THE CHEMICAL COMPOSITION OF GRANITE-RELATED AND MINERALIZATION-RELATED TOURMALINE IN NOVA SCOTIA

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MARCH 6, 1987

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ABSTRACT

Tourmaline is a common accessory mineral which occurs in a wide variety of mineralogical settings. This mineral is commonly found in sedimentary, metamorphic, and granitoid intrusive rocks and their associated aplites, pegmatites and hydrothermal aureoles (greisens). Tourmaline is also frequently found in association with many types of mineral deposits. These include massive sulfides, polymetallic sulfides, vein and breccia Sn, vein Au, Sn and Mo greisens and Be-Li pegmatites. The chemical composition of tourmalines from occurrences of these types in Nova Scotia has been determined by microprobe analysis for SiO_2, TiO_2, Al_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, and F. Both cores and rims of all grains were analyzed to determine possible chemical zoning; many grains show colour zoning. These analyses have shown distinct relationships exist between tourmaline composition and geological setting, however, significant overlap occurs among many of the groups studied. Chemical compositions and trends seen on binary plots for the elements analyzed are similar to those observed for tourmaline occurrences elsewhere. Boron isotope analyses were also carried out, however, no relationship between tourmaline paragenesis and boron isotope composition is evident.

CHAPTER 1 : INTRODUCTION

Tourmaline is a complex borosilicate mineral found in a variety of geological settings. This mineral is often characteristic of granites, pegmatites, pneumatolitic veins and greisens as a late-stage product of magmatic differentiation. It is also found in sedimentary rocks as a product of boron metasomatism or as a recrystallized detrital or authigenic mineral; tourmaline occurs frequently in evaporitic rocks.

The common occurrence of tourmaline in association with mineral deposits has been recognized, although specific relationships between crystal chemistry and paragenesis have not been accurately defined. Tourmalines associated with mineral deposits are of replacement, cavity-filling or metamorphic origin. Representatives of all above-mentioned occurrences are found throughout Nova Scotia.

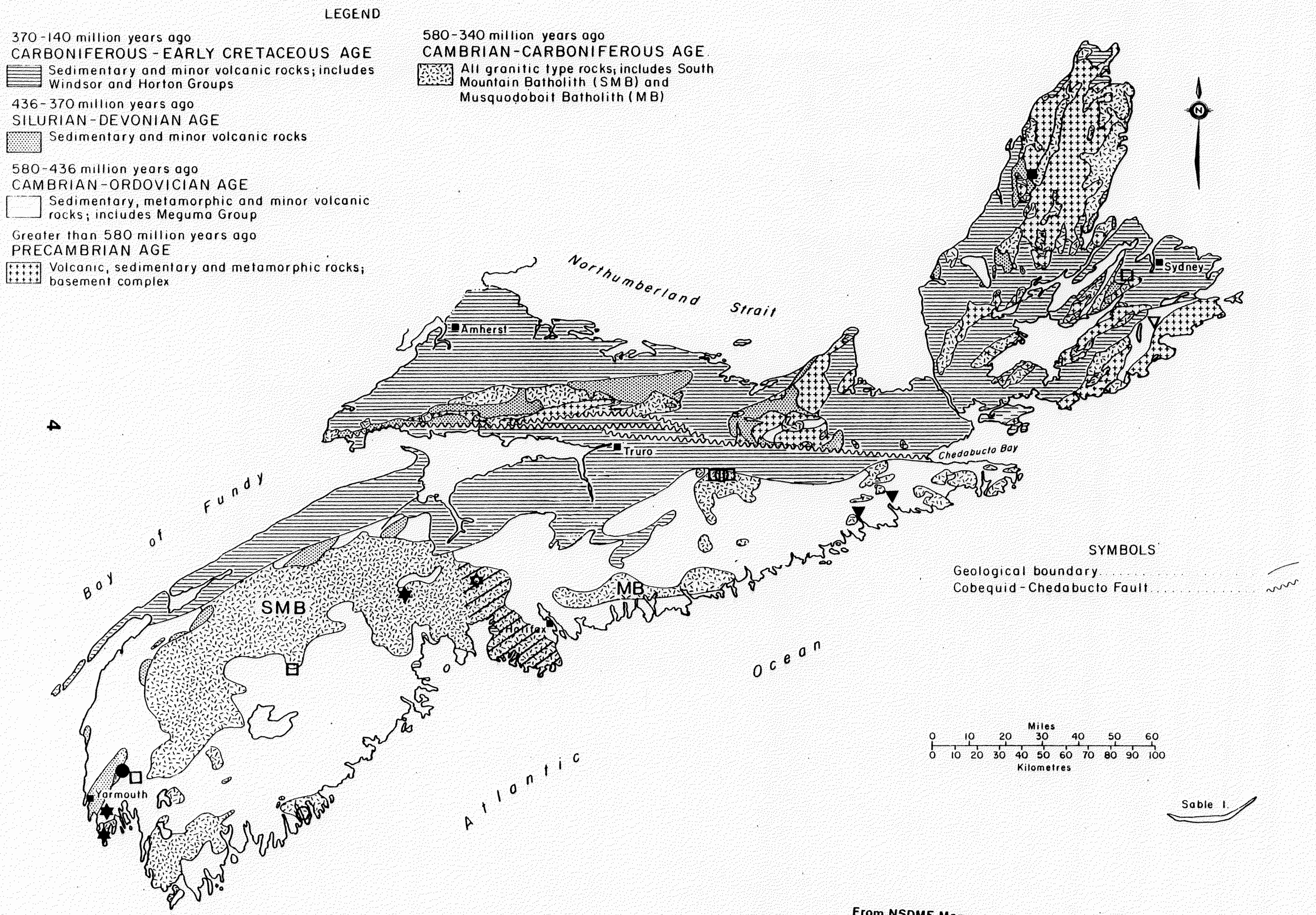
Recent interest in the composition of tourmalines from mineral deposits (Ethier and Campbell, 1977; Taylor and Slack, 1984; Brown and Ayuso, 1984 and others) has created similar enthusiasm in determining the compositions of tourmalines in Nova Scotia, particularly those associated with economic mineralization. Previous work in other areas has indicated a correlation between tourmaline chemistry and occurrence. Taylor and Slack (1984) concluded that tourmalines from Appalachian-Caledonian massive sulfide deposits have characteristic major and trace element compositions, Mg-rich dravites being typical. Fe-rich and Li-rich tourmalines are associated with granites, pegmatites and aplites (Neiva, 1974; Clarke, 1981; Manning, 1982 and others). Other relationships are less clear. Kitaev et al. (1985) report tourmalines from gold deposits as typically high in CaO; King and Kerrich (1986) report CaO abundances of tourmaline associated with Archean lode gold deposits as "systematically low". Apparently, the relationship between tourmaline composition and association is complex.

The purpose of this project is to carry out a reconnaissance survey of composition of tourmalines in Nova Scotia and to attempt to define a relationship between these compositions and tourmaline occurrence. Such relationships have been suggested (Slack, 1982) as an exploration guide for mineral deposits.

Occurrences of tourmaline in Nova Scotia have been classified as follows: 1) vein gold (Cochrane Hill and Forest Hill), 2) metamorphic (Corney Brook, Cape Breton), 3) massive sulfide (Blue Mountain, Cape Breton), 4) granite-related, including magmatic, pegmatitic, aplite-pegmatitic and quartz-tourmaline veins and pods (South Mountain Batholith, Liscomb Pluton, Port Mouton Pluton, Wedgeport Pluton, Brazil Lake), 5) greisen (Walker molybdenite deposit, Wedgeport Pluton, Pearl Lake, South Mountain Batholith), 6) polymetallic veins (Caledonia, Dominique) and 7) porphyry-like Cu (Coxheath, Cape

Breton). Sample locations are given in Figure 1.

Figure 1. General geology of Nova Scotia showing sample locations and tourmaline associations. ● = mineralized pegmatite, ○ = unmineralized pegmatite, ✡ = unmineralized greisen, ✶ = mineralized greisen, ▼ = vein gold, ■ = schist, \\\ = granite-related (SMB), □ = other.



From NSDME Map

CHAPTER 2 : BORON, BORON ISOTOPES AND TOURMALINE CRYSTAL CHEMISTRY

2.1.0 Boron

Boron is a member of the main group elements, having an atomic weight of 10.811 and occurring in the trivalent state, B^{3+}. Boron is a relatively rare and chemically unique element; the behavior of this element is largely controlled by its small ionic radius (0.23) which prevents boron from being easily incorporated into mineral structures. Thus, boron is commonly concentrated in late stage magmatic fluids, hydrothermal fluids and evaporites.

The terrestrial concentration of boron is very low. Average basalts contain 1.6 ppm boron; all igneous rocks average 3 ppm boron, in some areas (basic intrusions in Siberia) up to 22 ppm (Anastasenko, 1973 cited in Ethier and Campbell, 1977). Seawater is enriched in boron, having a mean boron content of approximately 4.6 ppm (White, 1968). Due to the adsorption of boron by clays, particularly illite (Schwarcz, 1969; Palmer et al., 1985), marine shales have relatively high boron content (up to 310 ppm). High boron concentrations are also found in some hot springs. The localization of boron in tourmaline and other boron-bearing minerals represents a significant concentration of this element. The boron content of a tourmaline containing 10.9% B_2O_3 is 33 870 ppm (Ethier and Campbell, 1977).

2.1.1 The Geochemical Cycle of Boron

The global quantity of boron is assumed to have remained constant over geological time. The creation of fresh ocean (basaltic) crust containg 0-3 ppm boron at seafloor speading centres provides a mechanism for the introduction of boron into the Earth's crust. Crustal boron is consumed during subduction processes and eventually released during metamorphism and magma generation in boron-bearing fluids (Shaw et al., 1984).

Boron adsorption by marine clays is part of the global cycle of boron. Other processes of boron removal from seawater include the formation of siliceous skeletal material and authigenic silicates, and low-temperature alteration of oceanic crust. Total boron removal from seawater, estimated at 42 X 10^{10} g/yr (Harriss, 1969), is comparable to boron input from rivers and ridge crest hydrothermal activity, however, an overall imbalance is found; calculated boron input is greater than boron loss for seawater. Seyfried et. al. (1984) have proposed boron enrichment of serpentinized peridotite as a possible sink for boron unaccounted for by the processes already mentioned.

2.1.2 Boron Isotopes

There are two naturally occurring stable isotopes of boron, ^{10}B and ^{11}B, with ^{11}B accounting for 80.29%. The large relative mass difference (10%) between the two stable isotopes and boron's ability to bond in either three-fold or four-fold coordination (Spivack and Edmond, 1984) allow a high degree of kinetic fractionation. This is reflected in the association of boron to late stage magmatic fluids and evaporitic environments. This factor, along with a large chemical isotope effect and low crustal and atmospheric boron concentrations make boron a potential stable isotope provenance tracer.

The preferential adsorption of ^{10}B onto clay minerals has been demonstrated (Schwarcz et al., 1969; Palmer et al., 1985 and others) for marine sediments. Clay adsorption probably accounts for most of the observed difference in the boron isotopic composition between seawater (δ^{11}B about +40 permil) and the average value for crustal rocks (δ^{11}B about -8 to +2 permil), corresponding to approximately four percent fractionation (Schwarcz et al., 1969). The retention of ^{11}B isotopes by seawater results in other boron sources having negative δB values. Fractionation may also occur by chemical exchange (Finley et al., 1962), by which isotopic separation occurs owing to the differing chemical properties of each isotope.

Boron is present in sea-water as $B(OH)_3$, $B(OH)_4^-$ and ion associates such as $NaB(OH)_4$, $MgB(OH)^{4+}$ and $CaB(OH)_4^+$ (Byrne and Kester, 1974). $B(OH)_3$ is trigonal, other molecules are tetrahedral. Isotopic exchange occurs between the trigonal and tetrahedral forms.

Boron isotopes have been used successfully to differentiate between marine and nonmarine evaporite borates (Swihart et al., 1986). Marine evaporites are typically heavy, having positive permil values, nonmarine evaporites are typically light, having negative permil values. High boron concentration in seawater (5 ppm) may lead to boron concentration in evaporitic and hot spring settings.

2.1.3 Boron in Tourmaline

Tourmaline is the most common mineral containing significant amounts of boron (approximately 9-11% B_2O_3). Tourmaline is often found in association with aplites, pegmatites, pneumatolitic veins and metasomatic alteration zones of these occurrences. This mineral is also found in association with massive sulfides believed to have formed in fumarolic environments, such as the Sullivan Pb-Zn deposit in Kimberley, British Columbia (Ethier and Campbell, 1977), and as a common constituent of evaporitic rocks. Such tourmaline associations are controlled by the concentration and deposition of boron in these environments, which is in turn related to the chemical behavior of boron. Boron and other volatiles (F, Li, H_2O) are commonly considered to play an important role in controlling the solubility and transportation of major and ore elements from crystallizing magmas (Manning and Pichavant, 1984). This is reflected by the common occurrence of tourmaline in association with late-stage magmatic mineralization.

2.1.4 Boron Isotopic Investigation

An investigation of $^{11}B/^{10}B$ ratios of tourmalines representing different stages in the formation of mineral deposits by Parwel et al. (1956) gave no indication of significant variation. Parwel concluded variations may occur at levels below detection, however, these variations are probably insignificant. $^{11}B/^{10}B$ ratios determined for a variety of tourmaline-bearing phases in a number of deposits in the USSR, including tourmaline-cassiterite veins, tourmaline-fluorite rocks, tourmaline-quartz greisens and veins, pegmatites and tourmaline alaskite and hornfels revealed little variation. This was interpreted as a lack of fractionation in these occurrences (Esikov and Esikova, 1974, cited in Dietrich, 1985).

2.2.0 CRYSTAL CHEMISTRY AND STRUCTURE OF TOURMALINE

Tourmaline is a complex borosilicate mineral belonging to the trigonal subsystem of the hexagonal crystal system. Individual crystals range in size from minute crystals to those greater than one meter in length. Crystals are predominantly prismatic, although nearly equant grains do occur. Twinning in tourmaline is rare. Groups of crystals commonly occur parallel, divergent or radially or as fine-grained fibrous masses. Crystal faces are typically strongly striated.

2.2.1 Crystal Structure

Three models have been proposed for the structure of tourmaline. Donnay and Buerger, (1950) and Ito and Sadanaga (1951, cited in Dietrich, 1985) based their models on 31 oxygen. The configuration of the Si-tetrahedra ring is hexagonal in the Ito-Sadanaga model, trigonal in the Donnay-Buerger model. Belov and Belova (1949 and 1950, cited in Dietrich, 1985) proposed a structural model based on 30 oxygen, the 31st oxygen is located in the central part of the structure and is common to three Mg octahedra.

Tourmaline structure may be decomposed to six basic components - an X site cation, located along the central axis, an Si6O18 ring of six SiO_4 tetrahedra, three Y-site and six Z-site octahedra, three BO_3 trigonal planar units, and anions. The general structural formula for tourmaline is given (Deer et al., 1962) as $XY_3Z_6(Si_6O_{18})(BO_3)_3(OH,F)_4$. X-site cations are predominantly Na and/or Ca +/- K, located along the threefold axis of symmetry, between levels of BO_3 trigonal planar units and levels of SiO_2 tetrahedra. Mg_2^+ may occupy this site in rarer circumstances, or the site may remain unoccupied. Y-site cations are most commonly Fe_2^+ and/or Mg_2^+, Al+/-Li and/or Fe_3^+. These are located at equal distances from the threefold axis of symmetry in octahedral coordination between layers of BO_3 triangles and SiO_4 tetrahedra. The Y-site may also contain significant amounts of Mn^{2+}, Cr^{2+}, V^{3+} and possibly Ti^{4+}. The

Z-site cations are Al^{3+}, Fe^{3+}, Cr^{3+} or (Al,Mg). Z-site octahedra are located peripherally around the larger Y-site octahedra. Anions, mostly O^{2-} and OH^{-} + F^{-} occupy the apices of coordination polyhedra (Deer et al., 1962). Chlorine is also known to occur in tourmaline in southwestern England (Fuge and Power, 1969) and northern Portugal (Neiva, 1974).

2.2.2 Solid Solution

As a result of considerable cation substitution in tourmaline structure there exist several solid solution series within the tourmaline group. John Ruskin (1890) stated that "the chemistry of it (tourmaline) is more like a mediaeval doctor's prescription than the making of a respectable mineral" (cited in Deer et al., 1962). In fact, substitution may involve partial or complete substitution in one or all of the X-, Y- or Z-sites as well as in the OH site. Coupled substitutions involving more than one site may occur and cation site deficiencies may be involved. A large number of trace elements are known to substitute into tourmaline structure.

Elbaite-schorl, schorl-dravite, elbaite-liddicoatite, and dravite-uvite constitute these solid solution series. The elbaite (X=Na, $Y=(Al,Li)_3$, $Z=Al_6$)-liddicoatite (X=Ca, $Y=(Li,Al)_3$, $Z=Al_6$) series involves Na^{+}:Ca^{2+} differences in the X-site accompanied by charge compensation between Al^{3+} and Li^{+} in the Y-sites. Na^{+}:Ca^{2+} differences are also involved in the dravite

(X=Na, Y=Mg_3, Z=Al_6)-uvite (X=Ca, Y=Mg_3, Z=Al_5Mg) solid solution series; charge compensation occurs by partial substitution of Mg^+ for Al^{3+} in Z-sites. Elbaite-schorl (X=Na, Y=Fe_3^{3+}, Z=Al_6), and schorl-dravite substitutions involve the Y-site. (Al^{3+}, Li^+) substitutes for Fe^{3+} and Fe^{2+} for Mg^{2+}. Other end members include buergerite (X=Na, Y=Fe_3^{3+}, Z=Al_6), chromdravite (X=Na, Y=Mg_3, Z=Cr_5Fe^{3+}), and ferridravite (X=Na, Y=Mg_3, Z=Fe_6^{3+}). Small amounts of chlorine and fluorine may substitute for oxygen in anion positions.

Boron-silicon substitution has been verified in marine clays (Stubican and Roy, 1962). It has been suggested that boron-silicon substitution occurs in sillimanite which may contain up to 0.43% B_2O_3 (Grew, 1983).

2.2.3 Colour

The source of coloration of tourmalines may be attributed to the presence of transition elements and/or colour centres within the crystal structure. Transition elements, such as iron, manganese, chromium and vanadium having partially filled d orbitals are commonly the cause of colour. Iron is particularly important in contributing colour to minerals. The presence of atoms in more than one oxidation state may also cause coloration as a result of charge transfer. Colour centres, or crystal imperfections (foreign ions or atoms, vacancies) may impart colour to minerals by trapping electrons (Rapp, 1977).

Virtually all colours have been recognized in tourmaline. Crystals often show colour zoning which may be very regular or in irregular patches. General relationships can be drawn between tourmaline composition and colour. Iron-bearing tourmalines are black, elbaites are commonly light blue, green or pink, dravites range from dark brown to yellow or colourless.

Green coloration may be due to the presence of ferrous iron. Blue tourmalines may be coloured by high manganese and iron content. Pleochroism in tourmaline is particularly strong in the iron-bearing variety. Tourmaline is a highly pleochroic mineral. Absorption ranges from almost undetectable to extreme, with W > ϵ.

CHAPTER 3 : SAMPLE LOCATIONS

All samples except PM1 (Port Mouton Pluton) and CBS (Corney Brook, Cape Breton) were collected by the Nova Scotia Department of Mines and Energy. PM1 was collected by D.B. Clarke and CBS by H.E. Plint. Original sample numbers have been changed by the author for ease of reference. Sample labels used are referenced to Nova Scotia Department of Mines and Energy and other original sample numbers in Appendix A.

3.0.0 GENERAL GEOLOGICAL SETTING

The geology of Nova Scotia may be divided into the Meguma Zone of southern Nova Scotia and the Avalon Zone to the north. These zones are separated by the Chedabucto Fault (see Figure 1). Tourmaline samples were collected from 33 localities within both the Meguma and Avalon zones.

The given location descriptions are brief outlines of tourmaline occurrence areas. Parageneses and sample locations are described in further detail in the references cited.

3.1.0 MEGUMA ZONE

The oldest member of the Meguma zone is the Cambro-Ordovician Meguma Group, consisting of the Goldenville Formation and conformably overlying Halifax Formation. The Goldenville

Formation consists of greywacke, quartzite and slate, with minor calcareous horizons. The Halifax Formation consists of slate and lesser greywacke, quartzite and calcareous horizons. The Meguma Group is conformably overlain by the White Rock, Kentville, New Canaan and Torbrook Formations (Taylor, 1969).

The Meguma Group rocks have been regionally metamorphosed and deformed by the Lower Devonian Acadian Orogeny. Metamorphic grade ranges from chlorite to sillimanite grade (Taylor and Schiller, 1966).

Meguma Group rocks were intruded by the South Mountain Batholith and satellite plutons during Devonian time. These intrusions have thermally and regionally metamorphosed the Meguma Group sediments up to amphibolite facies (Taylor, 1969 and Smitheringale, 1973 cited in Clarke and Muecke, 1981). Paleozoic Meguma Group strata and the South Mountain Batholith are unconformably overlain by the Horton Group sandstones and Windsor Group carbonate rocks.

3.1.1 Southeastern South Mountain Batholith

The South Mountain Batholith is an intrusive complex of peraluminous granodiorites, monzogranites and leucomonzogranites of late Devonian to early Carboniferous age. This complex crops out over an area of approximately 10 000 km^2 in southwestern Nova Scotia. The batholith intrudes deformed greenschist- to amphibolite facies meta-wackes and meta-pelites of the Cambro-Ordovician Meguma Group along most of its margin. The intrusive sequence of the South Mountain Batholith from oldest to youngest is biotite granodiorite, biotite-muscovite monzogranite, dykes and smaller intrusions of porphyry, leucomonzogranite, leucogranite and aplite (McKenzie and Clarke, 1975).

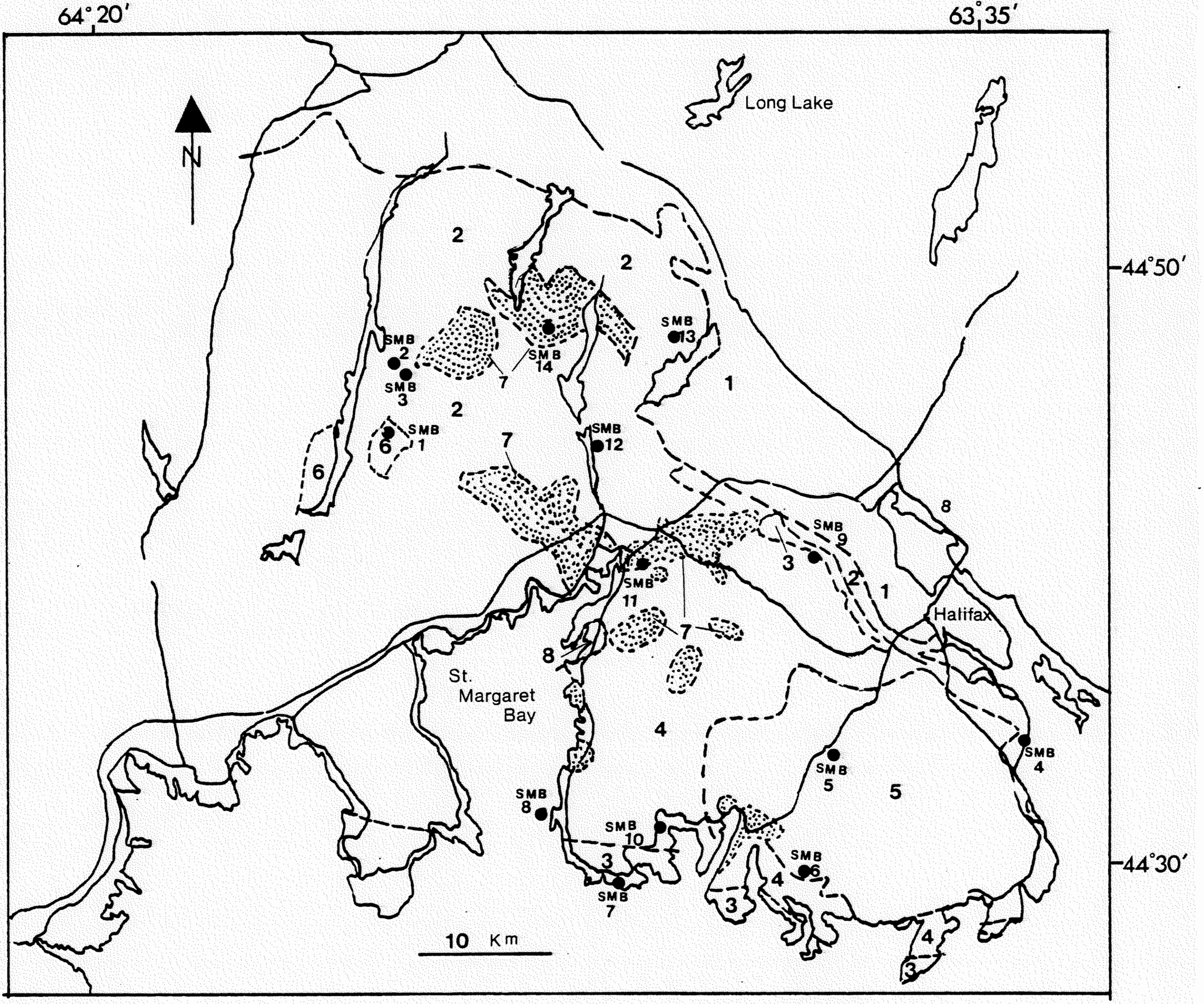
To the northwest the batholith intrudes meta-sedimentary and meta-volcanic rocks of the White Rock, Kentville, New Canaan and Torbrook Formations ranging in age from Ordovician to Lower Devonian. Lower Carboniferous clastic rocks of the Horton Group unconformably overlie the batholith (Taylor, 1969 and Smitheringale, 1973 cited in Clarke and Muecke, 1981).

