.092	0.141	-	-	0.063	-	-	-
Ca	6.382	6.383	6.495	5.085	6.443	6.365	5.953	6.429
Na	-	0.021	-	-	-	-	-	-
K	-	-	-	-	-	0.009	-	-

[+]The location of analyses 1-6 is shown in Fig 9.

Table 4: Whole-rock chemical analyses of representative samples

Sample No.	C395	C856	C857	C873	C1089	C1627	C1639	C1640	C1641	C1642
Major elements by XRF (wt%)										
SiO_2	73.20	78.50	74.10	76.50	64.00	48.51	74.50	59.08	45.00	70.32
TiO_2	0.23	0.20	0.20	0.17	1.01	3.44	0.30	1.69	1.49	0.42
Al_2O_3	13.10	10.90	12.60	12.20	15.90	14.08	12.60	15.67	17.25	15.42
Fe_2O_3	2.37	1.88	2.86	1.51	5.40	17.55	2.57	7.83	12.16	2.42
MnO	0.03	0.02	0.04	0.02	0.03	0.02	0.02	0.13	0.12	0.02
MgO	0.75	0.60	1.04	0.26	1.86	3.80	0.82	2.41	8.20	0.46
CaO	0.65	0.70	0.29	0.21	1.80	3.18	0.60	4.57	6.80	0.31
Na_2O	4.09	4.24	4.61	3.99	6.65	3.26	4.95	4.00	1.86	4.78
K_2O	4.32	2.40	3.03	4.53	1.62	4.23	3.00	3.11	2.73	5.41
P_2O_5	0.03	0.04	0.03	0.02	0.25	0.89	0.04	0.48	0.15	0.07
L.O.I	0.93	0.77	1.00	0.77	1.31	0.00	0.85	0.62	3.38	0.54
Total	99.70	100.25	99.80	100.18	99.83	98.96	100.25	99.59	99.14	100.17
Trace elements by XRF (ppm)										
Ba	498	341	479	383	214	309	253	637	252	724
Rb	86	38	47	86	78	349	56	122	167	125
Sr	82	82	58	55	162	130	67	230	166	53
Y	64	56	49	30	48	57	63	54	28	41
Zr	226	182	208	248	1107	240	375	378	97	370
Nb	31	25	25	32	27	17	40	23	8	19
Th	22	19	23	18	13	5	22	13	0	25
Pb	<10	<10	<10	13	<10	11	12	18	<10	16
Ga	17	14	17	15	24	26	17	21	20	19
Zn	18	19	21	13	26	26	16	83	76	18
Cu	<5	<5	<5	15	<5	<5	10	14	50	<5
Ni	9	7	10	6	7	47	17	20	117	13
V	7	16	11	2	46	373	28	118	264	15
Cr	6	8	<5	5	5	10	59	26	282	19

Table 4 (continued)

Sample No	C1643	C1663	C1666	C1672	C1673	C1674	C1675	C1772	C1778	C1779
Major elements by XRF (wt%)										
SiO_2	45.52	54.30	77.60	48.60	66.50	72.80	75.50	44.85	44.86	74.92
TiO_2	3.23	0.90	0.12	1.51	0.75	0.35	0.22	3.74	2.90	0.19
Al_2O_3	14.15	19.70	12.34	16.10	14.50	13.90	12.70	13.43	14.54	12.81
Fe_2O_3	0.00	7.77	0.61	11.10	4.55	2.12	1.70	14.97	14.42	1.97
MnO	0.21	0.08	0.03	0.10	0.03	0.01	0.01	0.26	0.21	0.01
MgO	6.58	2.63	0.41	6.88	1.51	0.37	0.26	6.28	6.85	0.19
CaO	9.82	4.40	0.82	8.67	2.41	0.54	0.38	9.81	9.07	0.16
Na_2O	2.33	6.49	6.91	2.44	3.97	4.14	3.70	2.10	1.50	3.59
K_2O	1.61	2.31	0.12	2.39	4.30	5.32	5.26	1.25	1.41	5.45
P_2O_5	1.79	0.25	0.02	0.19	0.13	0.05	0.04	0.67	0.59	0.02
L.O.I	0.00	1.31	0.60	1.77	0.85	0.62	0.54	1.80	1.90	0.31
Total	99.91	100.14	99.58	99.75	99.50	100.22	100.31	99.16	98.25	99.62
Trace elements by XRF (ppm)										
Ba	286	854	32	225	488	518	360	279	270	331
Rb	129	81	<5	117	168	205	198	73	87	189
Sr	237	343	45	293	116	51	30	290	293	30
Y	74	21	35	24	43	40	36	45	42	73
Zr	404	106	293	111	316	303	188	277	242	189
Nb	27	5	47	10	21	23	27	20	18	33
Th	<10	<10	10	<10	19	31	26	<10	<10	26
Pb	11	13	<10	15	19	22	19	<10	<10	19
Ga	23	20	19	19	20	18	18	31	32	18
Zn	124	34	14	44	14	14	16	100	69	18
Cu	27	22	<5	34	11	12	7	55	47	<5
Ni	58	6	11	69	22	15	17	47	58	18
V	194	228	2	236	72	9	7	375	284	<5
Cr	77	17	7	160	43	29	39	74	65	27
REE and selected trace elements by INAA (ppm)										
La	n.d.	n.d.	10.40	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ce	n.d.	n.d.	22.00	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nd	n.d.	n.d.	10.00	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sm	n.d.	n.d.	2.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Eu	n.d.	n.d.	0.55	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tb	n.d.	n.d.	0.70	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Yb	n.d.	n.d.	3.84	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Lu	n.d.	n.d.	0.62	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ba	n.d.	n.d.	110	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Co	n.d.	n.d.	67.00	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cs	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Hf	n.d.	n.d.	11.00	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sb	n.d.	n.d.	0.20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sc	n.d.	n.d.	0.68	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ta	n.d.	n.d.	3.40	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Th	n.d.	n.d.	15.00	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
U	n.d.	n.d.	3.20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 4 (continued)