Tourmaline is characteristic of peraluminous granitoid rocks (Chorlton and Martin, 1978; Clarke, 1981). Within the southeastern South Mountain Batholith tourmaline is a common accessory mineral in granitoid rocks and is frequently found in aplite-pegmatite and pegmatite dykes. Tourmaline may comprise a large percentage of quartz-tourmaline veins and greisen zones (Clarke, 1981) and also occurs in quartz-tourmaline pods. Samples analyzed are from the southeastern portion of the South Mountain Batholith (Figure 2).

3.1.2 Port Mouton Pluton

The Port Mouton Pluton is a complex granitoid intrusion

Figure 2. General geology and sample locations, Southeastern SMB. 1 = undivided Cambro-Ordovician metasediments, 2 = granodiorite, 3 = transitional monzogranite/granodiorite, 4 = biotite-muscovite monzogranite, 5 = biotite monzogranite, 6 = biotite-muscovite equigranular monzogranite, 7 = intrusive complex, 8 = undivided Carboniferous.



Modified from NSDME Map

located on the southeastern shore of Nova Scotia (Figure 3). The pluton intrudes the Goldenville Formation of the metasedimentary Devono-Carboniferous Meguma Group. Tourmaline is found in pegmatite dykes within the pluton and extending into the country rocks.

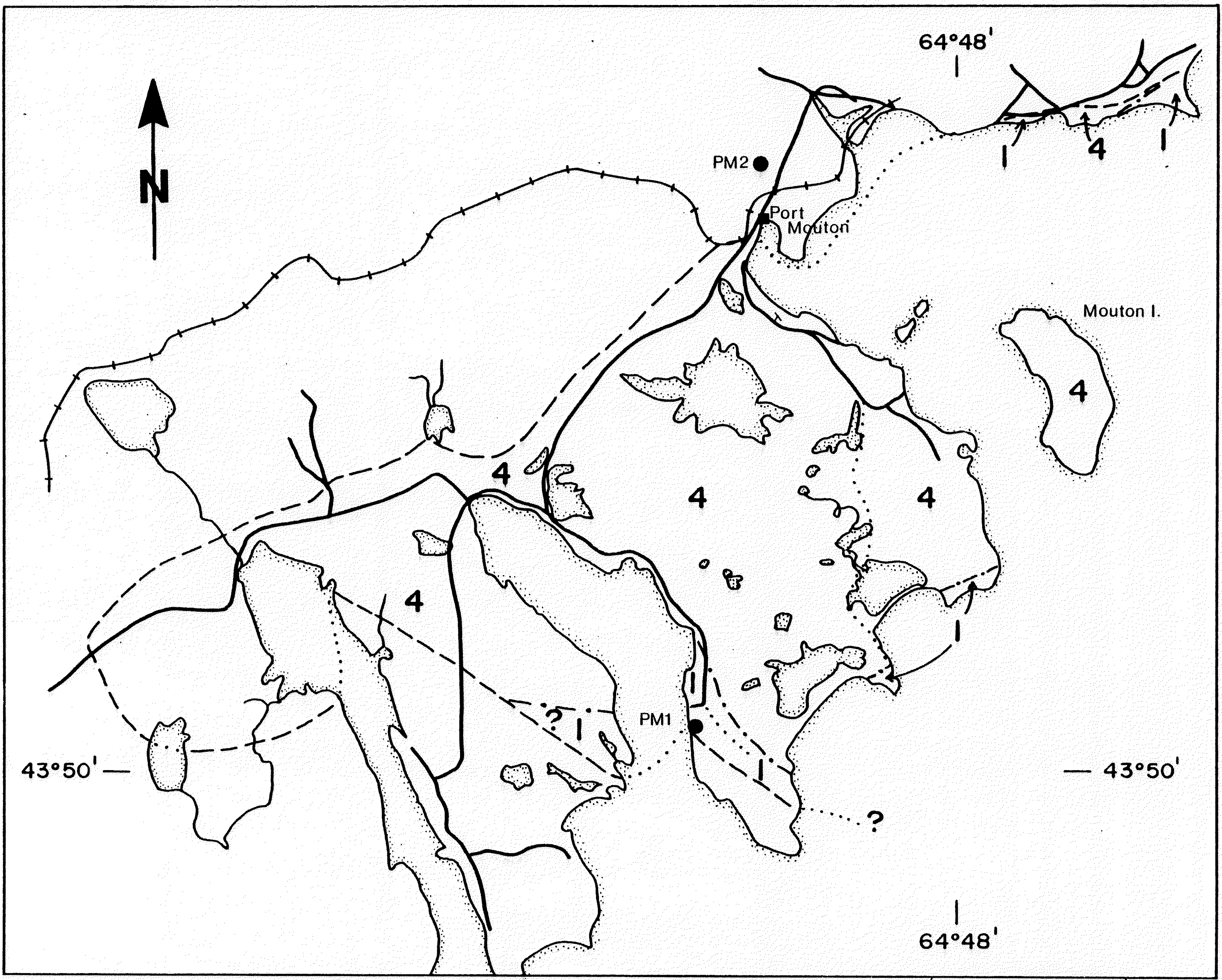
3.1.3 Liscomb Pluton

The Liscomb Pluton is a composite intrusive body located in the Eastern Meguma Zone of Nova Scotia (Figure 4). The pluton consists of a plutonic complex, high-grade metamorphic rocks (felsic and mafic gneisses) and what have been described as "diatremes/ breccia pipes characterized by a volatile-rich matrix ranging in composition from quartz-bearing gabbro to quartz-diorite containing a large assortment of xenoliths" (Giles and Chatterjee, 1986). Country rocks belong to the metasedimentary Meguma Group. Tourmaline occurs within granitoid rocks ranging in composition from granodiorite to leuco-monzogranite, in pegmatite dykes, an aplite intrusion in gneissic rocks and as an accessory mineral in monzogranite.

3.1.4 Wedgeport Pluton

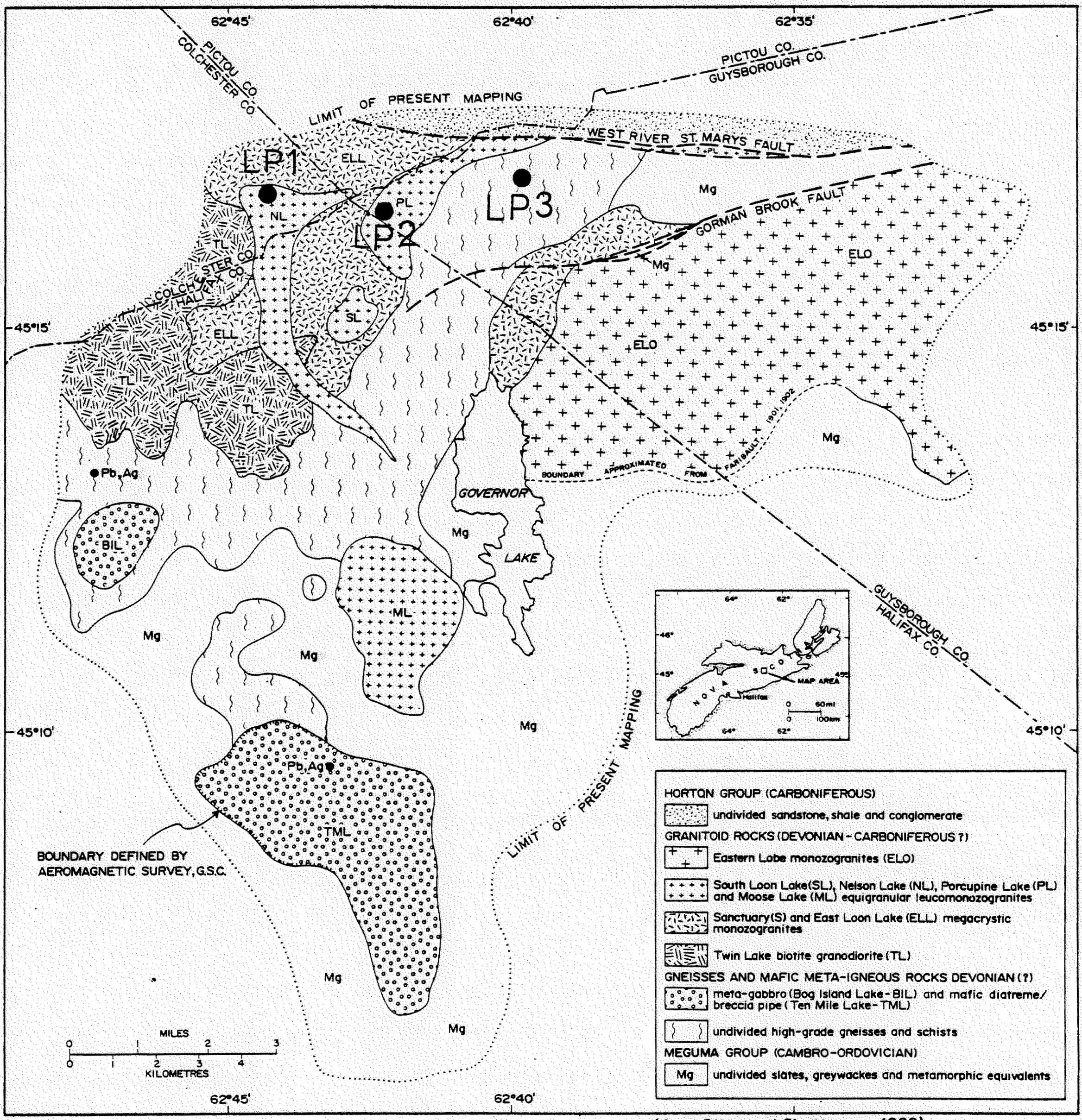
The Wedgeport Pluton is a monzogranitic intrusion located approximately 10 km south of Yarmouth, Nova Scotia (Figure 5). The pluton is in sharp contact with metasediments of the Goldenville Formation. Tin-tungsten mineralization is found

Figure 3. General geology of the Port Mouton Pluton showing sample locations PM1 and PM2. 1 = coarse-grained mafic biotite tonalite to coarse-grained mesocratic biotie-muscovite granodiorite, 4 = medium-grained biotite-muscovite granitiod to medium-grained mafic biotite granitiod, ? = uncertain boundary.



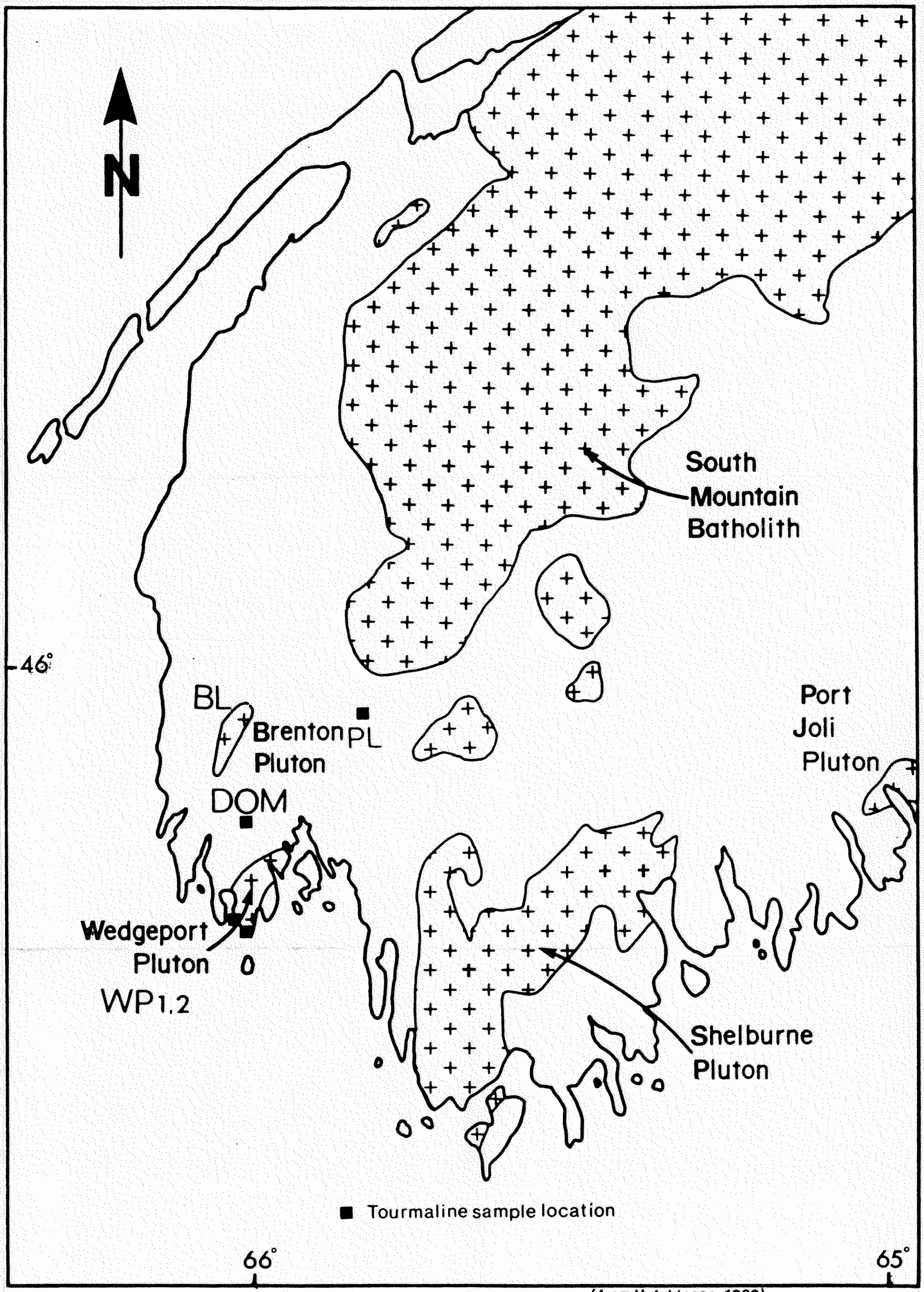
(Geology from Woodend, 1987)

Figure 4. Geological map of the Liscomb Complex showing sample locations LP1, LP2, and LP3.



(from Giles and Chatterjee, 1986)

<u>Figure 5.</u> General geology of Southwestern Nova Scotia showing sample locations BL, DOM, PL, and WP.



(from Hutchinson, 1982)

within quartz-tourmaline veins in the pluton which rarely contain minor amounts of sulfide, and within tourmalinized portions of the country rocks. Unmineralized pegmatites and greisen veins bearing abundant tourmaline occur within the pluton and in the surrounding country rocks (Wolfsen, 1983).

3.1.5 Dominique

Dominique is located north of Wedgeport (see Figure 5). Polymetallic vein-type mineralization occurs within metasediments of the Meguma Group. These veins are associated with strong chloritic alteration and contain garnet, muscovite, chlorite and rare tourmaline crystals occurring as small stumpy grains up to 0.5 centimeters in length (A.K. Chatterjee, pers. comm., 1987).

3.1.6 Brazil Lake

The Brazil Lake pegmatites are located approximately 25 kilometers northeast of Yarmouth (Figure 5). These spodumene-bearing pegmatites are believed to be igneous in origin, having been injected into fractures subparallel to regional schistosity of amphibolites and orthoquartzites of the White Rock Formation of Silurian or Ordivician age (Hutchinson, 1982). Hutchinson defined three distinct zones within these pegmatites. Tourmaline occurs in two generations within the pegmatite, schorl is found within aplitic albite and quartz-spodumene zones, elbaite (Li-rich member) is found within the microcline-quartz and quartz-spodumene zones. Tourmaline also occurs extensively as radiating clusters within the country rocks surrounding the pegmatite for up to 150 meters from the contact. This is believed to be the result of metasomatism during pegmatite emplacement (Hutchinson, 1982). Tourmaline analyzed from this occurrence is from the metasomatic aureole.

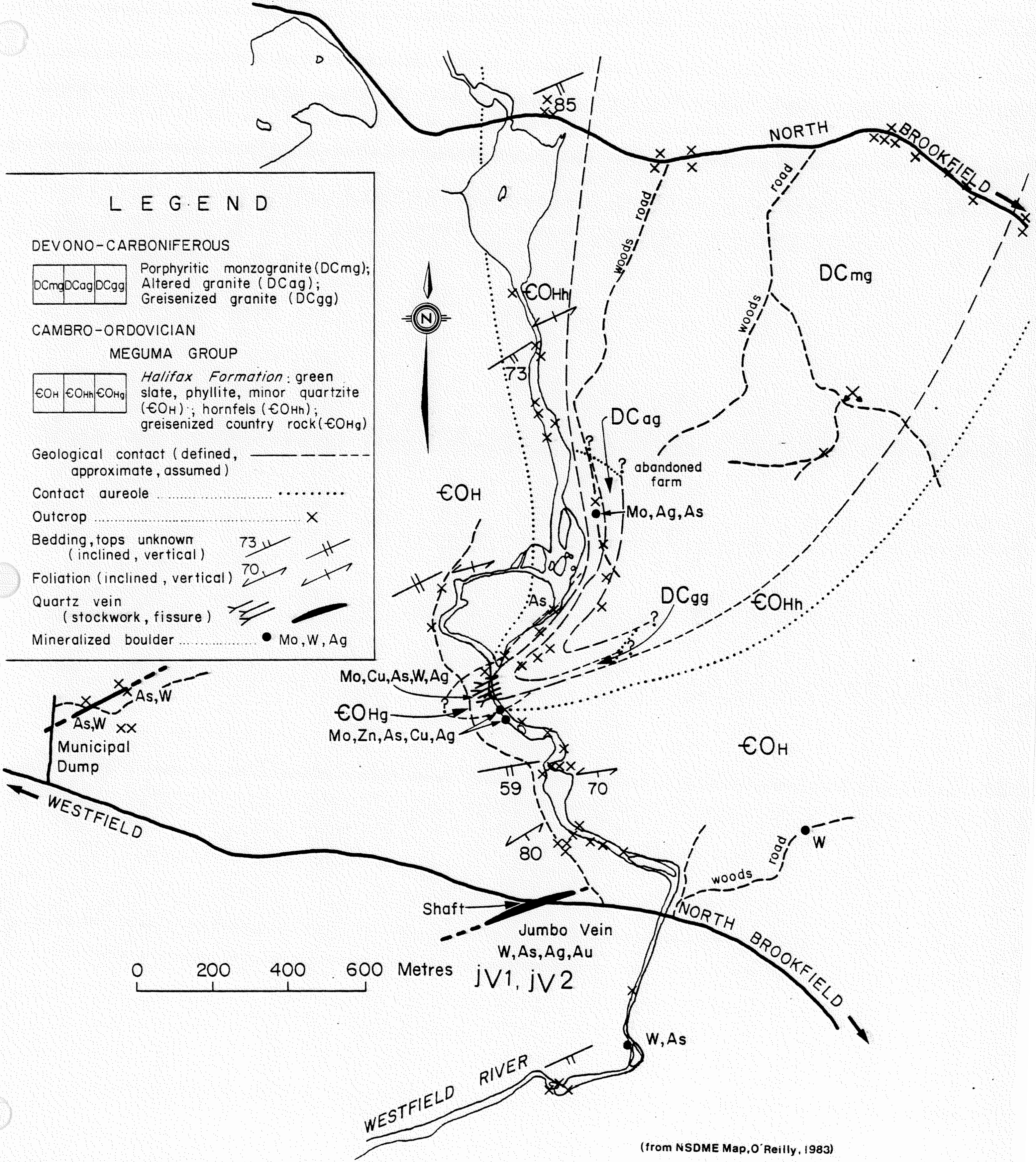
3.1.7 Pearl Lake

Pearl Lake is located approximately 25 kilometers northeast of Yarmouth (Figure 5). Mineralization occurs as polymetallic tin veins intruding interbedded slates and quartzites of the Meguma Group. These veins range in thickness from less than one centimeter to 8 centimeters in thickness and are characterized by quartz, carbonates, fluorite, garnet, sphene, chlorite, cassiterite and other opaque minerals (Chatterjee, 1980). Rarely, wall rocks are brecciated and infilled with sulfides, cassiterite and tourmaline. Smaller amounts of vein-filling occur. Tourmaline occurs as fine-grained needles (<1mm) and felted masses which are pale blue-green in colour.

3.1.8 Jumbo Vein

The Jumbo Vein deposit is located 0.9 km south of Caledonia, Nova Scotia (see Figure 6). Polymetallic mineralization consists of disseminated sulfides, including tin, and irregular development of wolframite and cassiterite within a quartz vein

Figure 6. General geology of the Brookfield Area (Jumbo Vein) showing sample locations JV1 and JV2.



(from NSDME Map, O'Reilly, 1983)

cutting Meguma Group metasediments. This vein ranges from less than one centimeter to 5 meters in width. Tourmaline occurs in felted masses or subhedral grains, beige to amber in colour, which are abundant along the quartz vein - wall rock contact or as radiating blades within the vein. This deposit is a rare example of tourmaline and fluorite existing in roughly equal proportions (A.K. Chatterjee, pers. comm., 1987).

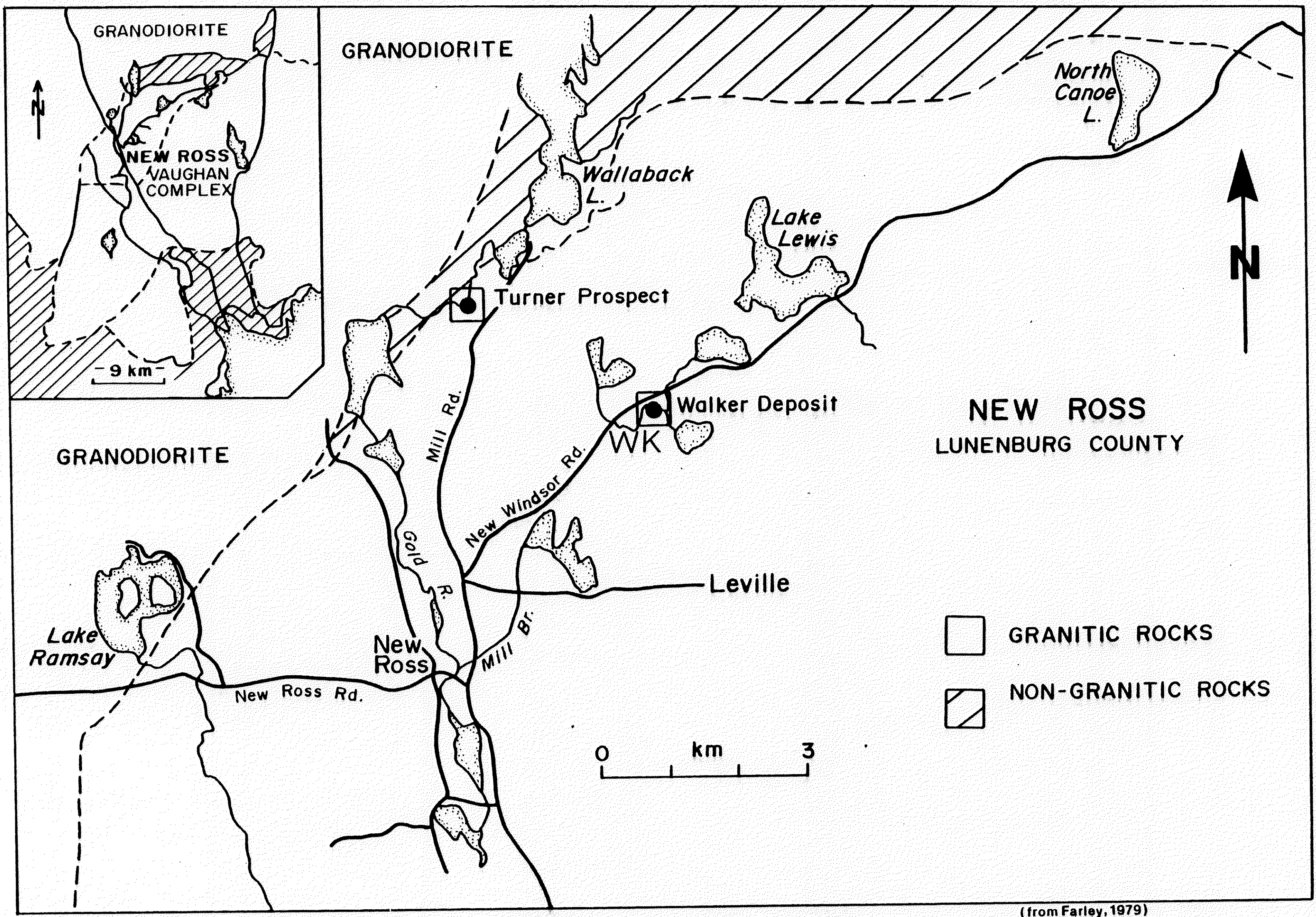
3.1.9 Walker Deposit

The Walker molybdenite deposit is located 6.4 km east of New Ross, within the New Ross-Vaughn Complex, a monzogranite pluton diapirically intruding the South Mountain Batholith (Figure 7). Molybdenite within this deposit is associated with aplite and pegmatite dykes emplaced in leucomonzogranite (Charest et al., 1985). Greisen selvages within pegmatite contain secondary mica, topaz and tourmaline. Fluorine, and less commonly, spinel occur as accessories, opaque minerals include wolframite, gahnite, cassiterite, uranite, bornite, mawsonite, tennantite, wittichenite, molybdenite, chalcopyrite and native bismuth (Farley, 1979).

3.1.10 Cochrane Hill

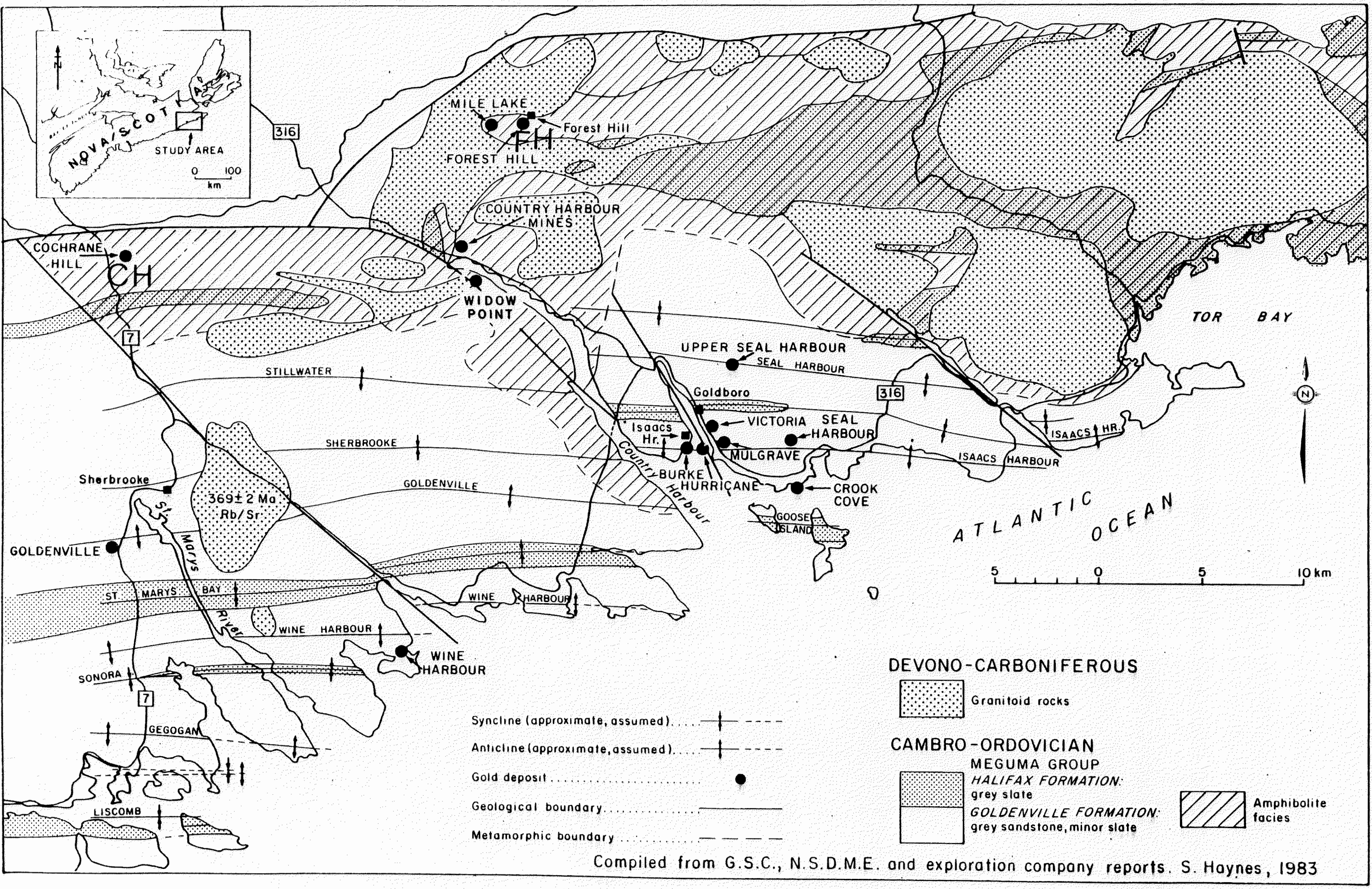
The Cochrane Hill gold deposit is located on the Cochrane Hill anticline in southeastern Nova Scotia (see Figure 8). This deposit is hosted by Cambro-Ordovician staurolite schist of the

<u>Figure 7.</u> General geology of the New Ross Area showing sample location WK.



(from Farley, 1979)

Figure 8. General geology and structure of the Cochrane Hill and Forest Hill Areas showing sample locations CH and FH.



Compiled from G.S.C., N.S.D.M.E. and exploration company reports. S. Haynes, 1983

Meguma Group. Gold and associated lead-zinc mineralization occur in arsenopyrite-rich, quartz-bearing veins, ranging in size from 3 to 30 centimeters, which have been classified into six types (A-F) by Smith (1982). Tourmaline occurs in "type E" andalusite-bearing pegmatoid veins assumed to be related to Devonian plutonism (Smith, 1983) both within veins and as a wall rock alteration product occurring irregularily adjacent to these veins. These tourmalines are characterized by zoning in many grains; cores are pale blue, rims are green-brown in colour in thin section.

3.1.11 Forest Hill

The Forest Hill gold deposit is located in central Guysborough County (see Figure 8). Mineralization occurs in quartz veins within metasedimentary rocks of the Meguma Group. Haynes (1983) recognized eleven quartz vein polytypes, four of which are known to contain gold. These include stratiform veins conformable to the schistosity of and confined to slate or schist horizons. Opaque minerals include pyrite, galena, sphalerite, arsenopyrite chalcopyrite and specularite. Tourmaline is found in zones of arsenopyrite-sericite-tourmaline wall rock alteration which parallels some of these veins. Veins range in size from less than 25 millimeters to more than 75 centimeters, some resemble pegmatitic segregation and appear as pods and lenses (A.K. Chatterjee, pers. comm., 1987). Crystals are faintly to strongly zoned from core to rim, and are amber/medium brown in colour, respectively.

3.2.0 AVALON ZONE

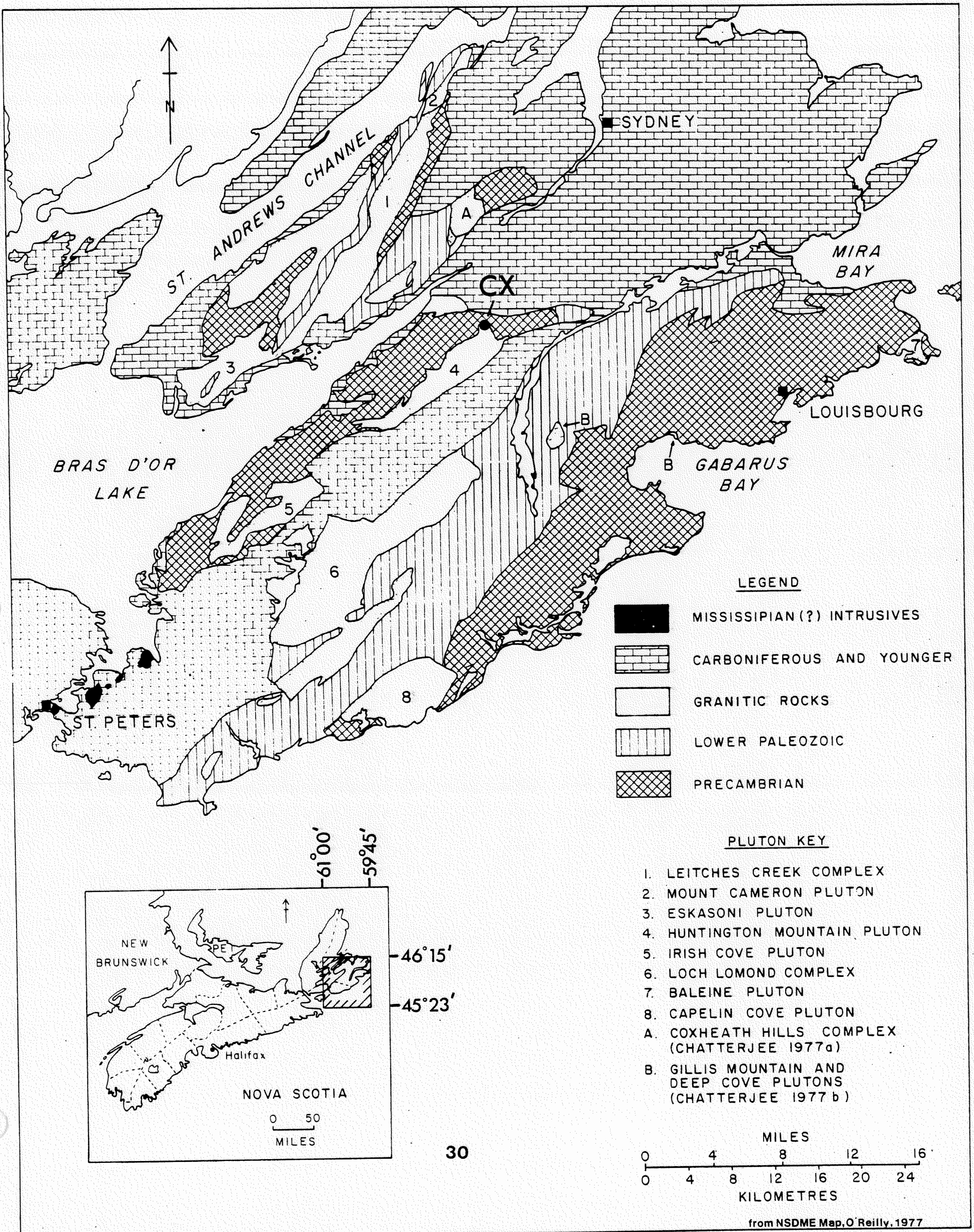
The Avalon Zone is comprised of the area north of the Chedabucto Fault. The zone consists of Precambrian age volcanic, sedimentary and metamorphic basement rocks intruded by Devonian age granitic rocks and overlain by sedmentary and minor volcanic rocks of Carboniferous to Early Cretaceous age (Roland, 1982).

3.2.1 Coxheath

The Coxheath copper-molybdenum deposit is located approximately 16 kilometers southwest of Sydney, Nova Scotia (see Figure 9). Sulfide mineralization occurs within the diorite-monzonite Coxheath Pluton. The following description of mineralization is based on a description of the deposit by Oldale (1966).

Fracture-associated mineralization occurs with two generations of quartz. The first generation occurs with some epidote cut by fractures containing chalcopyrite-bornite mineralization. Pyrite, magnetite and minor ilmenite and titanite are also present. Second generation quartz is associated with molybdenite mineralization. Gold is found associated with high grade copper mineralization (Oldale, 1966). Shear zone mineralization is characterized by stockwork veins and

Figure 9. General geology of the Coxheath Area showing sample location CX.



from NSDME Map, O'Reilly, 1977

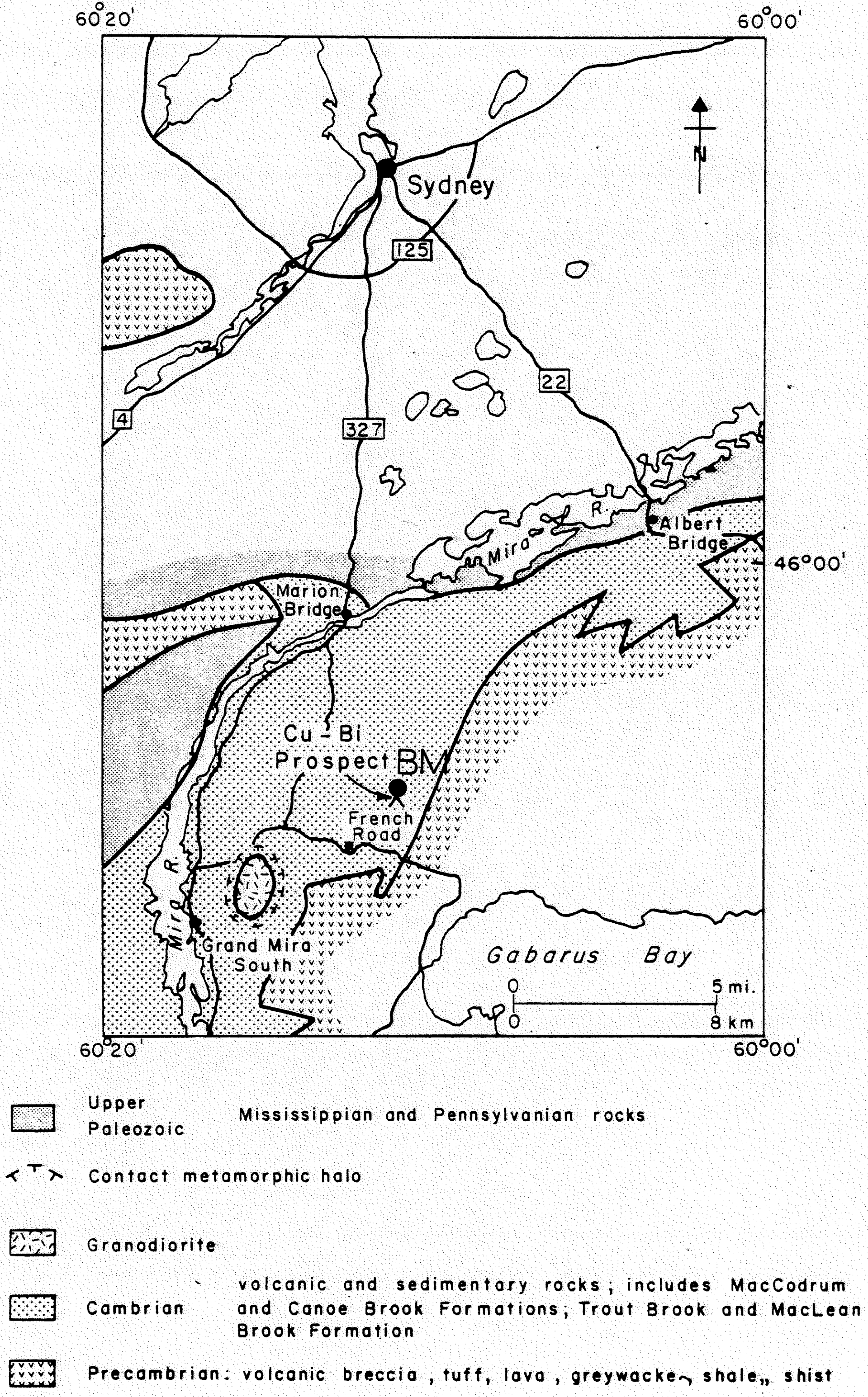
P.G.B

lenses of copper mineralization. Mineralized veins typically have quartz-tourmaline cores surrounded by pink albite. Sulfides occur in veinlets or blobs cutting the quartz-tourmaline rock, copper minerals are chalcopyrite and minor bornite. Pyrite, ilmenite and sphalerite are also present. Tourmaline associated with shear zone mineralization occurs as very fine grained (<0.5 millimeters) zoned crystals which are beige or blue-green in colour.

3.2.2 Blue Mountain

The Blue Mountain copper deposit is located approximately 27 kilometers south of Sydney, Cape Breton (see Figure 10). Mineralization occurs as replacements, disseminations and veinlets of massive to medium grained copper- and bismuth-bearing sulfides closely associated with calc-silicate felses and hornfelses of the Middle Cambrian Trout Brook Formation (Chatterjee, 1977; McDonald and Scott, 1980). Zoned, very fine-grained brown/blue-green tourmaline occurs in angular breccia fragments ranging in size from less than two millimeters to five centimeters in diameter, and as individual grains and felted masses in the matrix. Bisthmuthinite (Bi_2S_3) is closely associated with small tourmaline fragments and chalcopyrite is always associated with this rock type (Chatterjee, 1977).

Figure 10. General geology of the Blue Mountain Area showing sample location BM.



(from Chatterjee, 1977)

3.2.3 Corney Brook

Metamorphic tourmaline occurs in the Corney Brook Schist, located in the western highlands of Cape Breton Island at (see Figure 11). This is a folded and well-foliated schist containing biotite, andalusite, kyanite, staurolite and garnet which are concentrated in bands which define foliation. Tourmaline grains are one to three millimeters in size, occurring primarily in biotite-rich bands. Grains show strong but irregular zonation; cores are olive green, rims are lighter in colour. Grains are porphyroblastic and appear to have metamorphic overgrowths (rims), possibly of detrital tourmaline grains.

3.2.3 Corney Brook

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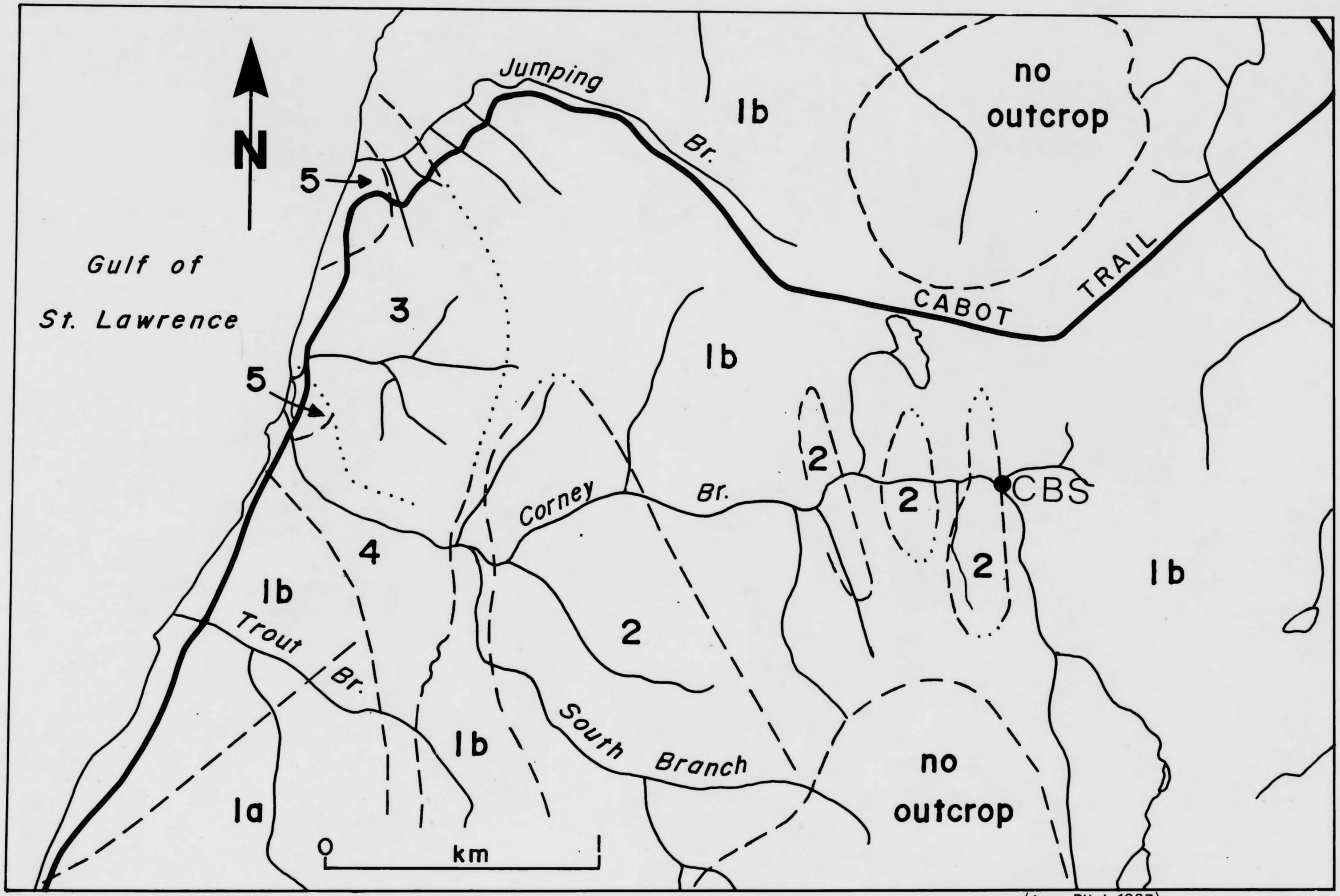
Figure 11. General geology of the Corney Brook Area, in Northeastern Cape Breton Island, showing sample location CBS.



(from Plint, 1987)

CHAPTER 4 : DISCUSSION

Tourmalines analyzed showed chemical variation among different paragenetic types; these include two main groups - those associated with granitic intrusions and those associated with economic mineralization. Granitic associations include the southeastern South Mountain Batholith, the Liscomb Pluton, the Port Mouton Pluton and the Wedgeport Pluton. Mineralized associations include Brazil Lake Be-Li pegmatite, Blue Mountain massive sulfide copper, Cochrane Hill vein gold, Coxheath porphyry-like copper-molybdenum, Dominique vein-type tin mineralization, Forest Hill vein gold, Caledonia vein type polymetallic, Pearl Lake vein and breccia tin, and Walker molybdenite deposits. The following is a summary of tourmaline chemistry for the occurrences of tourmaline in Nova Scotia.

Tourmaline analyses of weight percent SiO_2, TiO_2, Al_2O_3, FeO, MnO, MgO, Na_2O, CaO, and F were obtained by electron microprobe analysis. A description of analytical procedure is given in Appendix B, data obtained are given in Appendix C.

Ternary plots of Mg, Fe and Na expressed as cation proportions are given for granite-related and mineralization-related tourmalines in Figure 12 and Figure 13, respectively. From these plots it is apparent that large variations occur in Fe and Mg proportions, with little variation in Na. This is attributable to extensive solid solution between schorlitic (Fe-rich) and dravitic (Mg-rich) end members. By comparing the

<u>Figure 12.</u> Mg-Fe-Na plot for granite-related tourmaline samples. Dashed lines indicate Southeastern SMB pegmatite-related tourmalines. The solid line indicates all other granite-related samples.