Sample No.	C1880	C1881	C1884	C1885	C1891	C2388	C2406 B	C2569	C2572	C4130
Major elements by XRF (wt%)										
SiO_2	76.30	69.49	65.60	74.50	47.13	66.40	73.82	44.27	46.35	46.63
TiO_2	0.16	0.49	0.37	0.25	5.80	0.74	0.25	3.60	2.13	1.39
Al_2O_3	12.50	15.47	16.60	13.20	16.04	14.49	13.26	14.10	14.92	16.27
Fe_2O_3	1.21	3.17	4.29	1.51	13.98	4.58	1.70	15.71	13.11	11.03
MnO	0.01	0.02	0.04	0.01	0.18	0.05	0.03	0.28	0.14	0.22
MgO	0.22	0.77	1.46	0.53	4.14	1.82	0.71	5.77	7.40	9.64
CaO	0.35	0.61	1.99	0.50	1.82	2.68	0.58	9.28	8.30	10.11
Na_2O	3.95	4.74	6.09	5.46	4.94	3.28	2.90	2.50	2.37	1.79
K_2O	4.95	4.67	2.39	3.18	3.69	3.88	5.51	1.63	1.88	1.52
P_2O_5	0.03	0.15	0.10	0.04	0.50	0.12	0.04	0.73	0.30	0.14
L.O.I	0.70	0.54	1.16	0.62	1.20	0.90	0.20	1.90	2.90	2.20
Total	100.38	100.12	100.09	99.80	99.42	98.94	99.00	99.77	99.80	100.94
Trace elements by XRF (ppm)										
Ba	429	868	720	466	259	427	483	285	200	210
Rb	129	102	48	41	226	155	211	77	125	77
Sr	50	61	188	54	129	136	57	314	255	273
Y	61	46	17	39	28	45	51	47	30	27
Zr	191	515	141	194	426	327	239	284	164	99
Nb	31	22	6	25	79	23	25	22	12	6
Th	22	21	<10	22	<10	24	27	<10	<10	<10
Pb	13	10	<10	<10	12	23	31	<10	<10	<10
Ga	18	22	14	19	35	25	22	27	25	23
Zn	19	14	40	15	22	29	34	82	62	130
Cu	7	<5	201	14	6	7	<5	53	40	79
Ni	20	9	8	9	56	31	36	53	75	111
V	<5	17	78	15	251	76	6	359	280	268
Cr	32	<5	23	14	64	28	<5	55	187	95

Table 4 (continued)

Sample No.	C4137	C4462	C4463	C4467	C4823	C4824	C4827	C4829	C4831	C4832
SiO_2	44.60	44.85	45.74	45.45	45.14	75.85	45.63	56.27	46.79	45.13
TiO_2	2.69	1.75	1.94	2.75	2.52	0.15	2.96	1.34	1.79	2.68
Al_2O_3	14.62	13.77	15.17	14.99	15.50	12.51	14.89	15.58	16.05	15.24
Fe_2O_3	14.53	12.69	12.41	12.82	13.76	1.47	14.44	8.91	10.66	13.55
MnO	0.22	0.19	0.17	0.26	0.39	0.03	0.40	0.09	0.25	0.36
MgO	7.07	10.50	8.42	6.51	7.13	0.45	6.31	5.06	7.77	6.54
CaO	9.65	8.17	9.03	9.28	8.60	0.20	9.34	4.10	9.80	9.74
Na_2O	2.58	1.24	1.80	2.81	1.91	3.59	1.74	3.52	2.28	2.07
K_2O	0.57	2.38	0.75	0.89	1.32	5.43	0.92	3.35	1.41	0.78
P_2O_5	0.32	0.33	0.39	0.75	0.33	0.01	0.36	0.16	0.13	0.60
L.O.I	2.30	2.80	3.50	2.30	3.10	0.40	2.70	1.40	2.50	2.90
Total	99.15	98.67	99.32	98.81	99.70	100.09	99.69	99.78	99.43	99.59
Trace elements by XRF (ppm)										
Ba	203	64	122	376	309	390	241	231	297	285
Rb	27	256	56	59	72	145	43	279	105	55
Sr	262	146	183	376	258	48	277	208	207	290
Y	36	32	39	39	33	56	32	47	33	37
Zr	163	131	190	231	158	169	200	206	94	233
Nb	11	9	12	17	7	32	9	10	<5	16
Th	13	<10	<10	<10	<10	<10	<10	<10	<10	<10
Pb	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ga	27	18	19	27	20	16	20	22	20	25
Zn	136	103	90	211	101	14	139	69	136	137
Cu	67	40	20	49	62	25	57	13	74	59
Ni	11	355	174	110	92	<5	85	54	163	100
V	378	248	253	277	275	5	311	176	231	263
Cr	129	415	314	111	97	10	73	83	152	82
REE and selected trace elements by INAA (ppm)										
La	n.d.	13.70	25.80	27.30	11.25	71.14	13.69	24.57	n.d.	20.01
Ce	n.d.	31.00	39.00	60.00	28.32	137	34.79	56.30	n.d.	49.96
Nd	n.d.	17.00	24.00	31.00	18.47	69.72	23.03	24.55	n.d.	30.51
Sm	n.d.	4.38	6.19	7.23	4.95	13.06	5.93	5.85	n.d.	7.17
Eu	n.d.	1.28	1.50	2.61	1.96	0.84	2.32	1.28	n.d.	2.56
Tb	n.d.	1.00	1.20	1.30	0.99	2.11	1.08	1.09	n.d.	1.23
Yb	n.d.	2.77	3.72	3.57	2.56	6.63	2.96	3.57	n.d.	3.47
Lu	n.d.	0.42	0.58	0.53	0.37	0.89	0.43	0.49	n.d.	0.49
Ba	n.d.	100	150	210	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Co	n.d.	54.00	46.00	39.00	61.47	53.48	66.96	40.01	n.d.	59.76
Cr	n.d.	370	260	120	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cs	n.d.	11.70	3.30	4.60	6.03	0.46	5.67	10.09	n.d.	4.57
Hf	n.d.	3.50	4.50	5.50	3.59	6.96	4.49	5.27	n.d.	5.06
Sb	n.d.	0.50	0.70	0.40	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sc	n.d.	36.60	43.60	35.20	34.62	7.47	36.52	23.24	n.d.	33.38
Ta	n.d.	0.50	0.50	1.00	0.70	2.93	0.87	1.13	n.d.	1.01
Th	n.d.	0.40	0.50	0.80	0.59	22.49	0.73	8.54	n.d.	0.85
U	n.d.	0.50	0.30	0.40	0.28	3.56	0.52	2.26	n.d.	n.d.

Table 4 (continued)

Sample No.	C4838
SiO_2	46.76
TiO_2	1.78
Al_2O_3	16.75
Fe_2O_3	12.17
MnO	0.22
MgO	6.38
CaO	10.18
Na_2O	1.92
K_2O	0.92
P_2O_5	0.13
L.O.I	2.20
Total	99.41
Trace elements by XRF (ppm)	
Ba	533
Rb	52
Sr	247
Y	29
Zr	94
Nb	<5
Th	<10
Pb	<10
Ga	15
Zn	178
Cu	108
Ni	173
V	257
Cr	174
REE and selected trace elements by INAA (ppm)	
La	3.47
Ce	11.70
Nd	8.60
Sm	3.53
Eu	1.66
Tb	0.73
Yb	2.76
Lu	0.40
Ba	n.d.
Co	70.12
Cr	n.d.
Cs	2.98
Hf	2.47
Sb	n.d.
Sc	36.29
Ta	0.28
Th	0.53
U	n.d.