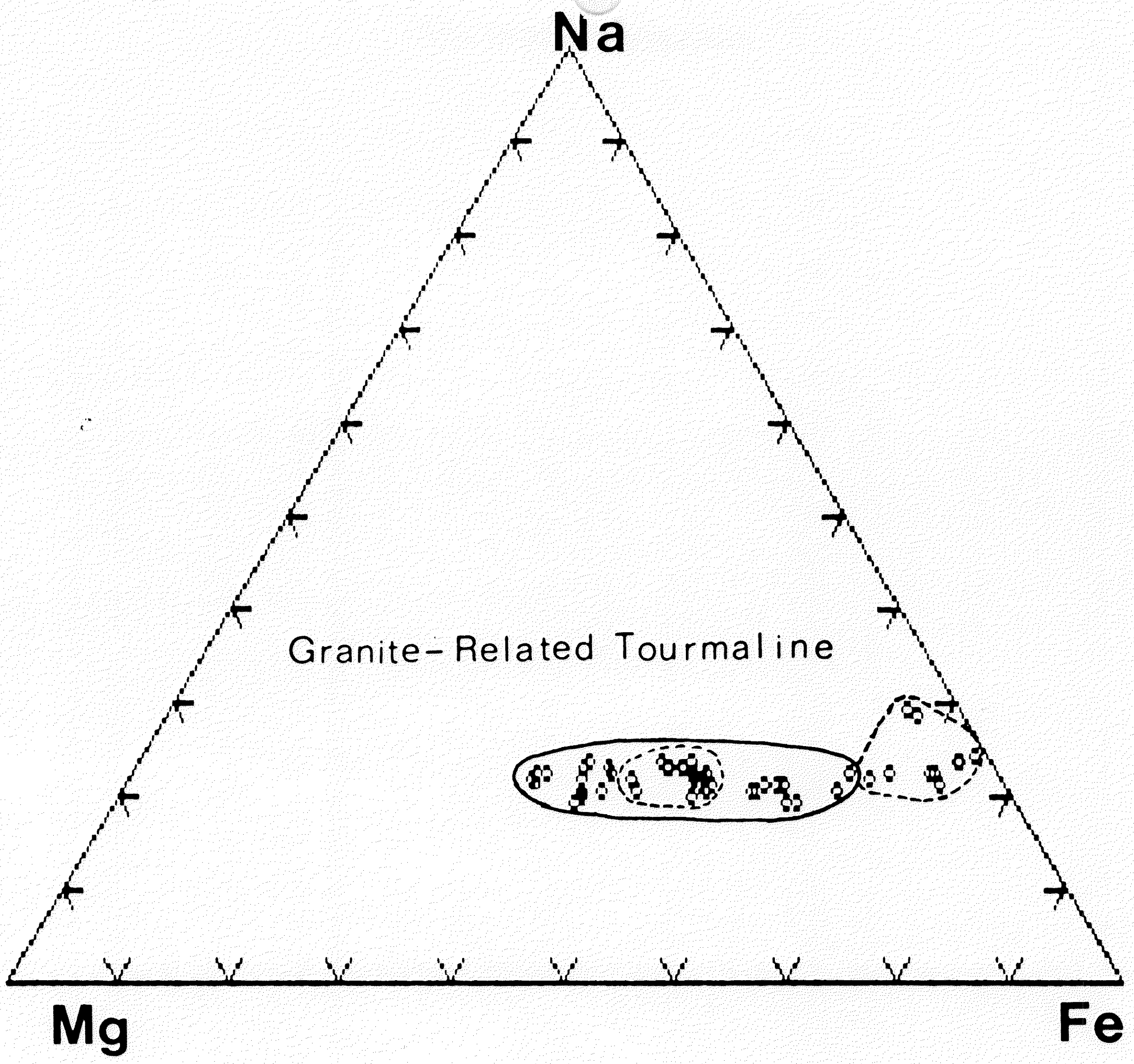
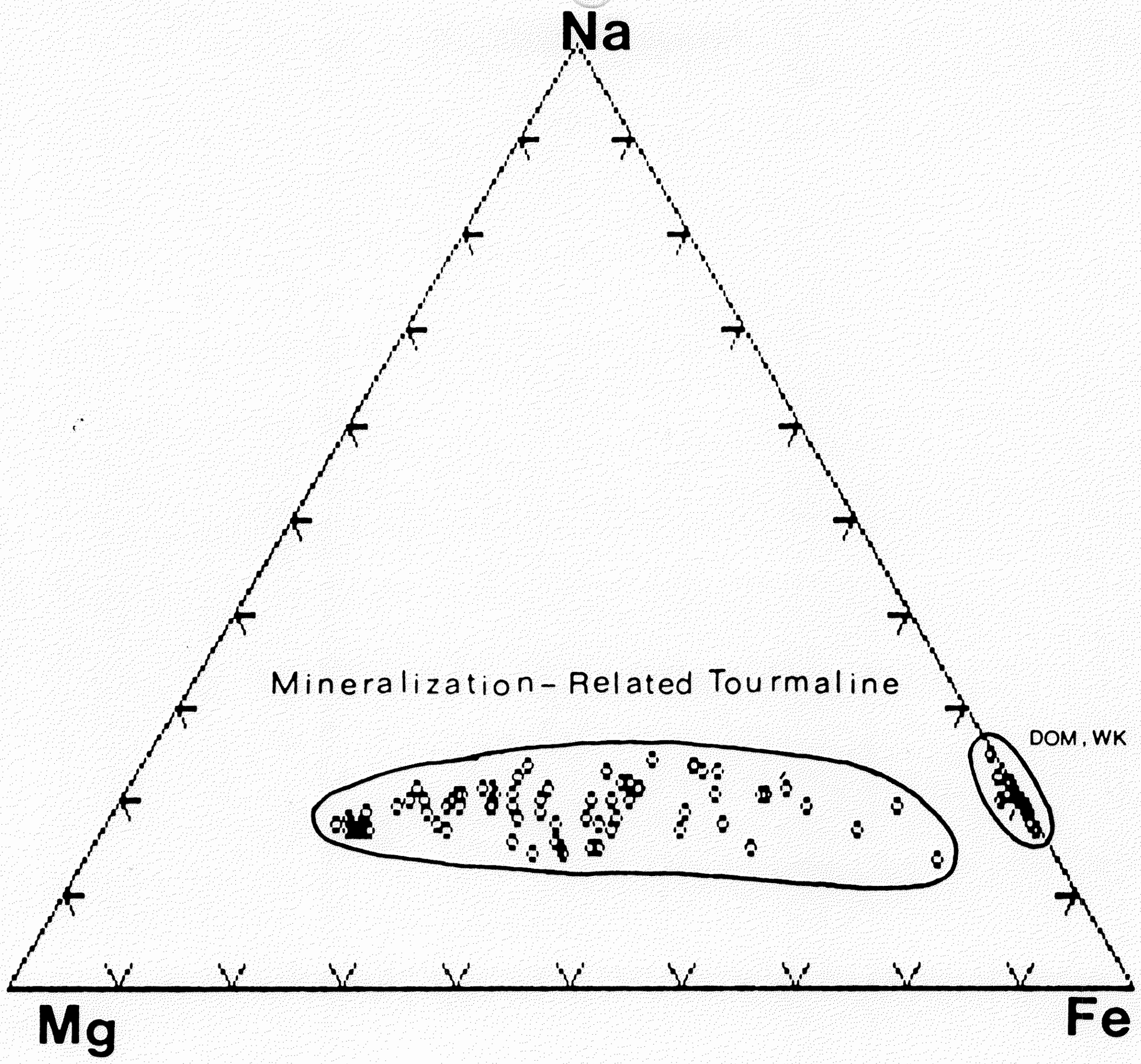

Na
Granite-Related Tourmaline
Mg
Fe

Figure 13. Mg-Fe-Na plot for mineralization-related tourmaline samples. Note distinct field defined by DOM (Dominique) and WK (Walker Deposit) samples.


Na
Mineralization- Related Tourmaline
DOM, WK
Mg
Fe

distributions of granite-related and mineralization-related tourmalines on these plots it can be seen that tourmalines related to mineralization are generally more Mg-rich and iron-poor than granite-related samples, however, significant overlap occurs between these two groups. All granite-related tourmaline fall within the mineralization-related tourmaline field. Minimums, maximums, means and standard deviations for each oxide and fluorine for all data are given in Table 1. In the following discussion "x" is equal to the mean value for all analyses for a given occurrence, "n" is equal to the number of analyses performed.

4.1.0 GRANITE-RELATED TOURMALINE

In general, tourmalines associated with granites, pegmatites and aplites are typically iron-rich (schorlitic) members of the schorl-dravite solution series (Neiva, 1974; Clarke, 1981, Benard et al., 1984 and others). This was found to be true for tourmalines associated with granitic intrusions in Nova Scotia. Variations in chemistry occur within this group, high iron (7.79-14.53% FeO), low magnesium (0.15-5.64% MgO) and calcium (0.00-0.97% CaO), and variable manganese (0.00-0.42% MnO) being typical. Sodium values were found to be relatively constant. Potassium was detected in very small amounts (less than 0.1 wt.%) in only two samples, these being from the South Mountain Batholith. This element may be present in other samples at concentrations below detection limits (approximately 0.07 wt.%).

	MINIMUM	MAXIMUM	MEAN	STD.DEV.
SiO_2	32.480	36.750	35.147	0.818
TiO_2	0.000	1.120	0.450	0.330
Al_2O_3	23.950	35.700	32.802	2.562
FeO	4.910	19.610	10.474	3.194
MnO	0.000	0.420	0.140	0.110
MgO	0.020	8.670	4.066	2.525
CaO	0.000	1.730	0.431	0.477
Na_2O	1.320	2.540	1.890	0.265
K_2O	0.000	0.080	0.003	0.014
B_2O_3	10.120	10.120	10.120	0.000
F	0.000	1.100	0.305	0.269
H_2O*	2.780	3.440	3.197	0.146
Total	–	–	99.025	–

* H_2O values were not obtained analytically, values used were calculated assuming F-O substitution.

<u>Table 1.</u> Statistics for granitic, metamorphic, and mineralization related tourmaline (all analyzed samples).

Minimums, maximums, means and standard deviations for each oxide and fluorine for all granite-related tourmaline data are given in Table 2 (SMB P = South Mountain Batholith pegmatites, SMB G = SMB greisen, unmineralized, SMB Q = SMB quartz-tourmaline veins, SMB M = SMB magmatic tourmaline). Mean values for each oxide and fluorine for individual granite-related tourmaline occurrences are given in Tables 3a and 3b. Figures 14, 16 and 19 show Ca-Mg, Mg-Al^{VI} and Ca-Al^{VI} plots for granite-related tourmalines. Values for Wedgeport Pluton and metamorphic tourmalines are common to all plots.

$^{11}B/^{10}B$ ratios in granite-related tourmalines range from 3.950-4.058 (x=4.013, n=14).

4.1.1 Southeastern South Mountain Batholith Pegmatites

Pegmatitic tourmalines from the eastern South Mountain Batholith are iron-enriched (x=12.025% FeO) relative to other granite-related samples. Iron shows high variability (FeO from 8.96-14.53%). These tourmalines are also magnesium-depleted (MgO from 0.15-3.84%), probably due to substitution of iron for this element. This substitution may also account for variability in iron and magnesium values.

Two distinct groups of pegmatite-associated tourmalines are present in the eastern South Mountain Batholith, suggesting that

	MINIMUM	MAXIMUM	MEAN	STD.DEV.
SiO_2	32.68	36.670	34.877	0.799
TiO_2	0.000	1.040	0.423	0.281
Al_2O_3	29.430	35.610	34.149	1.370
FeO	7.790	14.530	10.764	1.960
MnO	0.000	0.420	0.199	0.117
MgO	0.150	5.640	2.832	1.522
CaO	0.000	0.970	0.165	0.209
Na_2O	1.510	2.230	1.906	0.184
K_2O	0.000	0.080	0.008	0.022
B_2O_3	10.210	10.210	10.210	0.000
F	0.000	0.910	0.321	0.264
H_2O*	2.890	3.420	3.190	0.145
Total	-	-	98.954	-

* H_2O values were not obtained analytically, values used were calculated assuming F-O substitution.

Table 2. Statistics for granite-related tourmalines.

	SMB P	SMB G	SMB Q	SMB M	PMOUTON
SiO_2	34.399	35.967	34.783	34.528	34.967
TiO_2	0.479	0.295	0.610	0.550	0.382
Al_2O_3	34.674	34.622	33.517	34.365	34.927
FeO	12.025	8.167	9.862	10.363	9.502
MnO	0.250	0.105	0.122	0.243	0.270
MgO	1.416	4.552	3.968	3.080	3.618
CaO	0.103	0.073	0.173	0.153	0.143
Na_2O	1.875	1.815	2.037	1.915	1.962
K_2O	0.017	0.000	0.000	0.033	0.000
B_2O_3	10.120	10.120	10.120	10.120	10.120
F	0.436	0.128	0.460	0.173	0.165
H_2O*	3.118	3.333	3.128	3.258	3.250
Total	98.912	99.177	98.780	98.781	99.306
$^{11}B/^{10}B$	4.008	4.013	4.002	4.049	3.986
δ B	-38.7	-37.4	-38.4	-28.8	-43.8

* H_2O values were not obtained analytically, values used were calculated assuming F-O substitution.

Table 3a. Mean chemical and isotopic compositions for granite-related tourmaline occurrences.

	LP1	LP2	LP3	WP1	WP2
SiO_2	35.600	35.770	35.280	34.377	34.880
TiO_2	0.715	0.150	0.040	0.387	0.075
Al_2O_3	34.490	35.085	34.705	30.053	31.970
FeO	8.595	10.940	11.865	13.390	12.730
MnO	0.075	0.360	0.375	0.107	0.125
MgO	4.370	2.205	1.510	3.333	2.405
CaO	0.055	0.040	0.005	0.843	0.380
Na_2O	2.120	1.620	1.690	2.110	1.835
K_2O	0.000	0.000	0.000	0.000	0.000
B_2O_3	10.120	10.120	10.120	10.120	10.120
F	0.080	0.190	0.225	0.460	0.330
H_2O*	3.355	3.285	3.230	3.040	3.125
Total	99.575	99.765	99.045	98.220	98.975
$^{11}B/^{10}B$	4.018	4.011	4.025	3.997	3.950
∂ B	-36.2	-37.9	-34.5	-41.3	-52.3

* H_2O values were not obtained analytically, values used were calculated assuming F-O substitution.

Table 3b. Mean chemical and isotopic compositions for granite-related tourmaline occurrences.

two chemically different pegmatite types exist. The first group (SMB4, SMB12, SMB13) is characteristically calcium and magnesium enriched relative to the second (SMB3, SMB5, SMB7, SMB8 and SMB11). The second group has higher iron values than the first. SMB2 has a core composition representative of the first group and a rim composition similar to the composition of the second group. These groups plot in distinct clusters on Ca-Mg, Mg-Al and Ca-Al diagrams (see Figures 14, 16 and 19). The two groups do not show any correlation with location or granitoid rock type.

$^{11}B/^{10}B$ ratios in eastern South Mountain Batholith pegmatites range from 3.969-4.058 (x=4.008, n=16).

4.1.2 Southeastern South Mountain Batholith Magmatic Tourmaline

Magmatic tourmaline has been reported from France, Thailand and other localities by Manning and Pichavant (1984). These tourmalines were found to be schorlitic. The compositions of magmatic tourmalines of the southeastern South Mountain Batholith are similar to those of pegmatitic tourmalines of the latter, however, they are distinguishable from these by their higher magnesium (x=3.08% MgO, n=4), lower iron (x=10.363) and low fluorine content (x=0.173). More analyses are required to define the field representing this tourmaline association.

$^{11}B/^{10}B$ ratios for magmatic tourmaline from the southeastern South Mountain Batholith are 4.040 (SMB1) and 4.049 (SMB10).

4.1.3 Southeastern South Mountain Batholith Quartz-Tourmaline Veins

Tourmalines from quartz-tourmaline veins in the southeastern South Mountain Batholith are characteristically fluorine (x=0.460, n=6)- and titanium (x=0.610)-rich, having variable aluminum, iron and magnesium. These tourmalines have the highest sodium values of any granite-related tourmalines studied (x=2.037). They are distinguishable from tourmalines associated with pegmatites in the southeastern South Mountain Batholith by their lower iron (x=9.862) and manganese (x=0.122) values.

$^{11}B/^{10}B$ ratios in eastern South Mountain Batholith quartz-tourmaline veins range from 3.977-4.019 (x=4.002, n=6).

4.1.4 Southeastern South Mountain Batholith Greisen

These tourmalines may be distinguished from other southeastern South Mountain Batholith tourmalines by their relatively low iron (x=8.167, n=6) and high magnesium (x=4.552) content. Chemical compositions are distinct from those of tourmalines associated with mineralized greisens (Walker Deposit), showing a reverse trend for iron and magnesium.

The $^{11}B/^{10}B$ ratio for this sample is 4.013.

4.1.5 Liscomb Pluton

Generally, tourmalines from the Liscomb Pluton show generally high iron and manganese values; these are comparable to the South Mountain Batholith values for tourmalines associated with pegmatites, but have lower fluorine content. ^{11}B/^{10}B ratios range from 4.011-4.025 (x=4.018, n=3). Three samples were analyzed from the pluton, each representing a different tourmaline paragenesis. LP1 represents a magmatic tourmaline, LP2 a pegmatitic associated tourmaline, and LP3 an aplite-associated tourmaline. These types show distinct chemical compositions.

Titanium, magnesium and calcium values for these samples decrease in the sequence LP1→LP2→LP3. The reverse is true for iron, manganese and fluorine. Sodium content for LP1 is high (x=2.120, n=2) relative to LP2 and LP3. Similar trends were also found for granites, aplites and pegmatites from Northern Portugal (Neiva, 1974). ^{11}B/^{10}B values do not define a regular trend for this sequence.

4.1.6 Port Mouton Pluton

Tourmaline in the Port Mouton Pluton is associated with pegmatite dykes within the pluton and intruding the country rock. Chemical compositions are similar to tourmalines occurring in South Mountain Batholith pegmatites, but have lower fluorine (x=0.165, n=6) and iron (x=9.502) contents. These tourmalines are also distinct from the Liscomb Pluton pegmatite-associated sample, having lower concentrations of titanium (x=0.382), iron (x=9.502) and manganese (x=0.270), and higher magnesium content (x=3.618).

$^{11}B/^{10}B$ values range from 3.962-4.035 (x=3.986, n=2).

4.1.7 Wedgeport Pluton

Tourmalines from the Wedgeport Pluton, which include pegmatitic (WP1) and greisenized veins (WP2) within the Pluton, exhibiting unique chemical characteristics in comparison with other granite-associated tourmalines. The values obtained plot within distinct fields on Mg-Al, Ca-Al, and Ca-Mg binary plots, having trends inclined to those for other granite-related tourmalines (see Figures 14, 16 and 19). WP2 is similar to WP1 in iron, manganese and sodium content, but has distinctly lower sodium and fluorine values. WP2 is dissimilar from southeastern South Mountain Batholith greisen-related tourmaline, having higher iron (x=12.730) and lower magnesium (x=2.405) values.

These samples are typified by their high iron and fluorine content, very high calcium values (x=0.658) in comparison with other granite-related tourmalines, and low aluminum content (x=30.820). This is particularly true for WP1. The chemical composition of these tourmalines resembles that of mineralization-related tourmalines more than those of granite-related equivalents.

$^{11}B/^{10}B$ values for these samples are 3.95 and 3.997.

4.2.0 METAMORPHIC TOURMALINE

4.2.1 Corney Brook Schist

These tourmalines, found within biotite-rich layers of the Corney Brook Schist, are dravitic in composition and have a high magnesium content (x=6.075, n=4). Most grains show optical zoning, having dark khaki-green cores and lighter khaki-green rims; analyses reveal strong chemical zoning. Zoned tourmalines of the same colour from Thailand were also found to be chemically zoned, magnesium decreases from core to rim, titanium increases from core to rim (Manning, 1982). Chemical analyses of the Corney Brook Schist tourmalines show increasing magnesium, calcium and titanium from core to rim, iron and sodium decrease from core to rim. Dramatic core to rim zoning is probably attributable to metamorphic overgrowth of detrital tourmaline. Increasing pressure, temperature, and activity of fluids which accompany regional metamorphism cause the recrystallization of clay minerals and release boron, which is locally trapped by the crystallization of dravite about detrital tourmaline nuclei. This crystallization is complete at greenschist facies in carbonate rocks (Reynolds, R.C. Jr., 1965); the Corney Brook

Schist has undergone amphibolite-grade metamorphism (H.E. Plint, pers. comm., 1986), thus this mechanism of tourmaline growth is feasible.

No boron isotope data were obtained for this sample owing to the difficulty of tourmaline separation attributable to grain-size.

4.3.0 MINERALIZATION-RELATED TOURMALINE

Generally, mineralization-related tourmalines are magnesium (x=4.756, n=76) rich and having a wider range of values for this element relative to granite-related tourmalines. Iron values are moderate (x=10.462) and calcium (x=0.586) and manganese (x=0.105) poor. Some of these tourmalines are aluminum depleted.

Minimums, maximums, means and standard deviations for each oxide and fluorine for all mineralization-related tourmaline data are given in Table 4. Mean values for each oxide and fluorine for individual mineralization-related tourmaline occurrences are given in Tables 5a and 5b. Figures 15, 17 and 20 show Ca-Mg, Mg-Al^{VI} and Ca-Al^{VI} plots for mineralization-related tourmalines. Figures 18 and 21 show Mg-Al_{tot} and Ca-Al_{tot} plots for samples CX and BM. Values for Wedgeport Pluton and metamorphic tourmalines are common to all plots.

	MINIMUM	MAXIMUM	MEAN	STD.DEV.
SiO_2	32.480	36.750	35.316	0.810
TiO_2	0.000	1.120	0.460	0.364
Al_2O_3	23.950	35.700	31.905	2.825
FeO	4.910	19.610	10.462	3.777
MnO	0.000	0.310	0.105	0.090
MgO	0.020	8.670	4.756	2.771
CaO	0.000	1.730	0.586	0.529
Na_2O	1.320	2.540	1.883	0.312
K_2O	0.000	0.000	0.000	0.000
B_2O_3	10.120	10.120	10.120	0.000
F	0.000	1.100	0.303	0.277
H_2O*	2.78	3.440	3.196	0.150
Total	-	-	99.092	-

* H_2O values were not obtained analytically, values used were calculated assuming F-O substitution.

Table 4. Statistics for tourmaline associated with mineralization.

	BRAZILL	BLUEMTN	C HILL	CXHEATH	DOMINIQ
SiO_2	35.989	34.944	36.203	35.030	34.950
TiO_2	0.606	0.621	0.688	0.414	0.100
Al_2O_3	32.854	26.966	34.125	28.678	33.620
FeO	5.323	12.828	6.515	13.655	15.150
MnO	0.055	0.055	0.054	0.046	0.260
MgO	7.989	6.485	6.126	5.180	0.055
CaO	1.033	1.345	0.509	1.030	0.040
Na_2O	1.752	1.970	1.814	2.006	1.585
K_2O	0.000	0.000	0.000	0.000	0.000
B_2O_3	10.120	10.210	10.120	10.120	10.120
F	0.377	0.696	0.361	0.465	0.158
H_2O*	3.153	3.006	3.215	3.079	3.298
Total	99.251	99.036	99.730	99.703	99.336
$^{11}B/^{10}B$	3.990	4.036	4.045	4.016	N.D.
δ B	-42.9	-32.1	-29.7	-36.7	N.D.

* H_2O values were not obtained analytically, values used were calculated assuming F-O substitution.

Table 5a. Mean chemical and isotopic compositions for mineralization-related tourmaline occurrences.

	F-HILL	JUMBO V	PEARL-L	WALKER	CORNEYB
SiO_2	35.339	35.048	35.800	34.467	35.233
TiO_2	0.613	0.624	0.231	0.058	0.593
Al_2O_3	30.889	32.235	34.243	34.015	33.353
FeO	10.587	10.275	7.221	15.073	7.135
MnO	0.078	0.159	0.064	0.250	0.065
MgO	5.287	4.193	5.165	0.071	6.075
CaO	0.327	0.394	0.466	0.024	0.750
Na_2O	2.257	1.931	1.738	1.635	1.825
K_2O	0.000	0.000	0.000	0.000	0.000
B_2O_3	10.120	10.120	10.120	10.120	10.120
F	0.142	0.084	0.113	0.100	0.165
H_2O*	3.346	3.219	3.369	3.239	3.135
Total	98.985	98.282	98.530	99.052	98.639
$^{11}B/^{10}B$	4.010	4.029	3.976	4.013	3.995
δ B	-38.1	-33.6	-46.8	-37.4	-41.7

* H_2O values were not obtained analytically, values used were calculated assuming F-O substitution.

Figure 5b. Mean chemical and isotopic compositions for mineralization-related and metamorphic-related tourmaline occurrences.

4.3.1 Brazil Lake

Tourmalines from this location are magnesium-rich (x=7.989, n=10 - dravitic) and have low iron content (x=5.323). Magnesium values for this sample are the highest of all samples analyzed. High compositional variability for these tourmalines may be attributed to drammatic differences in core and rim compositions. Cores and rims plot in distinct fields on Ca-Mg, Mg-Al and Ca-Al plots (see Figures 15, 17 and 20). Cores have high Al and low Mg and Ca relative to rims compositions.

The ^{11}B/^{10}B ratio determined for this location was determined to be 4.010.