Appendix 1. Catalogue of hand specimens

Sample	Name	XRF Analysis whole rock	Thin Section	Probe Section
395	micg	+	+	
856	micg	+	+	
857	micg	+	+	
873	micg	+	+	
977	micg		+	
1089	fgorg	+	+	
1219	altgrnt		+	
1605	di			
1618	mafic			
1619	micg			
1620	mafic		+	
1622	micg		+	
1627	da	+	+	
1630	micg		+	
1630A	mgpog			
1639	micg	+	+	
1640	di	+	+	
1641	di	+	+	
1642	m-cgpg	+	+	
1642	fgorg	+	+	
1643	mafic	+	+	
1644	rhy?		+	
1661	di		+	
1663	micg	+	+	
1666	qrg	+	+	
1672	ga	+	+	
1673	di	+	+	
1674	fgorg	+	+	
1675	mgpog	+	+	
2c1682	di(m)			
1770	gr		+	
1772	da	+	+	
1774	gr		+	
1778	da			
1779	mgpog	+	+	
1783	gr		+	
1880	micg	+	+	
1881	fgorg	+		+
1884	fgorg	+		+
1885	mic	+		+
1891	di	+		+
2045	altgrnt			
2144	micg	+	+	
2388	di	+	+	
2397	di		+	
2399	mgpgg			
2400	gr			
2404	gr			
2406A	di			
2406B	di	+	+	
2464	di		+	
2465	mgpog		+	
2561	sed			
2562	mafic			
2563	sed			
2564	sed		+	
2565	micg		+	
2566	micg			

2567	mafic		
2568	sed		
2569	di	+	+
2570	gr		
2571	mgpgg		+
2572	ga	+	+
2573	rhy		
2574	mgpgg		+
2575	poprhy		
2576	mafic		
2577	mgpog		+
2578	sed		
2579	mgpgg		
2580	rhy		
2581	sed		
2582	mafic		
2583	sed		
2584	rhy		
2585	rhy		+
2586	myl		+
2587	sed		
2588	sed		
2589	mafic		
2590	pory		
2591	micg		+
2592	rhy		
2593	rhy		
2594	sed		+
2595	tuff		
2596	sed		+
2597	sed		
4130	da	+	+
4137	ga	+	+
4462	da	+	+
4463	cgda	+	+
4467	ga	+	+
4823	da	+	+
4827	da	+	+
4829	ms	+	+
4831	ga	+	+
4832	da	+	+
4838	da	+	+
6022	rhy		
6023	fgm		
6024	rhy?		
6025	fgm		
6026	rhy		
6027	rhy		
6028	di		
6029	fgpgg		
6030	ga/di?		
6031	mgpgg		
6032	tuff		
6033	fgm		
6034	mgpgg		
6111(cleaved)	fgm		
6112	mgm		
7056	mgm		
7058(cleaved)	mgm		
7059	mgpog		
7059A	fgm		
7060	fgpgg		

7061	fgm		
7062	fgpgg		
7063	mgpgg		
7064(contact)	sed/grnt		
7065	fgpg		
7066	fgpgg		
7067	rhy		
7068			
7069	mgpog		
7070	mgpgg		
7071	mgpgg	+	+
7072	rhy		
7073	mgpog		
7074	sed		
7075	mgpog		
7076	mgpog		
7077	mgm		
7078	gd		
7079	mgpgg		
7080	megga	+	+
7081(fine marg)	megga	+	+
7082	gd		
7083	mgpog	+	+
7084	mgpgg		
7085	mgpog		

Legend:
Granite: gr
Medium grained pink-orange granite: mgpog
Medium grained pink-grey granite: mgpgg
Fine grained pink-grey granite: fgpgg
Medium grained white granite: mgwg
Fine grained pink granite: fgpg
Microgranite: micg
Altered granite: altgrnt
Fine grained orange-red granite: fgorg
Quartz rich granite: qrg
Rhyolite: rhy
Porphyritic pink rhyolite: poprhy
Porphyry: pory
Mylonite: myl
Fine grained mafic: fgm
Medium grained mafic: mgm
Volcanic: vol
Diorite: di
Granodiorite: gd
Gabbro: ga
Diabase: da
Coarse grained diabase: cgda
Megacrystic gabbro: megga
Sediment: sed

Appendix 2: Microstructural Observations

SAMPLE: C1642 (fine grained orange red granite)
Slightly flexed albite crystals; some elongate feldspar phenocrysts are being broken by stretching, after compression or shortening has caused kinks to form in the twinned crystals. The fractures which have opened have been filled with quartz. There are some large quartz phenocrysts, with quartz-new grain domains subdividing them. Some plagioclase phenocrysts have well developed deformation twins.
Some (apparently primary) oxide veinlets are cut by veins which contain amphibole and oxide + or - biotite. Some of these veins display small sinistral offsets. Veins trend consistently subparallel across the section, but are truncated by newly formed quartz crystals.

SAMPLE: C1666A (quartz rich granite)
Deformed perlitic texture visible in feldspars; slight sinistral movement visible. Deformation is intensified close to deforming quartz crystals, and diminished in intensity where shielded by large plagioclase phenocrysts.
There are also dextral offsets of quartz phenocrysts across microfaults. Microfaults cut across quartz filled pull apart veins. Most quartz shows poorly developed undulose extinction, with stress being accommodated by fractures, some of which contain opaque oxides and quartz, and possibly amphibole. This may indicate deformation under conditions close to brittle, with high fluid pressure or highly to supersaturated fluids present.

SAMPLE: C1674 (fine grained orange red granite)
This sample is highly altered. Some quartz filled fractures are present; these cut all types of crystals present without making offsets. Some twinned feldspars are very slightly flexed(dextrally?). Some quartz shows evidence of new grain, and subgrain formation.

SAMPLE: C1675 (medium grained pink orange granite)
Quartz in this sample shows strongly developed undulose extinction. Formation of new and subgrains between quartz phenocrysts and k-feldspar porphyroblasts. Red-oxide rich veinlets in K-feldspar are truncated by the quartz domain(indicating rotation of porphyroblasts). Rotation is very slight and is clockwise, indicating dextral shear.

SAMPLE: C1779 (medium grained pink orange granite)
This sample displays pull apart quartz veins cutting across primary disequilibrium graphic intergrowth textures. Undulose extinction is well developed in most quartz. A very few small plagioclase crystals show slight dislocation of twinning. There are small dextral offsets across come of the oxide+quartz filled hydrothermal veinlets.

SAMPLE: C4461 (fine grained pink granite)
Flame shaped deformation twins in plagioclase are present in this sample, along with quartz filled pull apart veins. Dextral flexing of twinning is visible in plagioclase and albite crystals. Well developed undulose extinction in quartz phenocrysts; some show radiating subparallel quartz ribbons. This may indicate plastic deformation of the quartz.
Sinistral offsets occur along hydrothermal cracks. These offsets cut across the quartz filled pull apart veins. Much of the oxides appear to be rounded porphyroblasts which are the remnants of primary (or very early in deformation history) oxide veins. These primary veins may have contained epidote and chlorite.

SAMPLE: C4824 (medium grained pink granite)
Poorly developed deformation twins are visible in K-feldspar crystals. Undulose extinction is present in quartz, but is not strongly developed. No quartz ribbons are visible, and there is very little evidence of grain size reduction in quartz.

SAMPLE: 7083 (medium grained pink orange granite)
Deformation twins are present as dextrally sheared lamellae in albite. Intergrowth quartz has strong undulose extinction. Disequilibrium growth precedes deformation, and makes an interlocking texture which is extremely resistant to deformation.

PART II: "GILBERT MOUNTAIN PLUTON"

INTRODUCTION

The Gilbert Mountain pluton was mapped by Donohoe and Wallace (1982) as a large granite body extending 30 km from New Canaan in the west to Williamsdale in the west. Outcrop in this area is very sparse as a result of this till cover and rather shallow valleys. Three 1:20 000 maps are presented showing the location of outcrops. The results of mapping the eastern part of the Gilbert Mountain pluton were presented by Pe-Piper et al. (1994), who described an alkali-feldspar granite body some 8 km long immediately west of Williamsdale, exposed in several brooks including Sherman Brook. This report concentrates on the western part of the Gilbert Mountain pluton (see maps 2-4 with this report).

GEOLOGY

The few sparse outcrops in the western part of the "Gilbert Mountain pluton" mapped by Donohoe and Wallace (1982) consist of hornblende granite, quartz diorite to tonalite, and gabbro. As such, it more closely resembles the Folly Lake and Wyvern plutons farther east along the northern rim of the Cobequid Highlands. Alkali-feldspar granite of the type found in the plutons of the southern Cobequid Highlands has not been found in this area.

Outcrop is insufficient to define either the boundaries or the internal structure of the pluton. Study of aeromagnetic data by Piper et al. (1993) suggests that the strong E-W magnetic lineaments mapped in the headwaters of the River Philip to the east of the "Gilbert Mountain pluton" extend westwards through the pluton. The alkali feldspar granite in the Williamsdale area appears to be bounded on its southern side by a major E-W magnetic anomaly, probably marking a fault contact. South of this anomaly, the entire Gilbert Mountain pluton has a similar magnetic character to the Wyvern pluton to the east. The southern margin of the Wyvern and Gilbert Mountain plutons is marked by another major E-W magnetic anomaly, the northern margin of which corresponds to the Sand River fault of Ryan et al. (1990) in the Cumberland Basin. The ENE-trending northern margin of the Gilbert Mountain pluton also appears to be fault controlled.

We suggest that the term "Gilbert Mountain pluton" be abandoned. The term Wyvern plutonic complex should be used for the entire predominantly mafic plutonic complex west of Second River (i.e. west of the Folly Lake pluton as defined by Donohoe and Wallace, 1982), extending westwards to New Canaan. The term Sherman Brook granite can be used for the alkali feldspar granite in the Sherman Brook - Williamsdale area.

PETROGRAPHY

Granite

The granites in handspecimen are medium to coarse grained (e.g. samples 4371 and 4349) to porphyritic (e.g. sample 4352). These rocks are essentially pink, white and black in colour. The medium to coarse grained samples are fairly equigranular, consisting mainly of quartz and K-feldspar with lesser amounts of plagioclase and hornblende. It should be noted that the K-feldspar is somewhat coarser and more abundant than the quartz. The porphyritic samples consist essentially of quartz, K-feldspar with lesser amounts of plagioclase and hornblende. In some samples the plagioclase is altered in the cores (e.g. sample 4352). The most distinguishing feature between coarse grained and porphyritic samples is the amount of hornblende present being more abundant in the latter. Some granitic samples appear altered (e.g. samples 4366, 4367, 4368, 4091, 4092) and they are either pink in colour with a chalky appearance or dark red-brown to pink in colour with large red-brown crystals possibly hematite.

In thin section, the granites (e.g., samples 4349, 4352, 4371 and 4372) all illustrate an equigranular texture, whose mineral constituents are generally anhedral in outline. It is also observed that there are many subhedral plagioclase, hornblende and biotite crystals. The mineralogy of these granites consists essentially of quartz, plagioclase and K-feldspar (perthite), with accessory biotite, hornblende/actinolite, opaque minerals, zircon, sphene, epidote, muscovite/sericite, chlorite and apatite. The mineral crystals on average range between 0.5mm to 2mm in size and the accessory minerals are overall less than 0.1mm in size. The hornblende and biotite in some samples (e.g. 4371, 4372) are not as well formed as in other samples (e.g. sample 4352); also these minerals show a variable alteration to actinolite and chlorite respectively and often they occur in clots and a variable modal distribution. The hornblende and biotite are also mostly associated with zircon, epidote, sphene and chlorite. All samples show a deformation that is marked by small and large fractures. Many of these fractures are filled in with epidote and actinolite. The deformation is also shown by the development of subgrain boundaries in the quartz, although many quartz crystals show good uniform extinction.

Quartz Diorite - Tonalite

The quartz diorites in handspecimen are generally black and white in colour with some red, and fairly equigranular rocks. They consist essentially of quartz, plagioclase, hornblende, biotite and K-feldspar. The K-feldspar appears to be albitized in some samples (e.g. 4085, 4088). This group also contains rocks that are porphyritic (e.g. samples 4086, 4087 and 4089). These samples contain essentially the same minerals as the more equigranular samples. Some of these rocks (e.g. sample 4086) contain large plutonic rock fragments, whereas others (e.g. sample 4089) contain large feldspar phenocrysts. The equigranular samples also show more reddening compared to the porphyritic samples.

These rocks all illustrate an equigranular to porphyritic texture, whose mineral constituents are anhedral to subhedral in outline and with several euhedral crystals. The euhedral crystals are fairly small and are seen as zircon, apatite, sphene and some hornblende crystals. They consist predominantly of plagioclase, quartz, hornblende and biotite (collectively approximately 35-40% modal value), with accessory minerals including sphene, apatite, zircon, chlorite, muscovite/sericite, opaque oxides and K-feldspar (minor amounts).

The hornblende and biotite in many cases form very good large euhedral crystals. In contrast to the hornblende in the granites, here the hornblende is relatively unaltered and in cases quite fresh. The biotite here is much larger and only slight altered. Generally the mineral crystals range from 0.3 to 1.5mm in size and only the accessory minerals and opaques are less than 0.2mm in size. All of these rocks display the same mineralogy with only slight modal variations.