4.3.2 Blue Mountain

These tourmalines associated with massive sulfide mineralization are characteristically depleted in aluminum (x=26.966, n=8), having vacancies in the Al^{IV} site. They are also both iron- (x=12.828) and magnesium- (x=6.485) rich. This feature is unique to Blue Mountain and Coxheath tourmalines. Variations in composition from core to rim are irregular.

The ^{11}B/^{10}B value for this location was determined to be 4.029.

4.3.3 Cochrane Hill

Tourmalines from Cochrane Hill gold deposit are intermediate in composition between schorl and dravite and are characterized by high titanium content (x=0.688, n=8). Compositions are similar to those for Brazil Lake, with the exception of a lower calcium content for Cochrane Hill tourmalines. No regular compositional variation from core to rim is present.

The $^{11}B/^{10}B$ ratio for this sample was determined to be 3.976.

4.3.4 Coxheath

Systematically low aluminum (x=28.678, n=8) and high iron content (x=13.655) are typical of tourmalines from Coxheath. Compositions of these tourmalines closely resemble those for Blue Mountain, and are also variable and irregular.

The $^{11}B/^{10}B$ ratio for this sample was determined to be 4.013.

4.3.5 Dominique

Tourmalines from this deposit are remarkably similar to those from the Walker Deposit. Both are characterized by high iron (x=15.150, n=2) and Mn (x=0.260) as well as their deep indigo blue colour. Magnesium (x=0.055), calcium (x=0.040) and titanium (x=0.100) values are extremely low, fluorine values are high (x=0.355). As can be seen from Figure 13 and others, Dominique and Walker deposits plot in a distinct field on composition diagrams.

The $^{11}B/^{10}B$ ratio for this sample was determined to be 3.995.

4.3.6 Forest Hill

Tourmalines from Forest Hill show low aluminum values (x=30.889, n=12). These tourmalines are not similar in composition to those from the Cochrane Hill deposit, however, they are similar to the Jumbo Vein tourmaline compositions. Compositions are very variable; the only apparent trend from core to rim is increasing titanium content.

The $^{11}B/^{10}B$ ratio for this sample was determined to be 3.990.

4.3.7 Jumbo Vein

Jumbo Vein tourmalines have high Mn (x=0.159, n=8) and moderate iron content (x=10.275). Fluorine content is not high despite the known association of fluorite with this deposit. This low value be a result of the incorporation of most fluorine present into fluorite. No regular zoning trends are seen in these tourmalines.

The $^{11}B/^{10}B$ ratio for this sample was determined to be 4.019.

4.3.8 Pearl Lake

Tourmalines from Pearl Lake are of a composition intermediate between schorl and dravite. These tourmalines have low iron (x=7.221, n=8), titanium (x=0.231) and fluorine values (x=0.113). Compositionally, these tourmalines are similar to those of the Corney Brook Schist. No regular core to rim zonation is evident.

The $^{11}B/^{10}B$ ratio for this sample was determined to be 4.045.

4.3.9 Walker Molybdenite Deposit

Walker Deposit tourmalines are characterized by thier extremely high iron (x=15.073, n=11) and manganese (x=0.250) values and proportionately low magnesium (x=0.071), titanium (x=0.058) and calcium (x=0.024) values. This composition is very similar to the composition for Dominique tourmalines. No regular core to rim variations are observed.

The $^{11}B/^{10}B$ ratio for this sample was determined to be 4.016.

4.4.0 BORON ISOTOPIC DATA

δ values for boron were determined as $\delta\ ^{11}B_{sample} = [(\{^{11}B/^{10}B_{sample} * 0.959\} - 4.000)/4.000]*1000$ permil. Values for all tourmaline samples were found to be strongly negative, -26.6 to -52.3 permil, isotopic values ranged from 3.950 to 4.058. These values are in agreement with those determined by other workers (Agyei and McMullen, 1968; Shima, 1963 cited in Dietrich, 1985; Esikov and Esikova, 1974 cited in Dietrich, 1985). It is apparent that little isotopic variation has occurred among these samples, and that variation which does occur is not apparently systematic (see Figure 22).

SMBM	|	LP1	□
SMBP	+	LP2	X
SMBQ	—	LP3	■
SMBG	\	WP1	△
PM1	○	WP2	▼
PM2	●	CBS	/

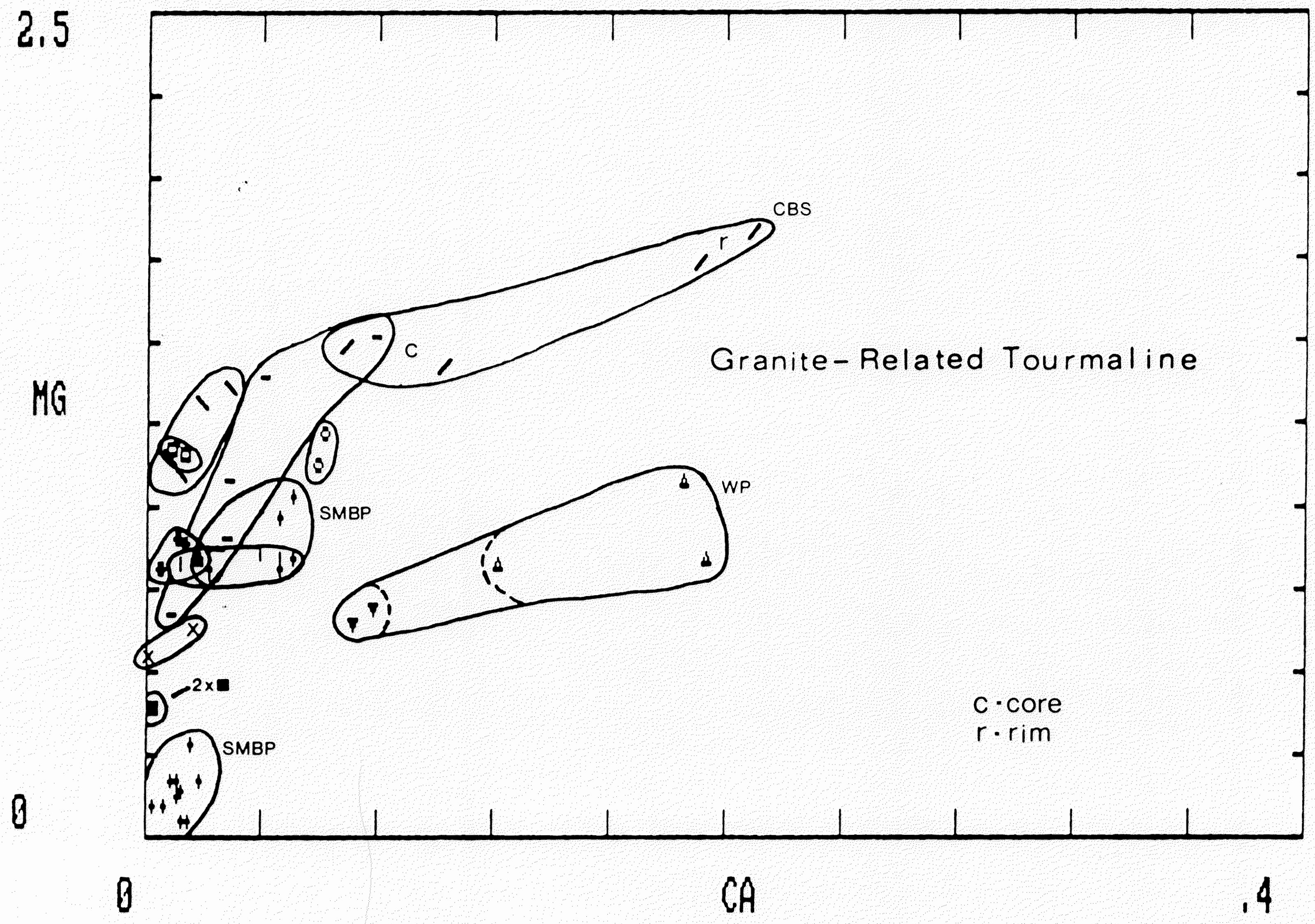
Key for granite-related
tourmaline plots.

BL	—	BM	+
CH	○	CX	X
FH	●	JV	△
WP1	□	PL	▼
WP2	■	DOM	\
CBS	/	WK	|

Key for mineralization-related
tourmaline plots.

* Note that all plotted values are given as cations per formula unit. Also, samples WP1, WP2 and CBS are on all plots except 18 and 21.

Figure 14. Ca-Mg plot for granite-related and metamorphic tourmaline.


Granite-Related Tourmaline
2.5
MG
0
0
CA
.4
CBS
r
c
WP
SMBP
SMBP
2x
c·core
r·rim

<u>Figure 15.</u> Ca-Mg plot for mineralization-related and metamorphic tourmaline.

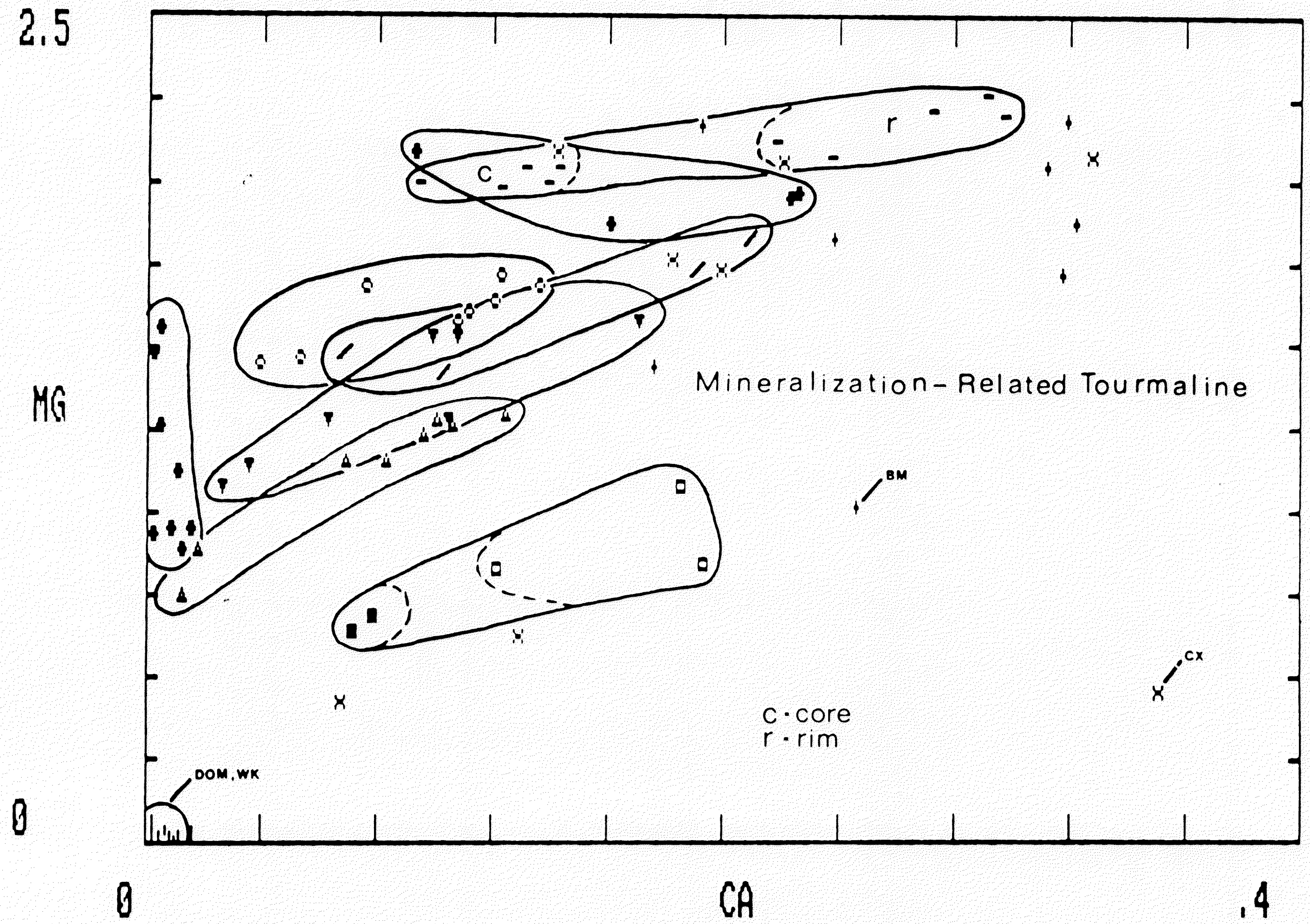

2.5
MG
0
0
CA
.4
Mineralization- Related Tourmaline
c
r
BM
CX
DOM, WK
c · core
r · rim

Figure 16. Mg-Al^{VI} plot for granite-related and metamorphic tourmaline.

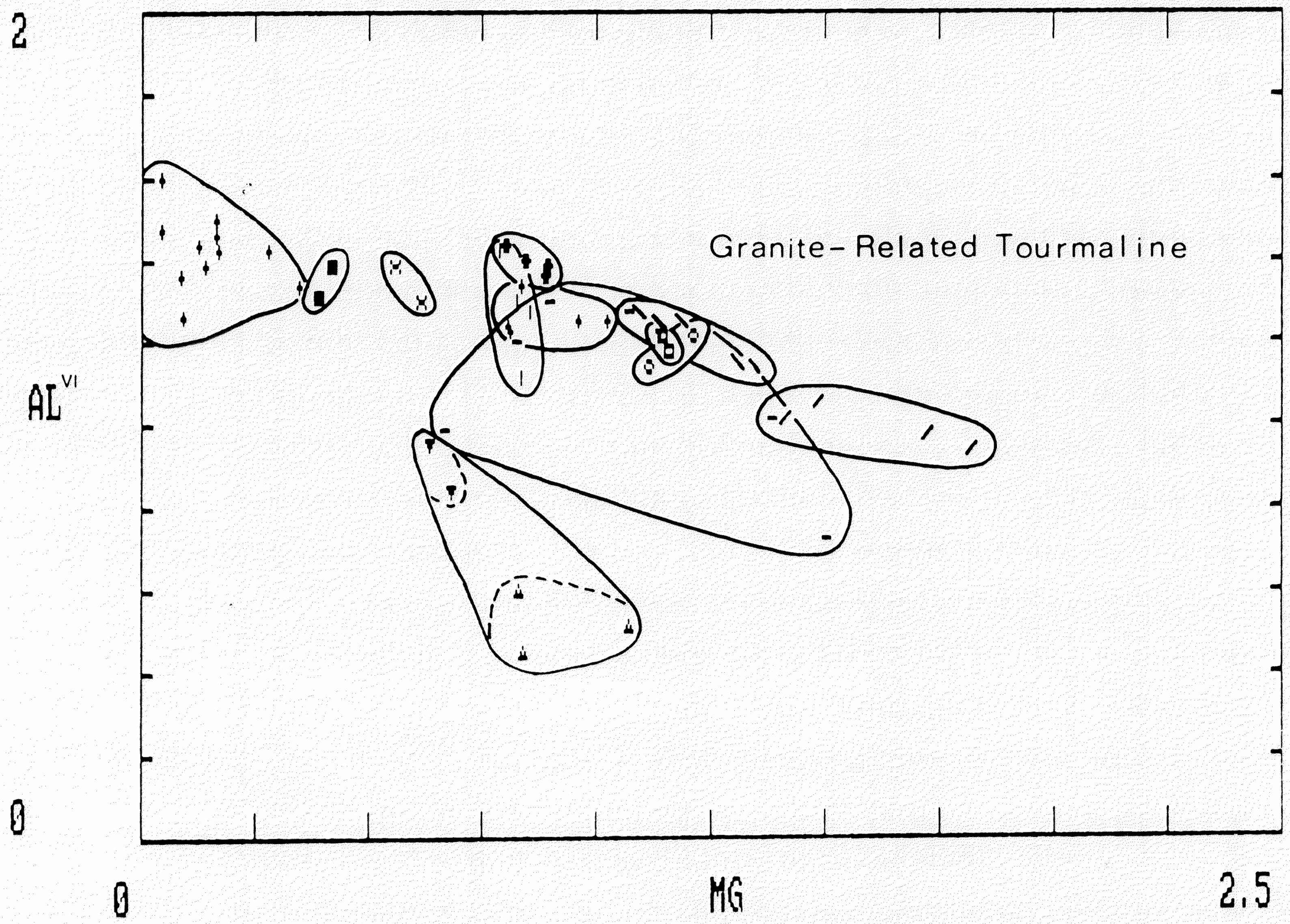

Granite-Related Tourmaline
2
0
AL^VI
0
MG
2.5

Figure 17. Mg-Al^{VI} plot for mineralization-related and metamorphic tourmaline.

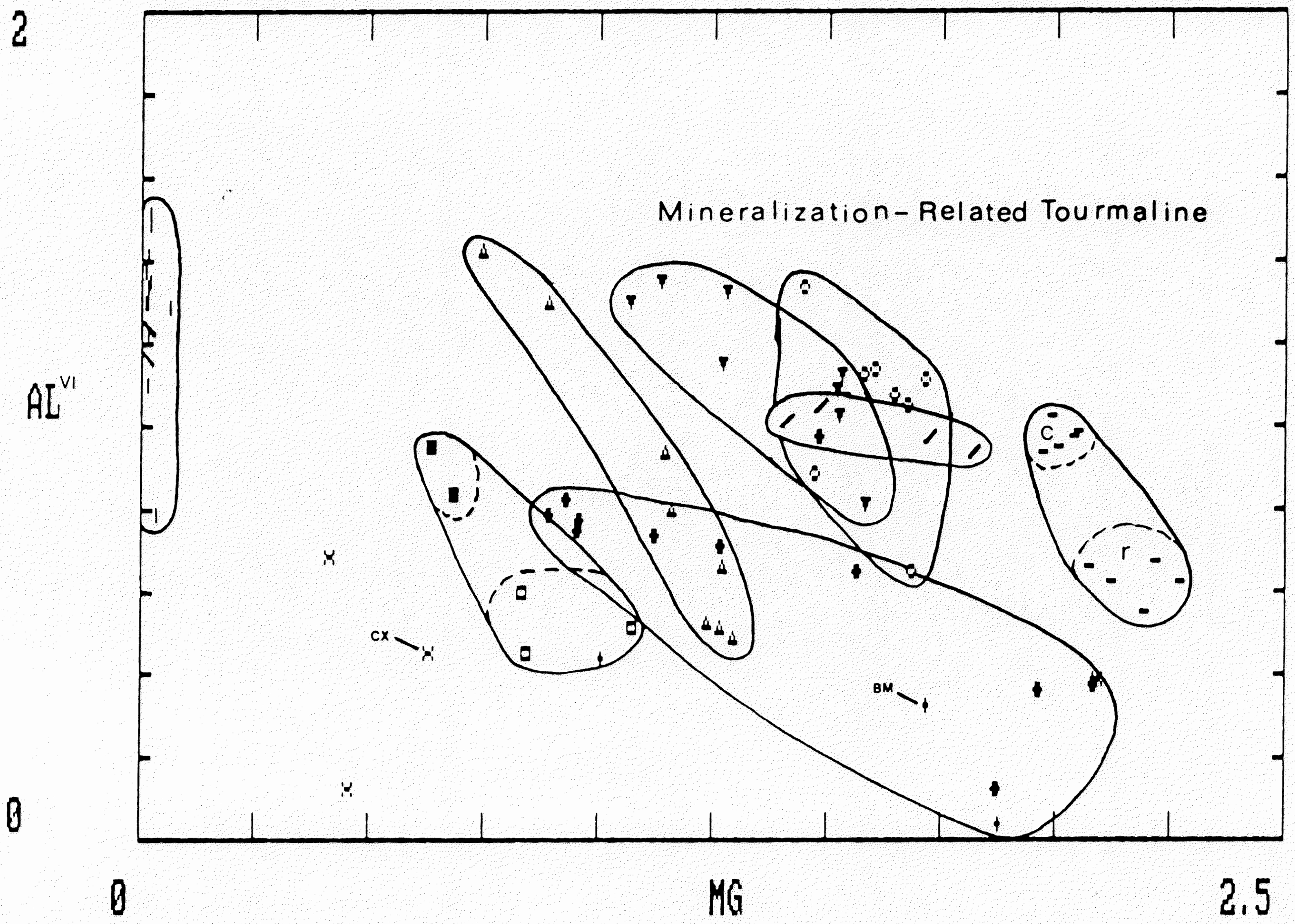

Mineralization- Related Tourmaline
2
0
AL^{VI}
0
MG
2.5
CX
BM
C
r

Figure 18. Mg-Al_{tot} plot for samples CX and BM mineralization-related tourmaline.

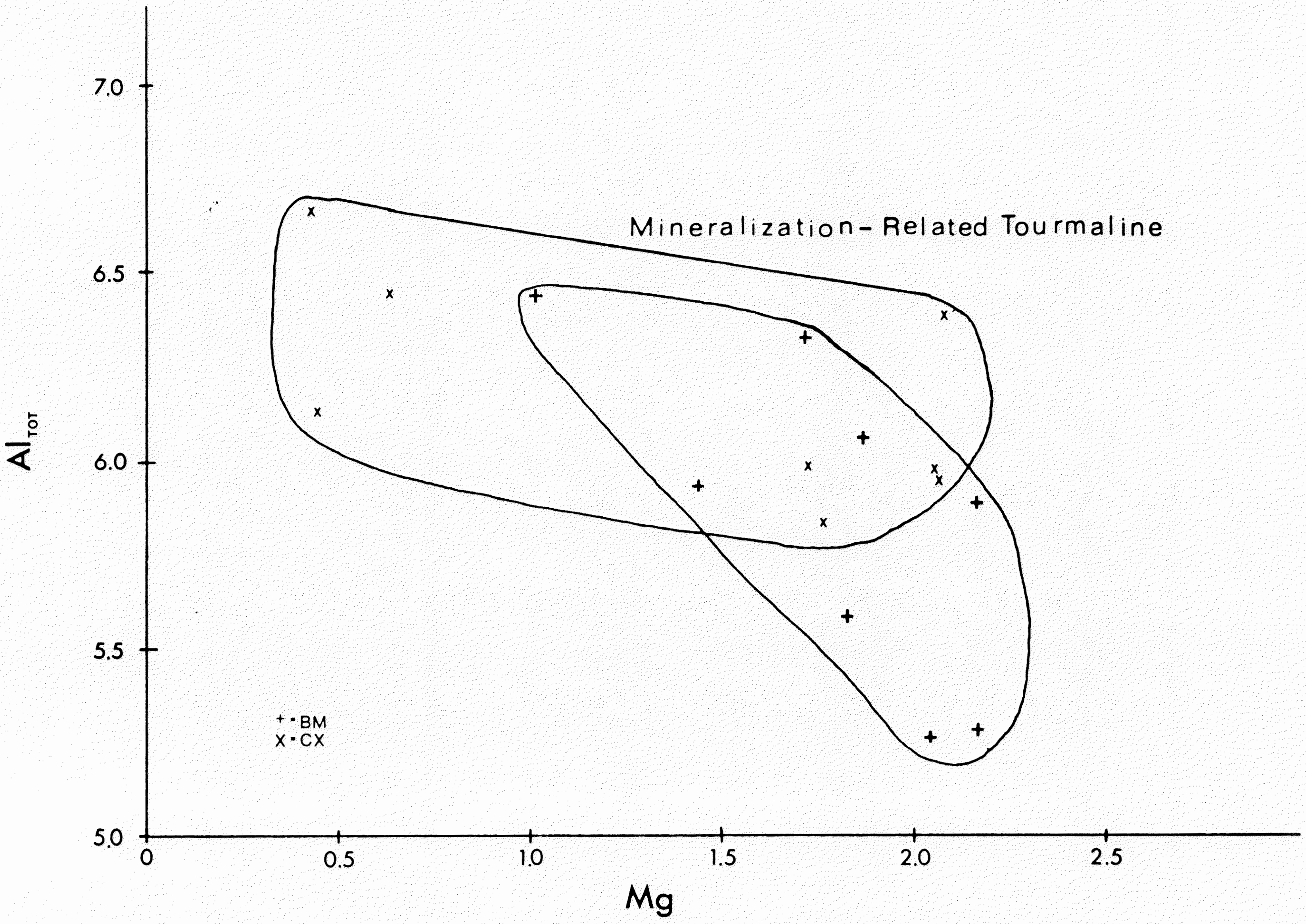

Mineralization- Related Tourmaline
Al_TOT
7.0
6.5
6.0
5.5
5.0
0
0.5
1.0
1.5
2.0
2.5
Mg
+ - BM
X - CX

Figure 19. Ca-Al^{VI} plot for granite-related and metamorphic tourmaline.

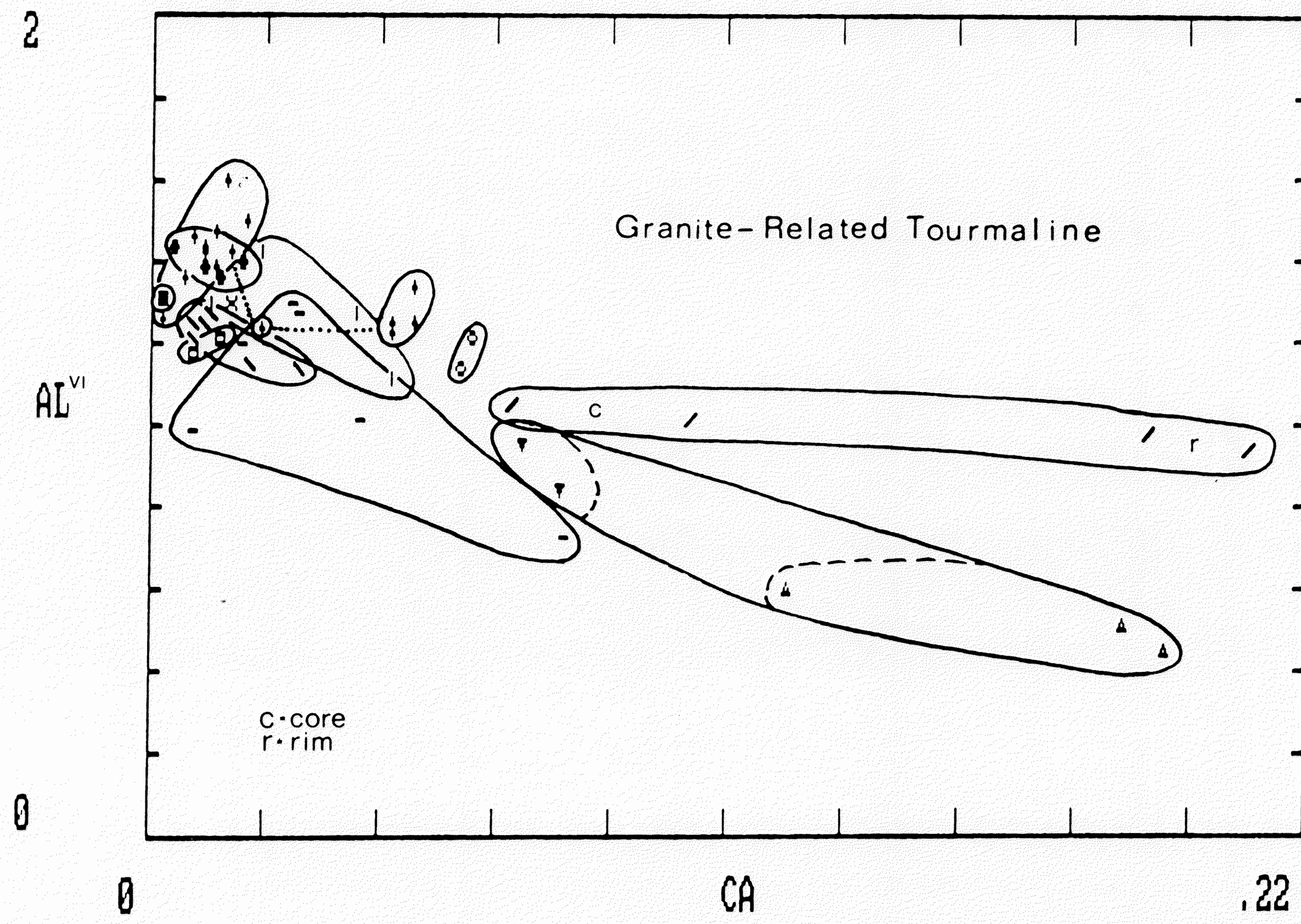
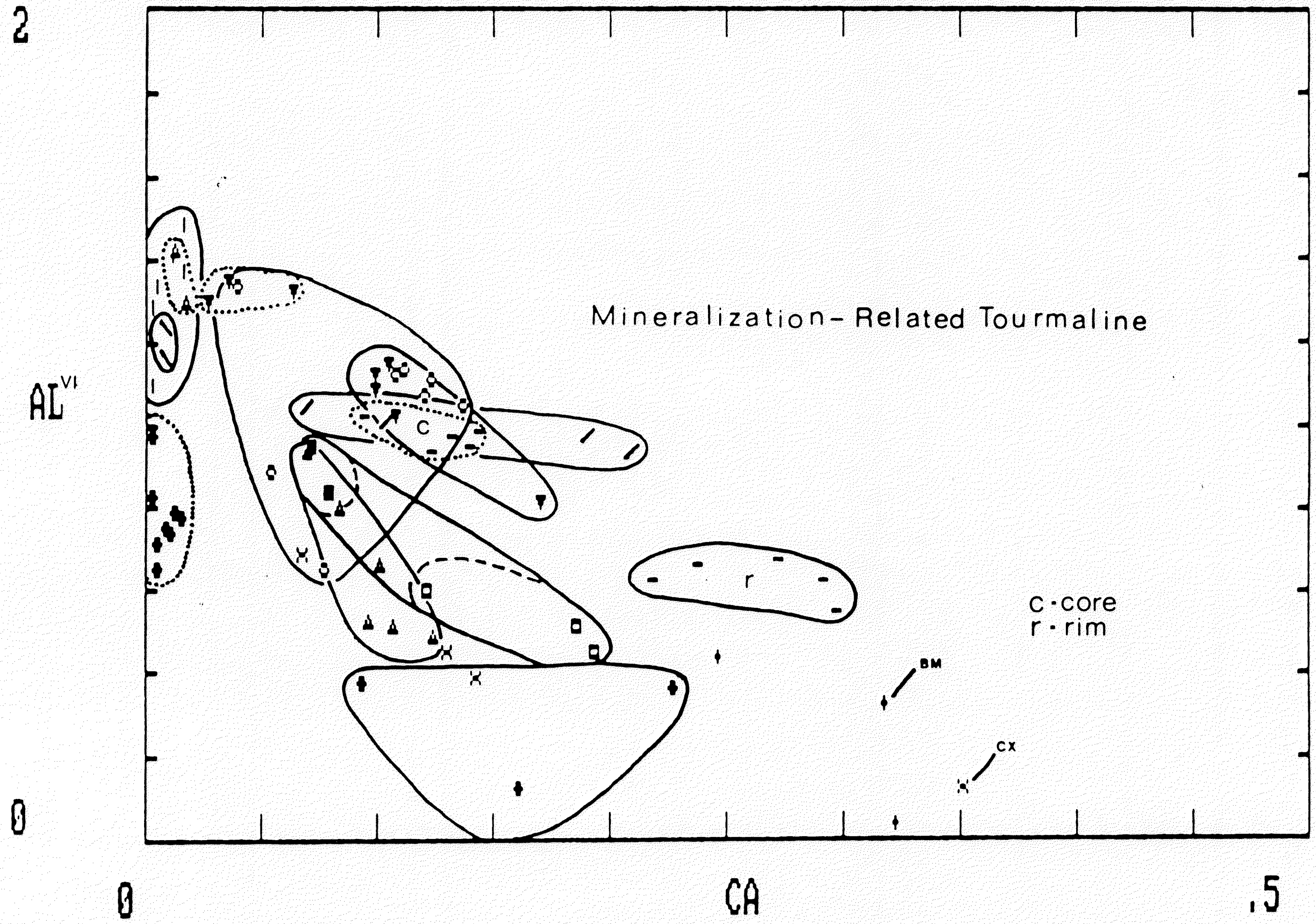

2
AL^VI
0
Granite-Related Tourmaline
c
r
c-core
r-rim
0
CA
.22

Figure 20. Ca-Al^{VI} plot for mineralization-related and metamorphic tourmaline.


2
0
AL^VI
0
CA
.5
Mineralization- Related Tourmaline
c
r
c · core
r · rim
BM
CX

<u>Figure 21.</u> Ca-Al_{tot} plot for samples BM and CX mineralization-related tourmaline.

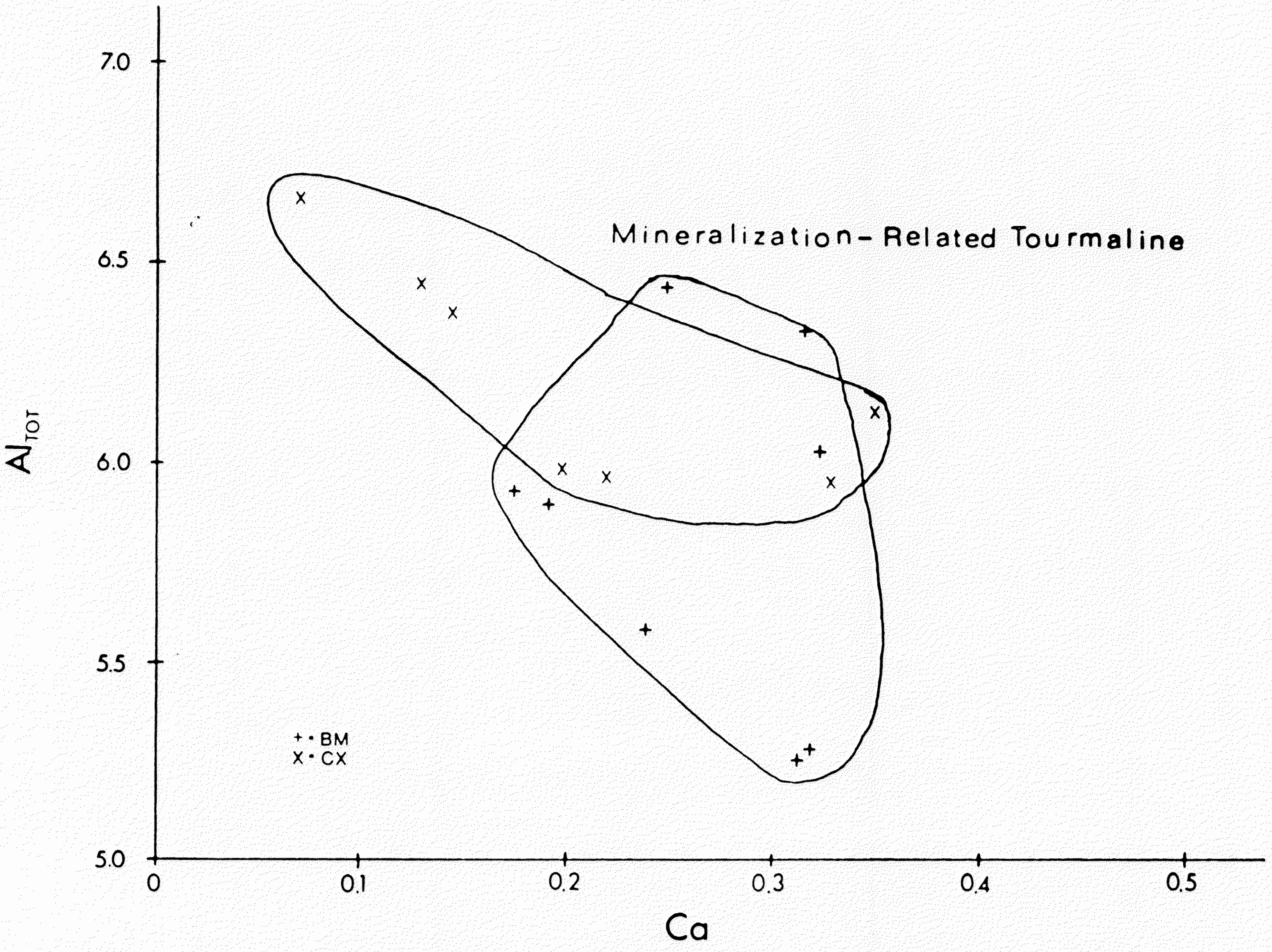
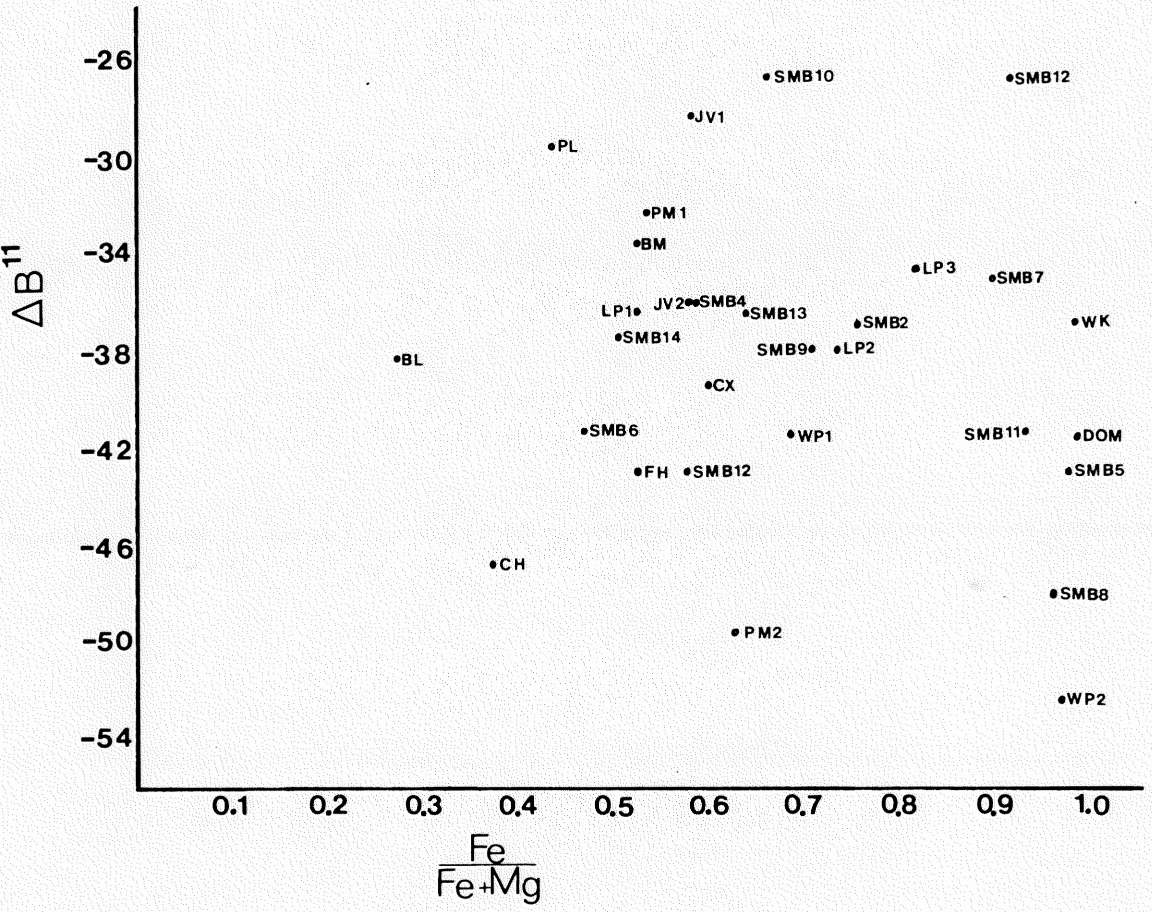

Mineralization- Related Tourmaline
Al_{TOT}
7.0
6.5
6.0
5.5
5.0
0
0.1
0.2
0.3
0.4
0.5
Ca
+ - BM
X - CX

Figure 22. $\delta^{11}B$-Fe/(Fe+Mg) plot for all tourmaline samples. No correlation is evident.


ΔB^{11}
-26
-30
-34
-38
-42
-46
-50
-54
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
$\frac{Fe}{Fe+Mg}$
SMB10
SMB12
JV1
PL
PM1
BM
LP3
SMB7
JV2
SMB4
LP1
SMB13
SMB2
WK
SMB14
SMB9
LP2
BL
CX
SMB6
WP1
SMB11
DOM
FH
SMB12
SMB5
CH
SMB8
PM2
WP2

CHAPTER 5 : CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDIES

5.1.0 CONCLUSIONS

Tourmalines from unmineralized granite-related occurrences overlap significantly with tourmalines from mineralized associations in chemical composition, however, specific occurrence types may be distinguished both between and within these two groups.

The chemical composition of tourmalines from unmineralized granite-related associations are characteristically schorlitic, having FeO values up to 14.53 wt.% and not less than 7.79 wt.%. MgO values are generally less than 5 wt.%, however, some samples showed slightly higher values.

Tourmalines associated with mineralization are characteristically magnesium rich, having a mean magnesium value of 4.756 ± 2.771, as compared with a mean magnesium value of 2.832 ± 1.522 for granite-related tourmalines. Exceptions are the Dominique and Walker deposits. The tourmalines associated with these locations have very distinct chemical compositions, characterized by very low magnesium and calcium content and extreme iron content. In fact, these tourmalines are almost pure schorl end-members.

All tourmalines studied indicated a relationship between Fe and Mg. These elements are inversely related by the schorl-dravite solid solution series.

Individual occurrence types typically show similar chemical compositions for tourmaline, however, some of these, such as Cochrane Hill and Forest Hill gold deposits, have dissimilar tourmaline compositions despite equivalent elemental associations.

Boron isotope values for granite-related tourmalines were also determined for comparison among tourmaline occurrences. No significant variations or relationships were found. From this it must be concluded that if boron isotopic variations do occur in tourmaline, these must be smaller than can be presently detected.

5.2.0 SUGGESTIONS FOR FURTHER STUDIES

More analyses are required in order to better define the fields outlined by binary plots of tourmaline compositions. Further statistical analysis would also be useful in defining composition-occurrence relationships. Smaller scale studies of occurrences would be useful in better defining the relationships seen in these tourmalines, including further investigation of chemical compositions by trace element analysis and further isotopic studies.

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APPENDIX A: NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY SAMPLE REFERENCES

Appendix A

Sample	Locality	NSDME (or other) Sample No.
BL	Brazil Lake	TR2
BM	Blue Mountain	K10-7539
CBS	Corney Brook	85-737a-1 (Plint)
CH	Cochrane Hill	F04-262
DOM	Dominique	20016 7016
FH	Forest Hill	GZ-6017
JV	Jumbo Vein	85-21854
	"	85-21855
	"	85-21856
	"	85-2299
LP1	Liscomb Pluton	LG060
LP2	"	108
LP3	"	LG120
PL	Pearl Lake	TR8
PM1	Port Mouton	PM1 (Clarke)
PM2	"	TR3
SMB1	South Mtn. Bath.	A16-3002-01
SMB2	"	A16-3017-01
SMB3	"	A16-3035-01
SMB4	"	D12-0010
SMB5	"	D12-0033-3
SMB6	"	D12-0039-3
SMB7	"	D12-0048-2
SMB8	"	D12-0059-4
SMB9	"	D12-0114-3
SMB10	"	D12-3082-01
SMB11	"	D12-3120-03
SMB12	"	D13-2014
SMB13	"	D13-2041
SMB14	"	D13-2090-05
WK	Walker Deposit	TR7
WP1	Wedgeport Pluton	20016-7027
WP2	"	20016-7015

APPENDIX B : ANALYTICAL PROCEDURE

APPENDIX B : ANALYTICAL PROCEDURE

Electron Microprobe (Crystal Chemistry) Data

Tourmaline samples were quantitatively analyzed for SiO2, TiO2, Al2O3, FeO, MnO, MgO, Na2O, CaO, and F by the Jeol 733 Superprobe wave-length dispersive electron microprobe at Dalhousie University, Halifax, Nova Scotia. An accelerating voltage of 15 KeV, a beam current of 5 nA and a beam diameter of approximately one micron were used. Data were acquired for 40 seconds or until a standard deviation of less than 0.4% was achieved. Analyses were obtained from standard polished thin sections and polished grain mounts, carbon coated before analysis. Two grains were analyzed from each slide, each grain was analyzed at both core and rim. Data were corrected using the Tracor Northern ZAF matrix correction procedure.

Analyses for B_2O_3 were performed using an accelerating voltage of 7KeV and a beam current of 100 nA. Other factors remained constant. CN-1, a synthetic borosilicate glass, was used as a standard for boron. Values obtained were very variable and often significantly low. The low values and high degree of variability in these values resulted in the abandonment of boron analysis owing to time limitations. Fe2O3, H2O, and LiO2 were not determined by microprobe analysis.

Standards used were natural silicate minerals - "JADITE" (jadeite) for silica and aluminum; "KK" (Kakanui Kaersutite) for sodium, calcium, titanium, magnesium and potassium; Mn_2O_3 for manganese; "GARNET 12442" for iron; and "FAPAT" (fluorine apatite) for fluorine. A tourmaline acquired from John Slack (ORN-401) was used as a control. This control grain was analyzed before and after every set of analyzes, each consisting of four slides. The mean values for analyses of ORN-401 are compared with those values obtained by Slack and Taylor (1984) in Table B below. Slack and Taylor considered their SiO2 and Al_2O3 values to be too high, possibly due to long counting times. This accounts for the difference in values obtained for these elements. Large differences in FeO and MgO values are probably due to chemical inhomogeneity within the crystal. Although analyses of this standard are dissimilar from those obtained by Taylor and Slack, they showed little variation.

Accuracy and Precision

Dunham and Wilkinson (1978) have estimated the analytical precision for microprobe analyses for both major and minor elements. Major elements are accurate (within one standard deviation) to within approximately 2% (relative, for example, 0.52% for 50 wt.% SiO2). Minor elements (those comprising less than 1%) are accurate to within approximately 5-10%.

OXIDE	ORN-401	ORN-401*
SiO_2	34.174	36.150
TiO_2	0.672	0.740
Al_2O_3	30.826	33.320
FeO	16.582	12.470
MgO	0.786	3.060
CaO	0.375	0.500
Na_2O	2.310	2.490
K_2O	0.001	N.D.
TOTAL	85.762	88.730

* Sample ORN-401 analysis determined by Slack and Taylor (1984).

Table B. Mean oxide weight percent values for 25 microprobe analyses of sample ORN-401.

Structural Formula Calculations

Calculations of structural formulae were based on 31 (O,OH,F) primarily according to the procedure used by Deer et al. (1966), however, H_2O values were also calculated. Calculated values for the procedure used here and for the procedure used by Deer et al. were compared and found to be satisfactory. Microprobe data and structural formulae are presented in Appendix C.

Boron Isotope Data

Thirty-five samples were analyzed for boron isotopes by D. Conrad Gregoire at the Geological Survey of Canada in Ottawa. Samples underwent carbon fusion followed by an ion-exchange separation of boron from major matrix elements. Mass discrimination effects were compensated for using NBS SRM 951 (optically analyzed boric acid) as a calibration standard.

For each sample a single fusion was done and three separate determinations acquired using inductively coupled plasma - mass spectrometry instrumentation. $^{11}B/^{10}B$ ratios and ∂B values are given in Appendix B. Precision for $^{11}B/^{1}0B$ values is given as the standard deviation for these three determinations. ∂B values are a measure of the isotope shift, calculated relative to values obtained for the $^{11}B/^{10}B$ value of NASS-1 NRC (National Research Council) reference seawater. A precision of + 7.7 is obtained for ∂B values using an isotope ratio of 4.000 and an average precision of + 0.016.