Sample 4086 contains a plutonic rock fragment of about 0.6mm in size. This rock fragment shows a granophyric texture and is composed essentially of altered plagioclase, quartz, opaques, biotite, muscovite, hornblende and calcite.

These rocks are moderately altered and deformed. The alteration is shown by the plagioclase, which in most cases contain sericitized cores. In other cases they are only weakly sericitized and the twinning lamellae are still completely visible. The alteration is also shown by the hornblende and biotite, which are both only slightly altered to chlorite. The deformation is noted by small fractures and only slight sub-grain boundary in a few quartz crystals. The majority of the quartz crystals show good even extinction.

Gabbro and diabase

The gabbros (e.g., samples 4084, 4351) are medium grained fairly equigranular grey and white rocks in handspecimen. They show good plagioclase laths in cases and are mainly massive. Good crystals are readily visible megascopically. The diabases are fine grained massive grey rocks relatively featureless in handspecimen. Small crystals can be seen megascopically.

The gabbros in thin section are generally medium grained with typical ophitic textures involving euhedral laths of plagioclase and possibly augite. The laths of plagioclase create the matrix and show little alteration. Clinopyroxene, hornblende and biotite are all present. Biotite seems to be strongly associated with the opaque minerals. Sphene is also commonly associated with the opaque minerals. The alteration minerals include chlorite, rutile, white mica and dusty opaque minerals.

GEOCHEMISTRY

Geochemically, the rocks analyzed from the "Gilbert Hills pluton" closely resemble those from the Wyvern pluton to the east (Pe-Piper et al. 1994). Some gabbro and quartz diorite is strongly enriched in LILE, particularly Ba. TiO_2 in mafic rocks generally is > 1.5 wt %. Y (mostly 45-55 ppm) and Zr (mostly > 200 ppm) contents are higher than in the Wyvern pluton. Rocks of intermediate composition appear more common than in the Wyvern pluton: some appear to be hybrids, but others are texturally homogeneous.

Table 5: Representative modal compositions of the Gilbert Mountain pluton

Sample No.	C4088	C4089	C4093	C4372
Plagioclase	53.5	53.3	52.2	17.2
K-feldspar	3.3	6.0	-	52.5
Quartz	8.2	7.3	17.1	25.7
Hornblende	10.3	7.8	14.0	1.4
Biotite	19.3	21.7	10.2	0.7
Opaques	4.6	3.7	4.3	0.4
Apatite	-	-	0.5	-
Chlorite	-	-	1.0	0.1
Epidote	-	-	0.5	1.7
Sphene	0.4	0.2	0.2	-
Others	0.4	0.1	0.2	0.3
Total	100	100.1	100.2	99.7
Colour Index	35.0	33.5	30.9	4.6
IUGS Nomenclature components				
Plagioclase	82.3	80.0	75.3	18.0
K-feldspar	5.1	9.0	-	55.0
Quartz	12.6	11.0	24.7	26.9
IUGS Name[1]	QDI	QDI	TON	GR

1: QDI=quartz diorite; TON=tonalite; GR=granite

Modes are based on counting 1000 to 1500 points in one or two thin sections (depending on grain size of rock) stained using a modification of the method of Bailey and Stevens (1960).

Table 6: Whole-rock chemical analyses of representative rocks

Sample No.	C4084	C4085	C4086	C4088	C4089	C4093	C4349	C4351	C4352	C4371	4372
Major elements by XRF (wt%)[1]											
SiO_2	46.26	55.93	57.24	53.41	54.32	55.40	71.53	47.52	62.74	71.22	71.13
TiO_2	1.88	2.00	1.76	2.42	2.23	2.12	0.38	1.25	1.06	0.38	0.33
Al_2O_3	15.88	15.16	15.83	14.69	15.18	15.04	13.56	15.89	15.79	13.87	13.86
Fe_2O_3	12.26	9.74	8.69	11.40	10.60	10.27	2.81	9.67	5.73	2.75	2.44
MnO	0.48	0.33	0.28	0.31	0.28	0.26	0.07	0.14	0.17	0.09	0.11
MgO	7.69	3.16	2.78	3.73	3.37	3.42	1.00	8.68	1.91	0.99	1.09
CaO	7.93	3.90	4.07	5.40	5.20	4.92	1.25	10.33	2.29	0.62	0.63
Na_2O	2.32	4.55	4.76	3.70	4.50	4.47	3.86	2.38	5.36	4.38	4.20
K_2O	1.66	2.21	2.40	1.64	1.79	2.17	4.96	0.54	3.04	4.71	4.95
P_2O_5	0.28	0.84	0.74	1.26	1.02	1.00	0.08	0.14	0.35	0.09	0.08
L.O.I	2.60	1.30	0.70	1.00	0.90	0.50	0.60	2.30	0.80	0.30	0.60
Total	99.24	99.12	99.25	98.96	99.39	99.57	100.10	98.84	99.24	99.40	99.42
Trace elements by XRF (ppm)[1]											
Ba	1092	1057	1114	887	933	929	463	215	1432	523	549
Rb	107	81	78	61	60	72	158	23	91	154	164
Sr	269	356	404	479	522	493	126	314	244	67	73
Y	26	49	52	55	55	53	45	21	49	45	46
Zr	144	274	396	240	224	288	278	107	415	311	276
Nb	11	25	28	24	23	23	31	7	25	24	21
Th	2	<10	<10	6	<10	<10	30	<10	15	18	8
Pb	171	19	130	32	23	24	17	<10	11	30	46
Ga	19	19	20	22	21	20	21	22	23	19	20
Zn	516	212	302	159	189	170	45	75	87	69	60
Cu	60	20	20	26	28	19	<5	65	<5	<5	<5
Ni	46	30	37	32	34	32	8	210	5	6	5
V	298	81	64	121	83	80	17	206	37	6	8
Cr	168	1	6	3	6	5	37	330	15	33	19
REE and selected trace elements by INAA (ppm)[1]											
La	n.d.	n.d.	n.d.	n.d.	47.61	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ce	n.d.	n.d.	n.d.	n.d.	112	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nd	n.d.	n.d.	n.d.	n.d.	62.36	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sm	n.d.	n.d.	n.d.	n.d.	13.72	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Eu	n.d.	n.d.	n.d.	n.d.	4.23	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tb	n.d.	n.d.	n.d.	n.d.	2.12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Yb	n.d.	n.d.	n.d.	n.d.	5.16	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Lu	n.d.	n.d.	n.d.	n.d.	0.74	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ba	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Co	n.d.	n.d.	n.d.	n.d.	20.24	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cs	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Hf	n.d.	n.d.	n.d.	n.d.	5.79	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sc	n.d.	n.d.	n.d.	n.d.	25.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ta	n.d.	n.d.	n.d.	n.d.	1.60	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Th	n.d.	n.d.	n.d.	n.d.	3.67	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
U	n.d.	n.d.	n.d.	n.d.	0.81	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

1: Analytical methods used as in Pe-Piper and Piper (1989)

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Figure Captions

Fig. 1. Regional geological map of the western Cobequid Highlands showing the location of the North River and Gilbert Mountain plutons.