APPENDIX C: MICROPROBE ANALYSES AND BORON ISOTOPE DATA

	BL1	BL1	BL1	BL1	BL2	BL2	BL2	BL2
	1	1	2	2	1	1	1	1
	CORE	RIM	CORE	RIM	COREA	COREB	RIMA	RIMB
	BRAZILL	BRAZILL	BRAZILL	BRAZILL	BRAZILL	BRAZILL	BRAZILL	BRAZILL
SIO2	36.44	35.54	36.64	35.75	36.68	36.39	36.03	35.33
TIO2	0.25	1.06	0.12	1.04	0.39	0.08	1.01	0.97
AL2O3	34.13	31.48	33.95	32.05	33.82	34.03	32.17	31.74
FEO	5.02	5.66	4.91	5.11	5.16	5.00	5.62	6.36
MNO	0.02	0.09	0.00	0.02	0.06	0.08	0.06	0.06
MGO	7.91	8.33	7.84	8.67	7.60	7.61	7.91	8.04
CAO	0.77	1.57	0.70	1.55	0.66	0.50	1.26	1.15
NA2O	1.68	1.73	1.73	1.82	1.80	1.60	1.69	2.07
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.20	0.34	0.00	0.18	0.08	0.07	0.23	0.13
TOTAL	96.54	95.92	96.01	96.31	96.37	95.48	96.10	95.97
O-F	0.08	0.14	0.00	0.08	0.03	0.03	0.10	0.05
H_2O	3.57	3.43	3.68	3.55	3.64	3.62	3.52	3.55
TOTAL	100.00	99.16	99.69	99.76	99.96	99.06	99.48	99.44
SI	5.949	5.922	5.972	5.890	5.981	5.971	5.955	5.867
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.569	0.184	0.524	0.226	0.502	0.583	0.268	0.214
B	2.851	2.910	2.847	2.878	2.848	2.866	2.886	2.900
FE	0.685	0.789	0.669	0.704	0.704	0.686	0.777	0.883
MG	1.925	2.068	1.905	2.129	1.847	1.861	1.948	1.990
TI	0.031	0.133	0.015	0.129	0.048	0.010	0.126	0.121
MN	0.003	0.013	0.000	0.003	0.008	0.011	0.008	0.008
NA	0.532	0.559	0.547	0.581	0.569	0.509	0.542	0.667
CA	0.135	0.280	0.122	0.274	0.115	0.088	0.223	0.205
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.103	0.179	0.000	0.094	0.041	0.036	0.120	0.068
OH	3.897	3.821	4.000	3.906	3.959	3.964	3.880	3.932
B R	4.010	4.010	4.010	4.010	4.010	4.010	4.010	4.010
D B	-38.1	-38.1	-38.1	-38.1	-38.1	-38.1	-38.1	-38.1

	BL2	BL2	BM1	BM1	BM1	BM1	BM2	BM2
	2	2	1	1	2	2	1	1
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	BRAZILL	BRAZILL	BLUEMTN	BLUEMTN	BLUEMTN	BLUEMTN	BLUEMTN	BLUEMTN
SIO2	35.56	35.53	34.84	35.40	35.11	34.44	34.70	34.63
TIO2	0.17	0.97	0.78	0.77	0.19	0.79	0.49	0.79
AL2O3	33.04	32.13	25.63	27.63	27.28	29.75	29.32	23.95
FEO	5.05	5.34	13.81	10.10	14.76	14.29	10.41	13.27
MNO	0.09	0.07	0.09	0.05	0.06	0.00	0.10	0.00
MGO	7.53	8.45	6.59	8.03	5.20	3.67	6.29	7.83
CAO	0.73	1.44	1.20	0.99	0.89	1.25	1.62	1.59
NA2O	1.68	1.72	2.23	2.47	2.10	1.54	1.65	2.01
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.00	0.19	0.18	0.16	0.13	0.00	0.00	0.20
	93.97	95.96	95.47	95.72	95.84	95.85	94.70	94.39
O-F	0.00	0.08	0.08	0.07	0.05	0.00	0.00	0.08
2O	3.59	3.53	3.36	3.44	3.40	3.49	3.51	3.31
TOTAL	97.56	99.38	98.72	99.07	99.17	99.34	98.21	97.58
SI	5.929	5.879	6.061	6.024	6.073	5.905	5.930	6.094
AL	6.000	6.000	5.257	5.543	5.563	6.000	5.908	4.969
AL	0.494	0.268	0.000	0.000	0.000	0.014	0.000	0.000
B	2.912	2.890	3.038	2.972	3.021	2.995	2.985	3.074
FE	0.704	0.739	2.009	1.437	2.135	2.049	1.488	1.953
MG	1.871	2.084	1.709	2.036	1.340	0.938	1.602	2.054
TI	0.021	0.121	0.102	0.099	0.025	0.102	0.063	0.105
MN	0.013	0.010	0.013	0.007	0.009	0.000	0.014	0.000
NA	0.543	0.552	0.752	0.815	0.704	0.512	0.547	0.686
CA	0.130	0.255	0.224	0.181	0.165	0.230	0.297	0.300
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.000	0.099	0.099	0.086	0.071	0.000	0.000	0.111
OH	4.000	3.901	3.901	3.914	3.929	4.000	4.000	3.889
B R	4.010	4.010	4.029	4.029	4.029	4.029	4.029	4.029
D B	-38.1	-38.1	-33.6	-33.6	-33.6	-33.6	-33.6	-33.6

	BM2	BM2	CBS	CBS	CBS	CBS	CH1	CH1
	2	2	1	1	2	2	1	1
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	BLUEMTN	BLUEMTN	CORNEYB	CORNEYB	CORNEYB	CORNEYB	C HILL	C HILL
SIO2	35.11	35.32	35.43	35.16	35.27	35.07	35.86	36.23
TIO2	0.04	1.12	0.33	0.79	0.59	0.66	0.82	0.67
AL2O3	27.94	24.23	33.56	33.32	33.33	33.20	34.03	34.61
FEO	11.73	14.25	7.60	6.36	8.18	6.40	5.53	5.58
MNO	0.13	0.01	0.09	0.04	0.04	0.09	0.04	0.04
MGO	6.86	7.41	5.59	6.52	5.30	6.89	6.39	6.14
CAO	1.64	1.58	0.36	1.00	0.54	1.10	0.72	0.59
NA2O	1.70	2.06	1.95	1.63	1.90	1.82	1.93	1.72
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.00	0.00	0.21	0.18	0.00	0.24	0.20	0.20
	95.27	96.10	95.24	95.12	95.27	95.59	95.64	95.90
O-F	0.00	0.00	0.09	0.08	0.00	0.10	0.08	0.08
2O	3.50	3.47	3.48	3.50	3.59	3.48	3.53	3.55
TOTAL	98.77	99.57	98.60	98.52	98.86	98.93	99.06	99.33
SI	6.009	6.096	5.930	5.867	5.886	5.848	5.925	5.957
AL	5.638	4.930	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.000	0.000	0.622	0.555	0.558	0.526	0.629	0.708
B	2.989	3.014	2.923	2.914	2.915	2.912	2.886	2.871
FE	1.679	2.057	1.064	0.888	1.142	0.892	0.764	0.767
MG	1.750	1.906	1.394	1.622	1.318	1.712	1.573	1.504
TI	0.005	0.145	0.042	0.099	0.074	0.083	0.102	0.083
MN	0.019	0.001	0.013	0.006	0.006	0.013	0.006	0.006
NA	0.564	0.689	0.633	0.527	0.615	0.588	0.618	0.548
CA	0.301	0.292	0.065	0.179	0.097	0.197	0.127	0.104
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.000	0.000	0.111	0.095	0.000	0.127	0.105	0.104
OH	4.000	4.000	3.889	3.905	4.000	3.873	3.895	3.896
B R	4.029	4.029	0.000	0.000	0.000	0.000	3.976	3.976
D B	-33.6	-33.6	0.0	0.0	0.0	0.0	-46.8	-46.8

	CH1	CH1	CH2	CH2	CH2	CH2	CX1	CX1
	2	2	1	1	2	2	1	1
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	C HILL	C HILL	C HILL	C HILL	C HILL	C HILL	CXHEATH	CXHEATH
SIO2	36.75	36.17	36.29	35.96	36.42	35.94	34.82	35.17
TIO2	0.16	0.77	0.42	0.85	0.99	0.82	0.32	0.54
AL2O3	35.70	34.60	33.17	34.59	31.97	34.33	31.01	27.90
FEO	5.77	5.53	8.71	6.53	7.96	6.51	16.13	12.71
MNO	0.06	0.02	0.06	0.11	0.04	0.06	0.05	0.10
MGO	5.57	6.57	5.60	6.05	6.39	6.30	1.51	6.34
CAO	0.21	0.66	0.28	0.57	0.40	0.64	0.34	1.02
NA2O	1.37	1.85	1.79	1.79	2.19	1.87	1.93	2.14
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.08	0.00	0.28	0.00	0.08	0.06	0.19	0.26
	95.79	96.29	96.72	96.57	96.56	96.65	96.42	96.30
O-F	0.03	0.00	0.12	0.00	0.03	0.03	0.08	0.11
O	3.63	3.67	3.48	3.67	3.59	3.63	3.39	3.37
TOTAL	99.37	99.96	100.04	100.24	100.10	100.25	99.70	99.52
SI	6.003	5.899	6.017	5.876	6.016	5.881	5.990	6.028
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	5.638
AL	0.875	0.653	0.484	0.663	0.225	0.623	0.289	0.000
B	2.853	2.848	2.896	2.854	2.885	2.858	3.004	2.993
FE	0.788	0.754	1.208	0.892	1.100	0.891	2.321	1.822
MG	1.356	1.597	1.384	1.473	1.573	1.536	0.387	1.619
TI	0.020	0.094	0.052	0.104	0.123	0.101	0.041	0.070
MN	0.008	0.003	0.008	0.015	0.006	0.008	0.007	0.015
NA	0.434	0.585	0.575	0.567	0.701	0.593	0.644	0.711
CA	0.037	0.115	0.050	0.100	0.071	0.112	0.063	0.187
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.041	0.000	0.147	0.000	0.042	0.031	0.103	0.141
OH	3.959	4.000	3.853	4.000	3.958	3.969	3.897	3.859
B R	3.976	3.976	3.976	3.976	3.976	3.976	4.013	4.013
D B	-46.8	-46.8	-46.8	-46.8	-46.8	-46.8	-37.4	-37.4

	CX1	CX1	CX2	CX2	CX2	CX2	DOM	DOM
	2	2	1	1	2	2	1	1
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	CXHEATH	CXHEATH	CXHEATH	CXHEATH	CXHEATH	CXHEATH	DOMINIQ	DOMINIQ
SIO2	35.21	35.24	34.75	32.80	35.77	36.48	34.93	34.97
TIO2	0.27	0.48	0.18	0.99	0.28	0.25	0.13	0.07
AL2O3	27.75	27.00	29.60	27.47	28.06	30.63	33.78	33.46
FEO	11.57	13.97	16.49	19.61	10.73	8.03	14.99	15.31
MNO	0.08	0.05	0.00	0.05	0.02	0.02	0.24	0.28
MGO	7.64	6.48	2.27	1.61	7.66	7.93	0.07	0.04
CAO	1.68	0.93	0.65	1.73	1.14	0.75	0.04	0.04
NA2O	1.76	2.37	1.79	1.47	2.32	2.27	1.57	1.60
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.06	0.00	0.00	0.04	0.25	0.00	0.28	0.43
	96.14	96.64	95.85	95.89	96.35	96.48	96.15	96.32
O-F	0.03	0.00	0.00	0.02	0.11	0.00	0.12	0.18
2O	3.49	3.51	3.47	3.37	3.41	3.62	3.37	3.28
TOTAL	99.60	100.15	99.32	99.23	99.62	100.10	99.36	99.35
SI	5.987	6.018	6.001	5.805	6.071	6.037	5.976	6.010
AL	5.563	5.436	6.000	5.732	5.615	5.975	6.000	6.000
AL	0.000	0.000	0.027	0.000	0.000	0.000	0.813	0.779
B	2.970	2.982	3.016	3.091	2.964	2.890	2.988	3.001
FE	1.645	1.995	2.382	2.903	1.523	1.111	2.145	2.200
MG	1.936	1.649	0.584	0.425	1.938	1.956	0.018	0.010
TI	0.035	0.062	0.023	0.132	0.036	0.031	0.017	0.009
MN	0.012	0.007	0.000	0.007	0.003	0.003	0.035	0.041
NA	0.580	0.785	0.599	0.504	0.763	0.728	0.521	0.533
CA	0.306	0.170	0.120	0.328	0.207	0.133	0.007	0.007
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.032	0.000	0.000	0.022	0.134	0.000	0.151	0.234
OH	3.968	4.000	4.000	3.978	3.866	4.000	3.849	3.766
B R	4.013	4.013	4.013	4.013	4.013	4.013	3.995	3.995
D B	-37.4	-37.4	-37.4	-37.4	-37.4	-37.4	-41.7	-41.7

	FH1	FH1	FH1	FH1	FH2	FH2	FH2	FH2
	1	1	2	2	1	1	2	2
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	F HILL	F HILL	F HILL	F HILL	F HILL	F HILL	F HILL	F HILL
SIO2	35.79	35.44	36.55	35.32	35.89	34.92	34.67	34.70
TIO2	0.18	0.19	0.11	0.45	0.39	0.93	0.79	0.95
AL2O3	28.81	30.19	30.62	25.76	33.41	31.73	31.26	31.77
FEO	11.55	10.26	8.55	14.08	7.79	11.32	10.75	11.74
MNO	0.04	0.06	0.09	0.00	0.04	0.11	0.18	0.23
MGO	6.97	7.36	7.92	7.09	5.61	3.54	4.11	3.29
CAO	0.83	1.18	0.49	1.13	0.01	0.04	0.05	0.06
NA2O	2.11	1.81	2.50	2.02	2.15	2.35	2.51	2.21
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.10	0.20	0.16	0.00	0.37	0.81	0.00	0.64
	96.50	96.81	97.11	95.97	95.78	95.87	94.44	95.71
O-F	0.04	0.08	0.07	0.00	0.16	0.34	0.00	0.27
2O	3.50	3.47	3.54	3.48	3.41	3.09	3.51	3.17
TOTAL	99.94	100.17	100.56	99.45	98.97	98.49	97.95	98.51
SI	6.045	5.950	6.054	6.076	6.000	6.023	5.923	5.979
AL	5.737	5.975	5.979	5.224	6.000	6.000	6.000	6.000
AL	0.000	0.000	0.000	0.000	0.584	0.452	0.296	0.454
B	2.950	2.932	2.893	3.004	2.919	3.012	2.983	3.009
FE	1.632	1.441	1.184	2.026	1.089	1.633	1.536	1.692
MG	1.755	1.842	1.955	1.818	1.398	0.910	1.046	0.845
TI	0.023	0.024	0.014	0.058	0.049	0.121	0.101	0.123
MN	0.006	0.009	0.013	0.000	0.006	0.016	0.026	0.034
NA	0.691	0.589	0.803	0.674	0.697	0.786	0.831	0.738
CA	0.150	0.212	0.087	0.208	0.002	0.007	0.009	0.011
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.053	0.106	0.084	0.000	0.196	0.442	0.000	0.349
OH	3.947	3.894	3.916	4.000	3.804	3.558	4.000	3.651
B R	3.990	3.990	3.990	3.990	3.990	3.990	3.990	3.990
D B	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9	-42.9

	FH3	FH3	FH3	FH3	JV1	JV1	JV1	JV1
	1	1	2	2	1	1	2	2
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	F HILL	F HILL	F HILL	F HILL	JUMBO V	JUMBO V	JUMBO V	JUMBO V
SIO2	35.39	34.90	35.54	34.96	35.06	34.95	35.32	35.09
TIO2	0.72	0.92	0.76	0.97	0.66	0.82	0.13	0.37
AL2O3	31.47	32.10	31.74	31.81	32.09	30.71	34.60	32.87
FEO	8.50	11.42	9.87	11.21	10.24	11.04	9.77	9.56
MNO	0.00	0.08	0.00	0.10	0.10	0.27	0.08	0.17
MGO	5.85	3.44	4.72	3.54	4.31	4.59	3.33	4.29
CAO	0.02	0.01	0.02	0.08	0.43	0.50	0.09	0.36
NA2O	2.54	2.26	2.33	2.29	2.07	2.16	1.55	2.05
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.62	0.61	0.53	0.48	0.58	1.01	0.31	0.93
	95.23	95.86	95.63	95.56	95.66	96.17	95.30	95.81
O-F	0.26	0.26	0.22	0.20	0.24	0.43	0.13	0.39
2O	3.22	3.21	3.27	3.27	3.23	2.98	3.41	3.05
TOTAL	98.09	98.71	98.59	98.55	98.56	98.56	98.53	98.32
SI	6.035	5.983	6.047	5.987	5.989	6.056	5.954	6.020
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.327	0.488	0.367	0.422	0.463	0.273	0.876	0.649
B	2.978	2.994	2.972	2.991	2.983	3.026	2.944	2.996
FE	1.212	1.637	1.404	1.605	1.463	1.600	1.377	1.372
MG	1.487	0.879	1.197	0.903	1.097	1.185	0.837	1.097
TI	0.092	0.119	0.097	0.125	0.085	0.107	0.016	0.048
MN	0.000	0.012	0.000	0.015	0.014	0.040	0.011	0.025
NA	0.840	0.751	0.769	0.760	0.686	0.726	0.507	0.682
CA	0.004	0.002	0.004	0.015	0.079	0.093	0.016	0.066
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.334	0.331	0.285	0.260	0.313	0.553	0.165	0.505
OH	3.666	3.669	3.715	3.740	3.687	3.447	3.835	3.495
B R	3.990	3.990	3.990	3.990	4.052	4.052	4.052	4.052
D B	-42.9	-42.9	-42.9	-42.9	-28.1	-28.1	-28.1	-28.1

	JV2	JV2	JV2	JV2	LP1	LP1	LP2	LP2
	1	1	2	2	1	1	1	1
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	JUMBO V	JUMBO V	JUMBO V	JUMBO V	LISCOMB	LISCOMB	LISCOMB	LISCOMB
SIO2	35.07	34.98	34.79	35.12	35.57	35.63	35.88	35.66
TIO2	0.98	0.09	1.01	0.93	0.71	0.72	0.11	0.19
AL2O3	31.43	34.99	30.51	30.68	34.56	34.42	35.24	34.93
FEO	10.02	9.62	11.10	10.85	8.63	8.56	10.89	10.99
MNO	0.08	0.15	0.23	0.19	0.00	0.15	0.33	0.39
MGO	4.73	2.78	4.81	4.70	4.34	4.40	2.09	2.32
CAO	0.52	0.06	0.64	0.55	0.07	0.04	0.00	0.08
NA2O	1.94	1.32	2.10	2.26	2.16	2.08	1.51	1.73
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.74	0.35	0.90	0.75	0.00	0.16	0.00	0.38
	95.63	94.46	96.21	96.15	96.16	96.28	96.17	96.79
O-F	0.31	0.15	0.38	0.32	0.00	0.07	0.00	0.16
[illegible]O	3.14	3.36	3.04	3.13	3.62	3.54	3.60	3.40
TOTAL	98.34	97.62	98.73	98.85	99.78	99.72	99.77	99.97
SI	6.018	5.942	6.014	6.036	5.882	5.911	5.966	5.974
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.359	1.007	0.217	0.216	0.737	0.732	0.908	0.899
B	2.997	2.967	3.019	3.002	2.888	2.897	2.904	2.926
FE	1.438	1.367	1.605	1.560	1.193	1.188	1.514	1.540
MG	1.210	0.704	1.239	1.204	1.070	1.088	0.518	0.579
TI	0.126	0.011	0.131	0.120	0.088	0.090	0.014	0.024
MN	0.012	0.022	0.034	0.028	0.000	0.021	0.046	0.055
NA	0.646	0.435	0.704	0.753	0.693	0.669	0.487	0.562
CA	0.096	0.011	0.119	0.101	0.012	0.007	0.000	0.014
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.402	0.188	0.492	0.408	0.000	0.084	0.000	0.201
OH	3.598	3.812	3.508	3.592	4.000	3.916	4.000	3.799
B R	4.019	4.019	4.019	4.019	4.018	4.018	4.011	4.011
D B	-36.0	-36.0	-36.0	-36.0	-36.2	-36.2	-37.9	-37.9

	LP3	LP3	PL1	PL1	PL1	PL1	PL2	PL2
	1	1	1	1	2	2	1	1
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	LISCOMB	LISCOMB	PEARL L	PEARL L	PEARL L	PEARL L	PEARL L	PEARL L
SIO2	35.64	34.92	35.90	36.00	35.91	36.03	36.54	35.95
TIO2	0.08	0.00	0.49	0.27	0.14	0.41	0.12	0.25
AL2O3	35.01	34.40	32.69	33.98	34.26	33.92	35.63	34.57
FEO	11.49	12.24	7.53	6.07	7.67	6.87	6.75	7.25
MNO	0.42	0.33	0.08	0.01	0.06	0.06	0.14	0.04
MGO	1.57	1.45	5.99	5.75	4.81	5.82	4.91	5.87
CAO	0.00	0.01	0.90	0.52	0.55	0.57	0.34	0.53
NA2O	1.58	1.80	2.00	1.76	1.84	1.96	1.55	1.77
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.00	0.45	0.48	0.39	0.23	0.53	0.33	0.47
	95.91	95.72	96.18	94.87	95.59	96.29	96.43	96.82
O-F	0.00	0.19	0.20	0.16	0.10	0.22	0.14	0.20
2O	3.58	3.30	3.35	3.40	3.49	3.35	3.49	3.40
TOTAL	99.49	98.76	99.25	98.04	98.94	99.33	99.73	99.95
SI	5.962	5.961	6.010	6.022	5.982	5.999	6.008	5.949
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.905	0.923	0.452	0.701	0.728	0.659	0.907	0.744
B	2.922	2.981	2.924	2.921	2.909	2.908	2.872	2.890
FE	1.608	1.747	1.054	0.849	1.069	0.957	0.928	1.003
MG	0.391	0.369	1.495	1.433	1.194	1.444	1.203	1.448
TI	0.010	0.000	0.062	0.034	0.018	0.051	0.015	0.031
MN	0.060	0.048	0.011	0.001	0.008	0.008	0.019	0.006
NA	0.513	0.596	0.649	0.571	0.594	0.633	0.494	0.568
CA	0.000	0.002	0.161	0.093	0.098	0.102	0.060	0.094
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.000	0.243	0.254	0.206	0.121	0.279	0.172	0.246
OH	4.000	3.757	3.746	3.794	3.879	3.721	3.828	3.754
B R	4.025	4.025	4.045	4.045	4.045	4.045	4.045	4.045
D B	-34.5	-34.5	-29.7	-29.7	-29.7	-29.7	-29.7	-29.7

	PL2	PL2	PM1	PM1	PM2	PM2	PM2	PM2
	2	2	1	1	1	1	2	2
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	PEARL L	PEARL L	PMOUTON	PMOUTON	PMOUTON	PMOUTON	PMOUTON	PMOUTON
SIO2	36.24	33.83	34.92	34.87	35.04	34.80	35.42	34.75
TIO2	0.05	0.12	0.90	0.86	0.15	0.17	0.07	0.14
AL2O3	35.05	33.84	34.60	34.18	35.25	35.31	35.38	34.84
FEO	7.84	7.79	8.78	9.22	9.76	9.91	9.63	9.71
MNO	0.06	0.06	0.17	0.16	0.18	0.24	0.25	0.23
MGO	4.05	4.12	4.59	4.22	3.37	3.18	3.02	3.33
CAO	0.14	0.18	0.32	0.31	0.05	0.09	0.02	0.07
NA2O	1.58	1.44	2.01	2.17	2.03	1.97	1.60	1.99
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.30	0.16	0.16	0.62	0.15	0.42	0.00	0.15
	95.43	91.66	96.57	96.73	96.10	96.21	95.51	95.33
O-F	0.13	0.07	0.07	0.26	0.06	0.18	0.00	0.06
2O	3.45	3.39	3.53	3.27	3.52	3.36	3.60	3.49
TOTAL	98.71	94.96	100.01	99.64	99.53	99.33	99.11	98.73
SI	6.036	5.851	5.797	5.870	5.849	5.854	5.902	5.848
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.883	0.900	0.772	0.783	0.937	1.002	0.950	0.912
B	2.909	3.021	2.899	2.940	2.915	2.938	2.910	2.939
FE	1.092	1.127	1.219	1.298	1.363	1.394	1.342	1.367
MG	1.005	1.062	1.136	1.059	0.838	0.797	0.750	0.835
TI	0.006	0.016	0.112	0.109	0.019	0.022	0.009	0.018
MN	0.008	0.009	0.024	0.023	0.025	0.034	0.035	0.033
NA	0.510	0.483	0.647	0.708	0.657	0.643	0.517	0.649
CA	0.025	0.033	0.057	0.056	0.009	0.016	0.004	0.013
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.158	0.088	0.084	0.330	0.079	0.223	0.000	0.080
OH	3.842	3.912	3.916	3.670	3.921	3.777	4.000	3.920
B R	4.045	4.045	4.035	4.035	3.962	3.962	3.962	3.962
D B	-29.7	-29.7	-32.1	-32.1	-49.7	-49.7	-49.7	-49.7