Fig. 2. Summary geological map of the North River pluton and adjacent areas. H = Harrington River, N = North River, B = Bass River, E = East River.

Fig. 3. Lower hemisphere stereographic projection showing poles to foliation planes in wall-rock metasediments north of the Pleasant Hills (PH), North River (NR) and West Moose River (WMR) plutons (N=32). Great circles represent the generalised trend of the northern contact of each pluton.

Fig. 4. Field sketch from photographs of detailed kinematic features at a near tip of a granite sill at northern margin of North River pluton. Total length of sill is 10 m. Sketches of (a) flame structures at margin of mafic enclave and, synmagmatic foliations (curved crosses) showing northward motion. (b) Folded epidote vein and (c) deformed quartz vein indicating southward motion.

Fig. 5. (B) Horizontal thrust planes and sigmoidally-deformed, subvertical fracture cleavage planes. North River pluton. Photo looking east, hammer for scale.
(E) Subvertical duplex from the North River pluton, defined by a floor thrust (FT) and a roof thrust (RT). Internally, this duplex is separated into five horses with four link thrusts. Photo looking west, lens cap 5 cm.

Fig. 6. I.U.G.S. classification of the rocks of the North River and Gilbert Mountains plutons based on modal compositions. Field names after Streckeisen, 1976.

Fig. 7. Schematic cross-section of outcrop of interbedded marble, slate and chert, with insets showing microstructure and relationship of mineral phases to structure. "Mineralized marble" is a yellowish calc-silicate/carbonate/quartz rock (yellow marble) with bands of sphalerite and magnetite.

Fig. 8. Photomicrograph showing fracture cleavage (subhorizontal) through garnets. Photograph is approximately 2.5 mm wide. See inset, Fig. 7, for location in section.

Fig. 9. Sketches of analyzed euhedral garnet crystals showing optical zoning. Andradite cores (1-3, 5-6) show fracture cleavage; spessartine-rich rim (4) is uncleaved. See inset, Fig. 7, for location in section.

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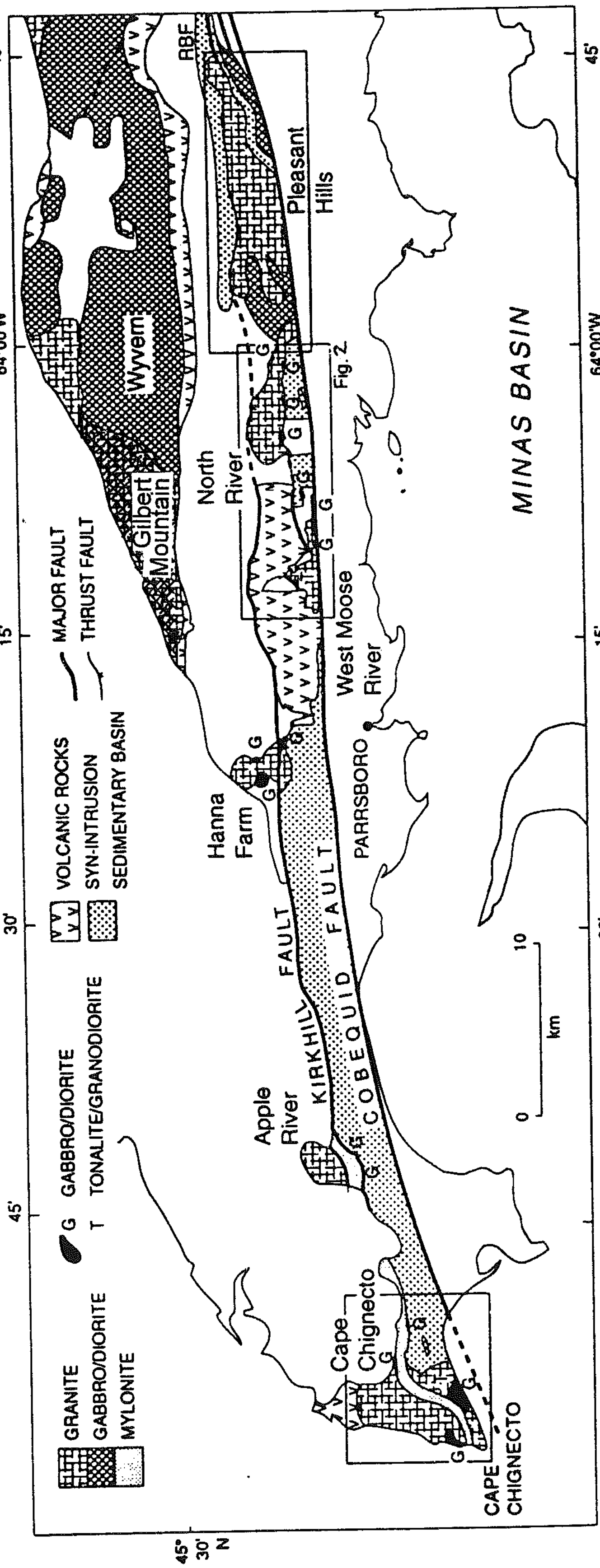

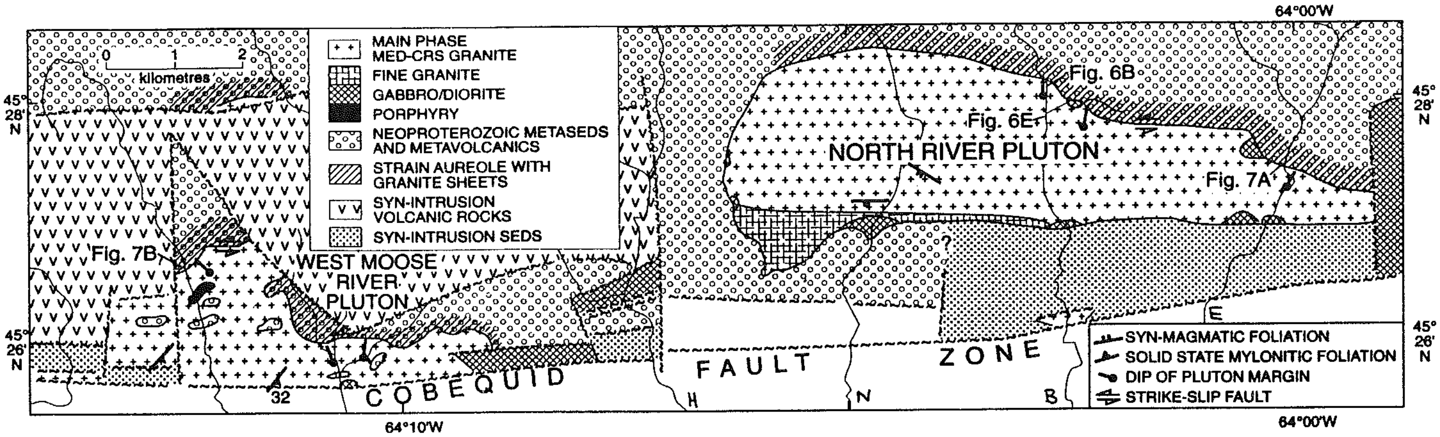

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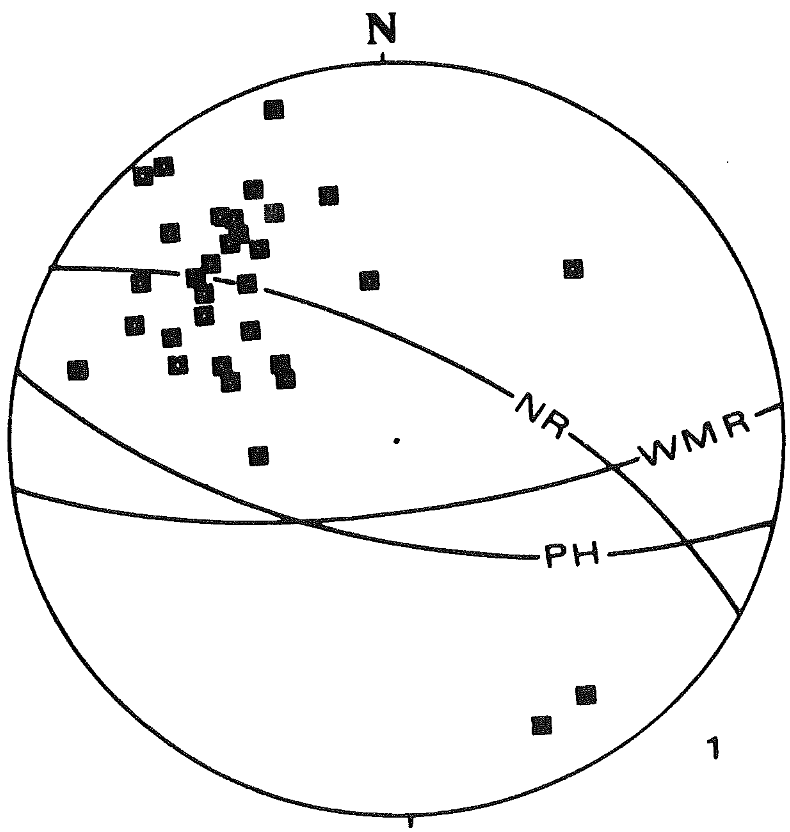

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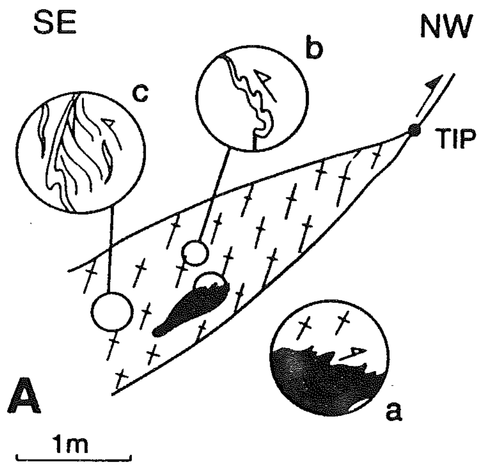

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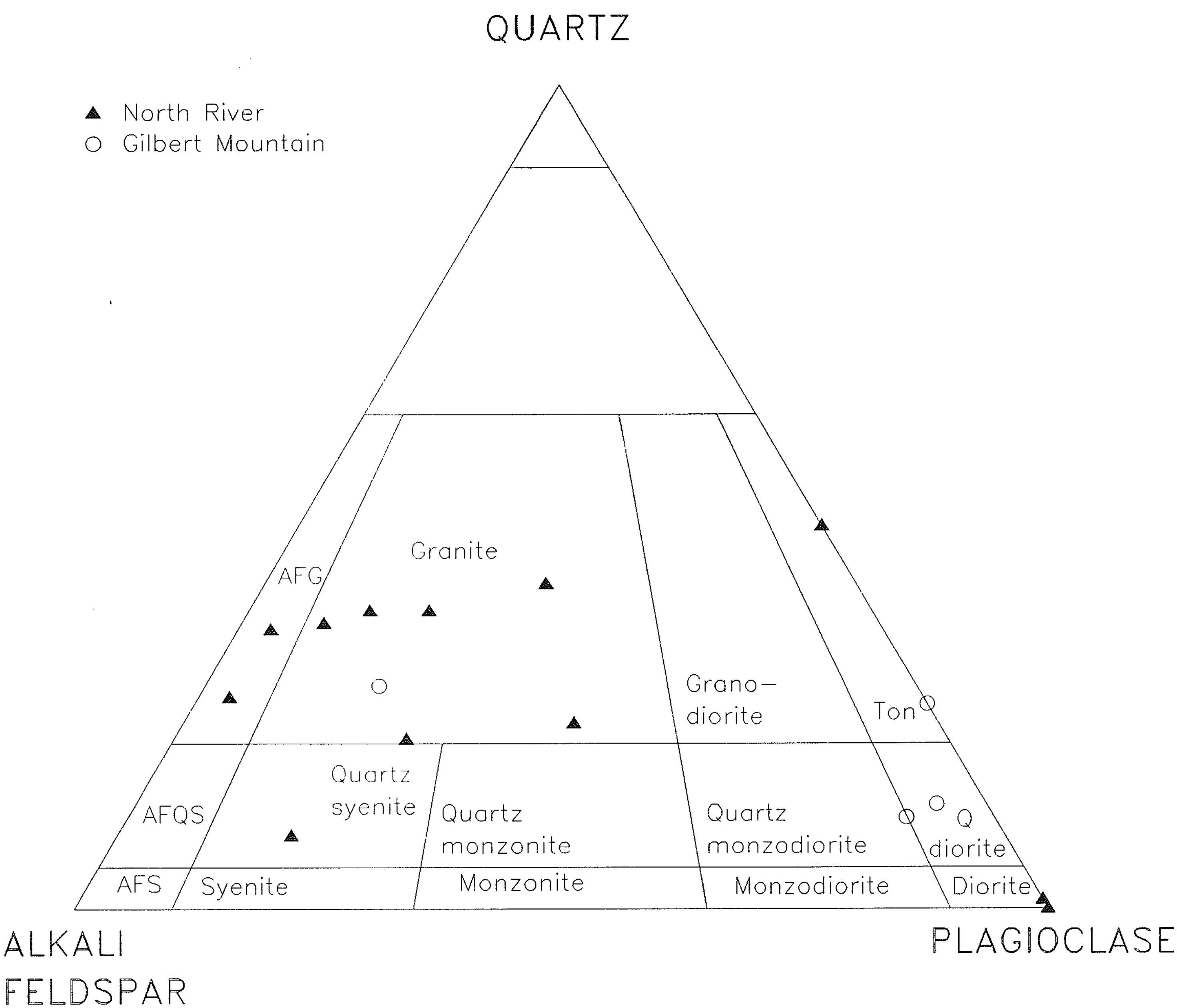

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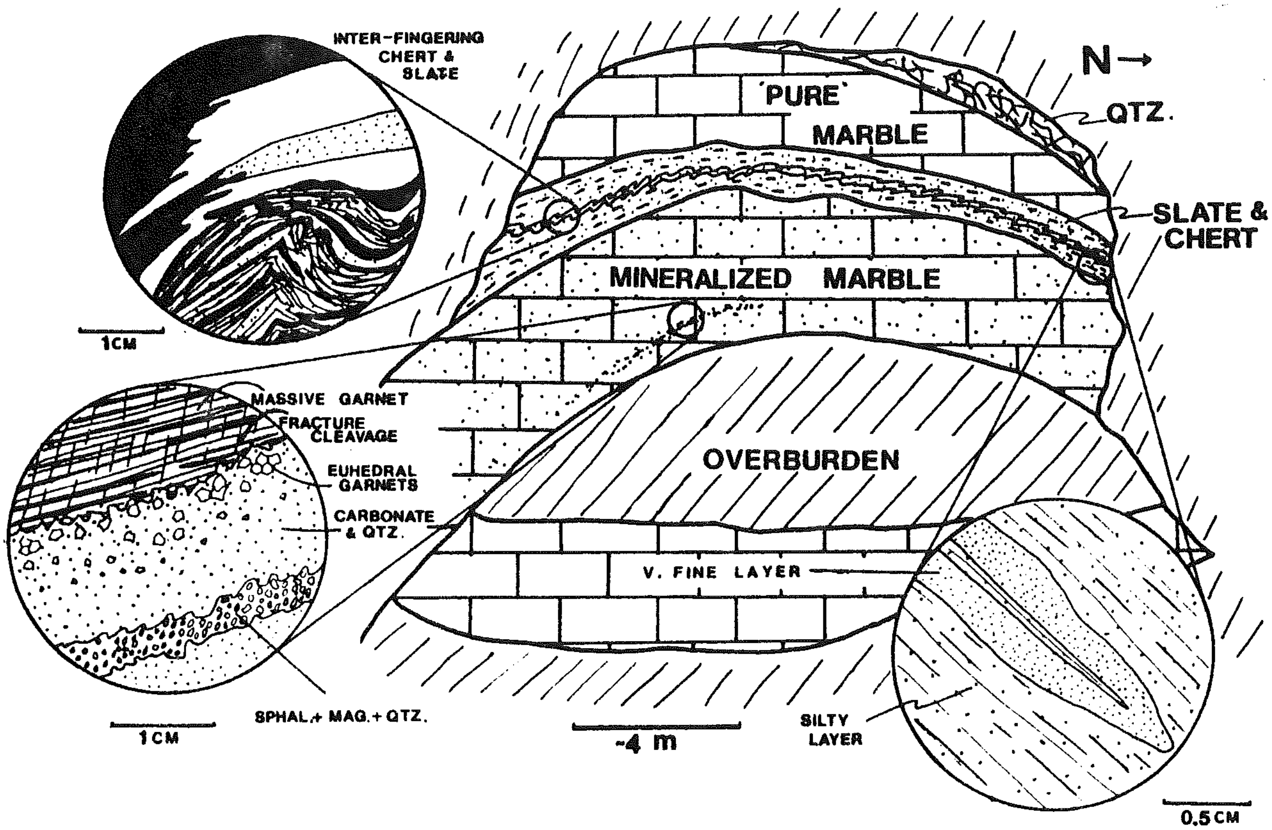

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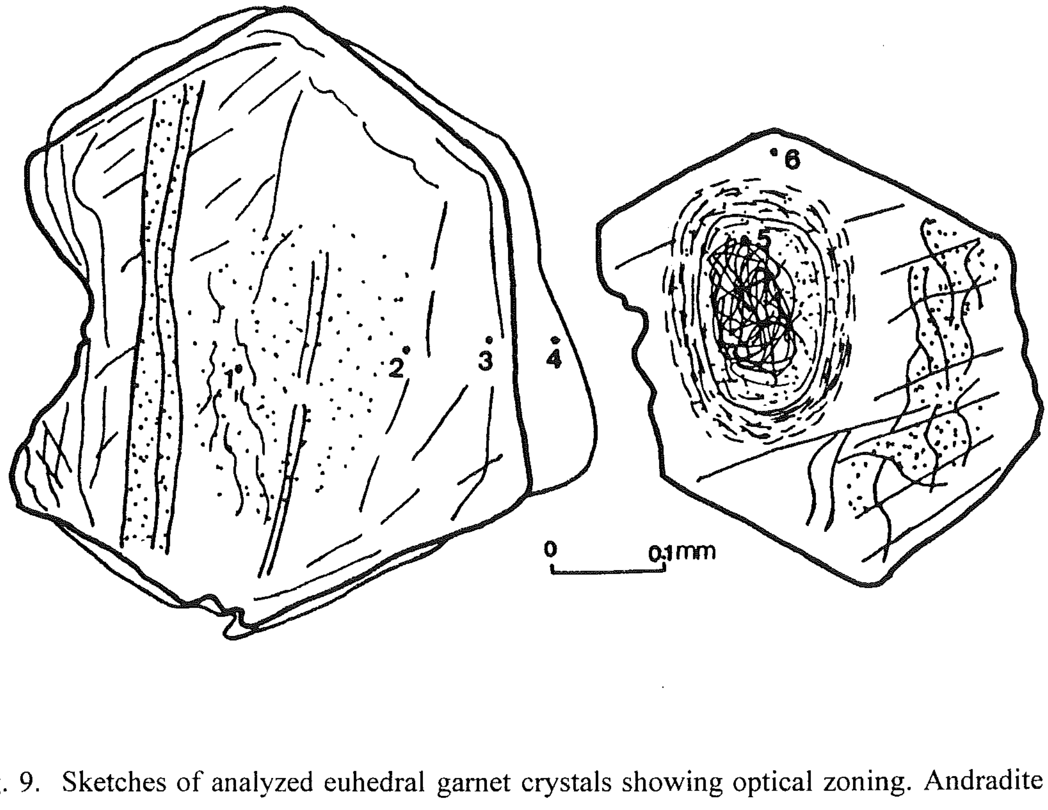

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