	SMB1	SMB1	SMB10	SMB10	SMB11	SMB11	SMB12	SMB12
	1	1	1	1	1	1	1	1
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	BSMBL	BSMBL	BIGLAKE	BIGLAKE	UP TAN	UP TAN	RAFTERL	RAFTERL
SIO2	35.24	35.05	33.00	34.82	34.60	34.35	35.69	35.04
TIO2	0.48	0.52	0.57	0.63	0.54	0.57	0.56	0.58
AL2O3	35.61	34.94	33.51	33.40	35.08	34.65	34.60	34.47
FEO	9.79	10.26	10.86	10.54	11.99	11.85	8.96	9.26
MNO	0.11	0.22	0.32	0.32	0.27	0.33	0.28	0.26
MGO	2.99	3.13	3.11	3.09	0.45	0.50	3.63	3.84
CAO	0.11	0.06	0.20	0.24	0.05	0.06	0.24	0.26
NA2O	1.86	1.90	2.03	1.87	2.16	2.23	1.68	1.88
K2O	0.00	0.00	0.06	0.07	0.00	0.00	0.06	0.08
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.15	0.54	0.00	0.00	0.67	0.91	0.00	0.00
	96.46	96.74	93.78	95.10	95.93	95.57	95.82	95.79
O-F	0.06	0.23	0.00	0.00	0.28	0.38	0.00	0.00
O	3.54	3.31	3.48	3.55	3.18	3.03	3.61	3.59
TOTAL	99.91	99.74	97.26	98.65	98.72	98.07	99.43	99.38
SI	5.855	5.893	5.679	5.883	5.930	5.954	5.926	5.842
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.975	0.925	0.798	0.652	1.088	1.080	0.772	0.775
B	2.901	2.936	3.005	2.951	2.993	3.027	2.900	2.912
FE	1.360	1.443	1.563	1.489	1.719	1.718	1.244	1.291
MG	0.740	0.784	0.798	0.778	0.115	0.129	0.898	0.954
TI	0.060	0.066	0.074	0.080	0.070	0.074	0.070	0.073
MN	0.015	0.031	0.047	0.046	0.039	0.048	0.039	0.037
NA	0.599	0.619	0.677	0.613	0.718	0.749	0.541	0.608
CA	0.020	0.011	0.037	0.043	0.009	0.011	0.043	0.046
K	0.000	0.000	0.013	0.015	0.000	0.000	0.013	0.017
F	0.079	0.287	0.000	0.000	0.363	0.499	0.000	0.000
OH	3.921	3.713	4.000	4.000	3.637	3.501	4.000	4.000
B R	4.040	4.040	4.058	4.058	3.997	3.997	3.996	3.996
D B	-30.9	-30.9	-26.6	-26.6	-41.3	-41.3	-42.9	-42.9

	SMB13	SMB13	SMB14	SMB14	SMB14	SMB14	SMB14	SMB14
	1	1	1	1	2	2	3	3
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	ISLANDL	ISLANDL	KEHOE H	KEHOE H	KEHOE H	KEHOE H	KEHOE H	KEHOE H
SIO2	34.77	34.38	36.19	36.45	36.67	35.91	35.37	35.21
TIO2	0.91	0.58	0.12	0.45	0.17	0.66	0.22	0.15
AL2O3	34.17	34.49	34.77	34.73	34.88	34.48	34.58	34.29
FEO	9.96	9.75	8.18	7.79	8.38	7.84	8.61	8.20
MNO	0.33	0.27	0.16	0.07	0.16	0.07	0.04	0.13
MGO	3.04	3.10	4.29	5.01	4.35	5.14	4.09	4.43
CAO	0.24	0.26	0.04	0.10	0.04	0.15	0.06	0.05
NA2O	2.03	1.93	1.73	2.02	1.72	2.02	1.77	1.63
K2O	0.07	0.06	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.00	0.00	0.00	0.18	0.00	0.21	0.16	0.22
	95.64	94.94	95.60	96.92	96.49	96.60	95.02	94.43
O-F	0.00	0.00	0.00	0.08	0.00	0.09	0.07	0.09
[illegible]O	3.57	3.55	3.62	3.57	3.65	3.53	3.50	3.45
TOTAL	99.21	98.49	99.22	100.38	100.14	100.01	98.43	97.75
SI	5.830	5.796	5.986	5.981	6.014	5.927	5.928	5.937
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.755	0.855	0.780	0.719	0.745	0.709	0.833	0.816
B	2.929	2.944	2.889	2.866	2.864	2.882	2.927	2.945
FE	1.397	1.375	1.132	1.069	1.149	1.082	1.207	1.156
MG	0.760	0.779	1.057	1.225	1.063	1.264	1.022	1.113
TI	0.115	0.074	0.015	0.056	0.021	0.082	0.028	0.019
MN	0.047	0.039	0.022	0.010	0.022	0.010	0.006	0.019
NA	0.660	0.631	0.555	0.643	0.547	0.646	0.575	0.533
CA	0.043	0.047	0.007	0.018	0.007	0.027	0.011	0.009
K	0.015	0.013	0.000	0.000	0.000	0.000	0.000	0.000
F	0.000	0.000	0.000	0.093	0.000	0.110	0.085	0.117
OH	4.000	4.000	4.000	3.907	4.000	3.890	3.915	3.883
B R	4.018	4.018	4.013	4.013	4.013	4.013	4.013	4.013
D B	-36.2	-36.2	-37.4	-37.4	-37.4	-37.4	-37.4	-37.4

	SMB2	SMB2	SMB3	SMB3	SMB4	SMB4	SMB5	SMB5
	1	1	1	1	1	1	1	1
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	BSMBL	BSMBL	BSMBL	BSMBL	H COVE	H COVE	HTCHT L	HTCHT L
SIO2	34.71	34.68	35.05	35.13	34.87	34.28	32.68	33.11
TIO2	0.85	0.33	0.33	0.31	0.78	0.82	0.19	0.23
AL2O3	34.39	34.72	35.10	35.47	35.03	34.57	35.01	34.71
FEO	10.78	12.74	12.83	12.84	9.03	9.48	13.68	14.53
MNO	0.05	0.16	0.08	0.20	0.08	0.11	0.41	0.40
MGO	3.03	1.29	0.63	0.60	4.08	3.37	0.15	0.15
CAO	0.11	0.00	0.05	0.04	0.15	0.14	0.07	0.06
NA2O	1.88	1.78	1.71	1.56	2.04	2.05	1.89	1.99
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.44	0.70	0.47	0.58	0.75	0.64	0.48	0.64
	96.36	96.52	96.37	96.85	96.93	95.58	94.68	95.94
O-F	0.19	0.29	0.20	0.24	0.32	0.27	0.20	0.27
2O	3.34	3.17	3.31	3.26	3.21	3.21	3.21	3.14
TOTAL	99.45	99.29	99.40	99.78	99.70	98.42	97.61	98.71
SI	5.858	5.927	5.950	5.952	5.861	5.838	5.704	5.756
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.842	0.996	1.025	1.085	0.942	0.941	1.204	1.113
B	2.947	2.985	2.965	2.959	2.936	2.974	3.048	3.036
FE	1.522	1.821	1.822	1.819	1.269	1.350	1.997	2.112
MG	0.762	0.329	0.159	0.151	1.022	0.855	0.039	0.039
TI	0.108	0.042	0.042	0.039	0.099	0.105	0.025	0.030
MN	0.007	0.023	0.012	0.029	0.011	0.016	0.061	0.059
NA	0.615	0.590	0.563	0.512	0.665	0.677	0.640	0.671
CA	0.020	0.000	0.009	0.007	0.027	0.026	0.013	0.011
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.235	0.378	0.252	0.311	0.399	0.345	0.265	0.352
OH	3.765	3.622	3.748	3.689	3.601	3.655	3.735	3.648
B R	4.015	4.015	4.058	4.058	4.019	4.019	3.990	3.990
D B	-36.9	-36.9	-26.6	-26.6	-36.0	-36.0	-42.9	-42.9

	SMB6	SMB6	SMB7	SMB7	SMB8	SMB8	SMB9	SMB9
	1	1	1	1	1	1	1	1
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	BGLHILL	BGLHILL	W DOVER	W DOVER	SHUTIN	SHUTIN	BM HILL	BM HILL
SIO2	35.16	34.92	34.28	33.61	34.28	34.02	34.86	34.61
TIO2	1.04	0.29	0.32	0.14	0.68	0.55	0.61	0.12
AL2O3	31.89	33.13	34.95	35.05	34.22	33.70	33.81	32.67
FEO	8.74	8.48	12.67	13.22	13.43	13.91	10.39	13.05
MNO	0.11	0.15	0.35	0.41	0.04	0.16	0.01	0.27
MGO	5.64	5.18	1.03	0.59	0.31	0.32	3.07	2.47
CAO	0.41	0.21	0.08	0.09	0.03	0.01	0.09	0.04
NA2O	2.14	2.16	1.77	1.75	1.83	1.93	1.81	2.02
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.43	0.34	0.63	0.72	0.15	0.59	0.07	0.53
	95.68	94.98	96.20	95.70	95.09	95.31	94.84	95.90
O-F	0.18	0.14	0.27	0.30	0.06	0.25	0.03	0.22
2O	3.34	3.38	3.20	3.12	3.43	3.17	3.51	3.23
TOTAL	98.77	98.16	99.03	98.40	98.43	98.14	98.31	98.82
SI	5.948	5.914	5.873	5.822	5.870	5.910	5.894	5.956
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.360	0.614	1.059	1.158	0.908	0.902	0.739	0.628
B	2.954	2.958	2.992	3.025	2.991	3.034	2.953	3.005
FE	1.236	1.201	1.815	1.915	1.923	2.021	1.469	1.878
MG	1.422	1.307	0.263	0.152	0.079	0.083	0.774	0.633
TI	0.132	0.037	0.041	0.018	0.088	0.072	0.078	0.016
MN	0.016	0.022	0.051	0.060	0.006	0.024	0.001	0.039
NA	0.702	0.709	0.588	0.588	0.608	0.650	0.593	0.674
CA	0.074	0.038	0.015	0.017	0.006	0.002	0.016	0.007
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.230	0.182	0.341	0.394	0.081	0.324	0.037	0.288
OH	3.770	3.818	3.659	3.606	3.919	3.676	3.963	3.712
B R	3.977	3.977	4.023	4.023	3.969	3.969	4.011	4.011
D B	-41.3	-41.3	-35.0	-35.0	-48.0	-48.0	-37.9	-37.9

	WK1	WK1	WK1	WK1	WK2	WK2	WK2	WK2
	1	1	2	2	1	1	2	2
	CORE	RIM	CORE	RIM	CORE	RIM	CORE	RIM
	WALKER	WALKER	WALKER	WALKER	WALKER	WALKER	WALKER	WALKER
SIO2	34.73	34.10	34.11	32.48	34.57	34.48	34.34	35.16
TIO2	0.13	0.08	0.00	0.10	0.08	0.07	0.09	0.03
AL2O3	34.63	33.37	34.94	34.53	34.59	33.12	30.59	34.33
FEO	16.00	16.18	14.78	15.70	14.78	15.23	14.97	14.64
MNO	0.31	0.19	0.22	0.20	0.26	0.15	0.27	0.31
MGO	0.06	0.05	0.06	0.07	0.02	0.05	0.11	0.22
CAO	0.00	0.00	0.00	0.08	0.08	0.01	0.00	0.01
NA2O	1.38	1.56	1.35	1.86	1.50	2.19	1.89	1.59
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.19	0.03	0.00	0.64	0.41	1.10	0.70	0.37
	97.55	95.68	95.58	95.78	96.41	96.52	93.08	96.78
O-F	0.08	0.01	0.00	0.27	0.17	0.46	0.29	0.16
O	3.45	3.47	3.52	3.12	3.31	2.90	3.01	3.35
TOTAL	100.89	99.13	99.10	98.53	99.48	98.78	95.68	99.91
SI	5.871	5.861	5.814	5.687	5.915	6.045	6.161	5.981
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.901	0.762	1.021	1.127	0.978	0.845	0.470	0.884
B	2.952	3.002	2.977	3.058	2.988	3.062	3.133	2.971
FE	2.262	2.326	2.107	2.299	2.115	2.233	2.246	2.083
MG	0.015	0.013	0.015	0.018	0.005	0.013	0.029	0.056
TI	0.017	0.010	0.000	0.013	0.010	0.009	0.012	0.004
MN	0.044	0.028	0.032	0.030	0.038	0.022	0.041	0.045
NA	0.452	0.520	0.446	0.631	0.498	0.744	0.657	0.524
CA	0.000	0.000	0.000	0.015	0.015	0.002	0.000	0.002
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.102	0.016	0.000	0.354	0.222	0.610	0.397	0.199
OH	3.898	3.984	4.000	3.646	3.778	3.390	3.603	3.801
B R	4.016	4.016	4.016	4.016	4.016	4.016	4.016	4.016
D B	-36.7	-36.7	-36.7	-36.7	-36.7	-36.7	-36.7	-36.7

	WK3	WK3	WK3	WK3	WP1	WP1	WP1	WP2
	1	1	2	2	1	2	2	1
	CORE	RIM	CORE	RIM	CORE	CORE	RIM	CORE
	WALKER	WALKER	WALKER	WALKER	WPPLUT	WPPLUT	WPPLUT	WPPLUT
SIO2	35.07	35.02	35.08	34.81	35.09	34.09	33.95	35.02
TIO2	0.02	0.04	0.00	0.08	0.18	0.32	0.66	0.15
AL2O3	34.46	34.45	35.15	34.17	30.59	30.14	29.43	31.81
FEO	14.72	13.98	14.82	14.81	13.20	13.44	13.53	12.63
MNO	0.28	0.26	0.30	0.24	0.09	0.07	0.16	0.15
MGO	0.05	0.04	0.05	0.03	3.04	3.92	3.04	2.50
CAO	0.00	0.02	0.06	0.00	0.62	0.94	0.97	0.40
NA2O	1.75	1.39	1.52	1.71	2.04	2.22	2.07	1.92
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B2O3	10.12	10.12	10.12	10.12	10.12	10.12	10.12	10.12
F	0.63	0.70	0.34	0.42	0.39	0.47	0.52	0.51
	97.10	96.02	97.44	96.39	95.36	95.73	94.45	95.21
O-F	0.27	0.29	0.14	0.18	0.16	0.20	0.22	0.21
2O	3.21	3.15	3.39	3.30	3.28	3.23	3.15	3.23
TOTAL	99.94	98.76	100.63	99.45	98.42	98.68	97.30	98.14
SI	5.996	6.033	5.925	5.962	6.065	5.921	5.985	6.052
AL	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
AL	0.945	0.996	0.999	0.899	0.233	0.171	0.116	0.481
B	2.986	3.009	2.950	2.991	3.018	3.033	3.079	3.018
FE	2.105	2.014	2.093	2.121	1.908	1.952	1.995	1.825
MG	0.013	0.010	0.013	0.008	0.783	1.015	0.799	0.644
TI	0.003	0.005	0.000	0.010	0.023	0.042	0.087	0.019
MN	0.041	0.038	0.043	0.035	0.013	0.010	0.024	0.022
NA	0.580	0.464	0.498	0.568	0.684	0.748	0.707	0.643
CA	0.000	0.004	0.011	0.000	0.115	0.175	0.183	0.074
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.341	0.381	0.182	0.227	0.213	0.258	0.290	0.279
OH	3.659	3.619	3.818	3.773	3.787	3.742	3.710	3.721
B R	4.016	4.016	4.016	4.016	3.997	3.997	3.997	3.950
D B	-36.7	-36.7	-36.7	-36.7	-41.3	-41.3	-41.3	-52.3

```
            WP2
----------------
            2
            CORE
            WPPLUT
----------------
  SIO2      34.74
  TIO2       0.00
  AL2O3     32.13
  FEO       12.83
  MNO        0.10
  MGO        2.31
  CAO        0.36
  NA2O       1.75
  K2O        0.00
  B2O3      10.12
  F          0.15
----------------
            94.49
  O-F        0.06
    O        3.41
----------------
  TOTAL     97.81
----------------
  SI        5.984
  AL        6.000
  AL        0.525
  B         3.008
  FE        1.848
  MG        0.593
  TI        0.000
  MN        0.015
  NA        0.584
  CA        0.066
  K         0.000
  F         0.082
  OH        3.918
----------------
  B R       3.950
  D B       -52.3
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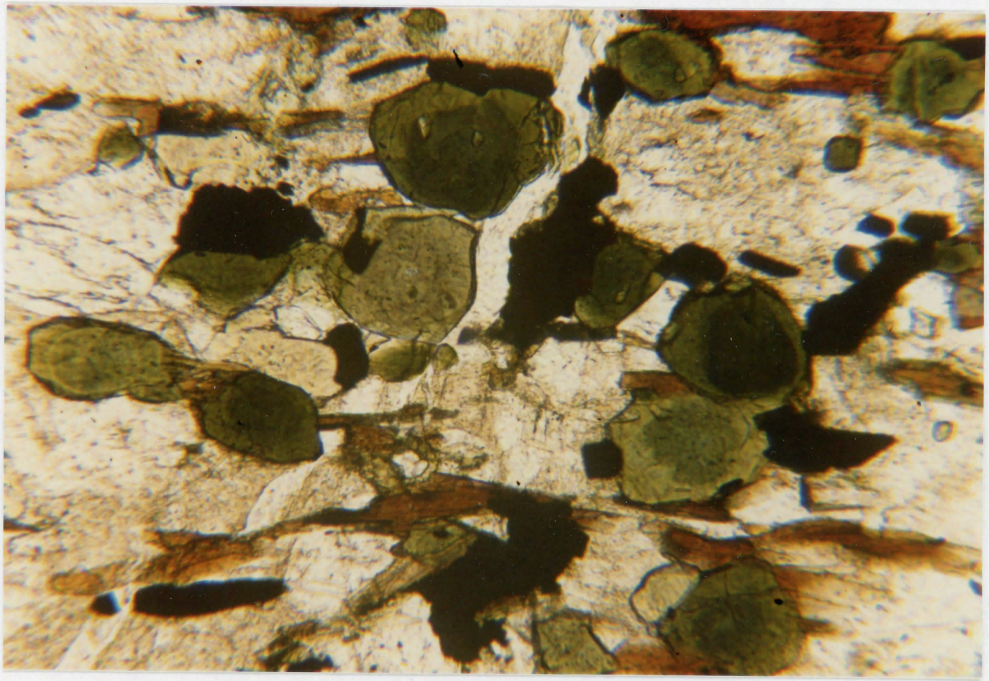
Plate 1. Corney Brook Schist: zoned green tourmaline associated with biotite-staurolite-kyanite-garnet rich layers within the well foliated Corney Brook Schist (2.5X, ppl, field of view = 5 mm).

Plate 2. Corney Brook Schist: see Plate 1 (10X, ppl, field of view = 1.5 mm).



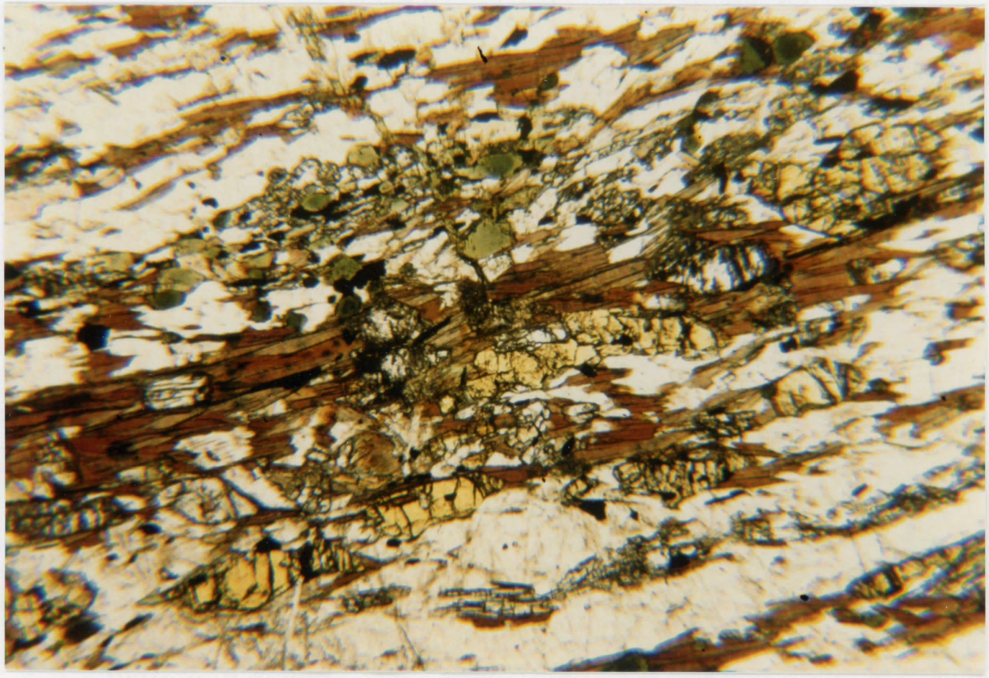
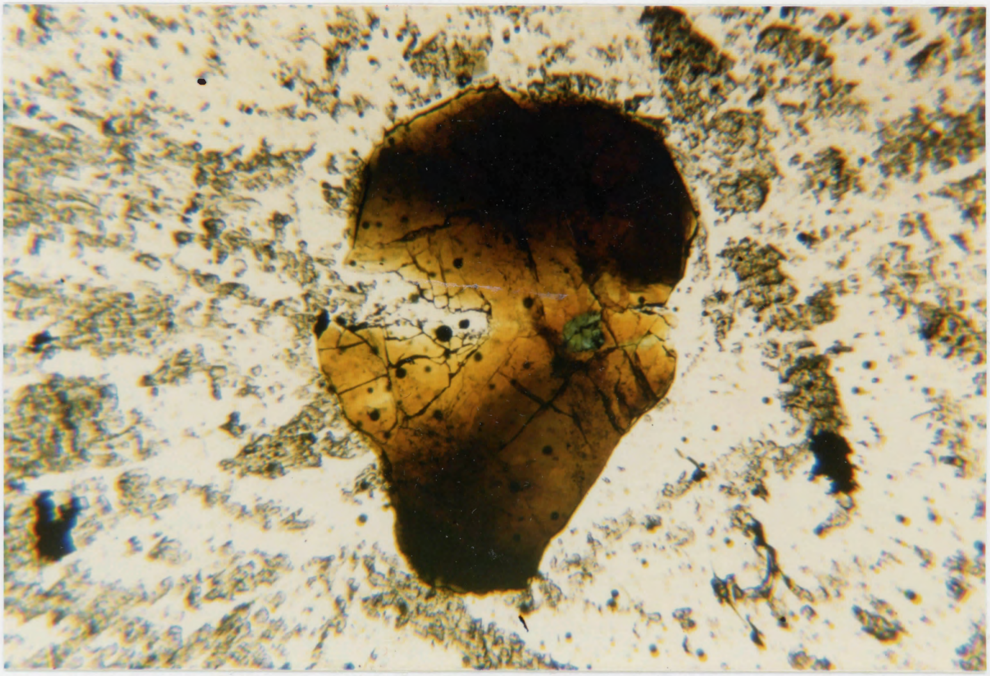


Plate 3. South Mountain Batholith 13: isolated yellow-brown tourmaline partially replaced by dark-brown tourmaline, note replacement along fractures (2.5X, ppl, field of view = 5 mm).

Plate 4. South Mountain Batholith 4: isolated brown subhedral tourmaline, grain showing blue core (2.5X, ppl, field of view = 5 mm).



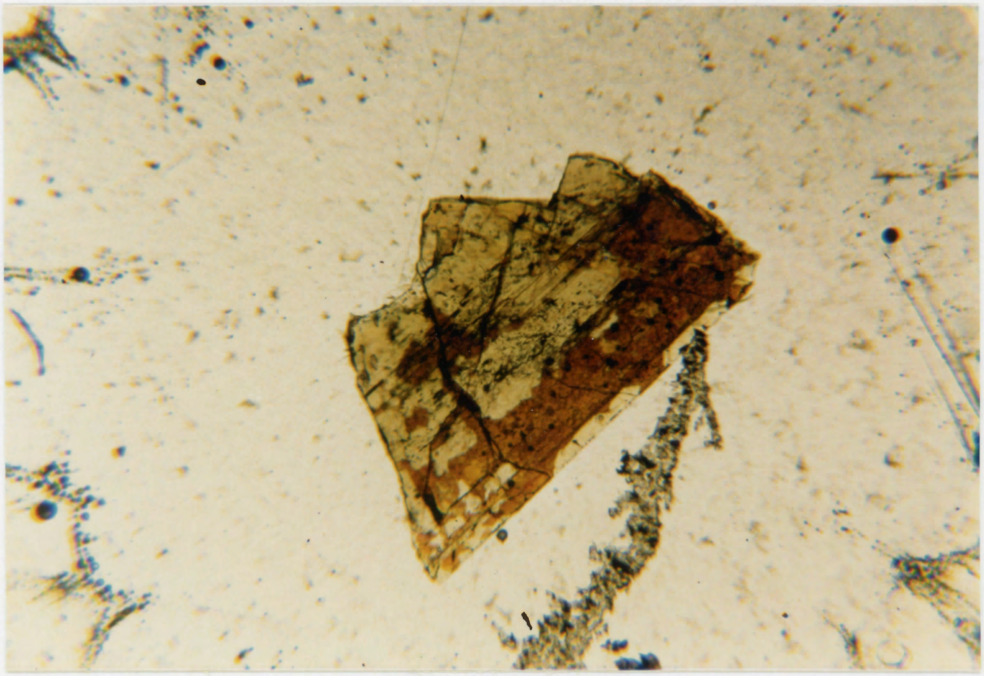
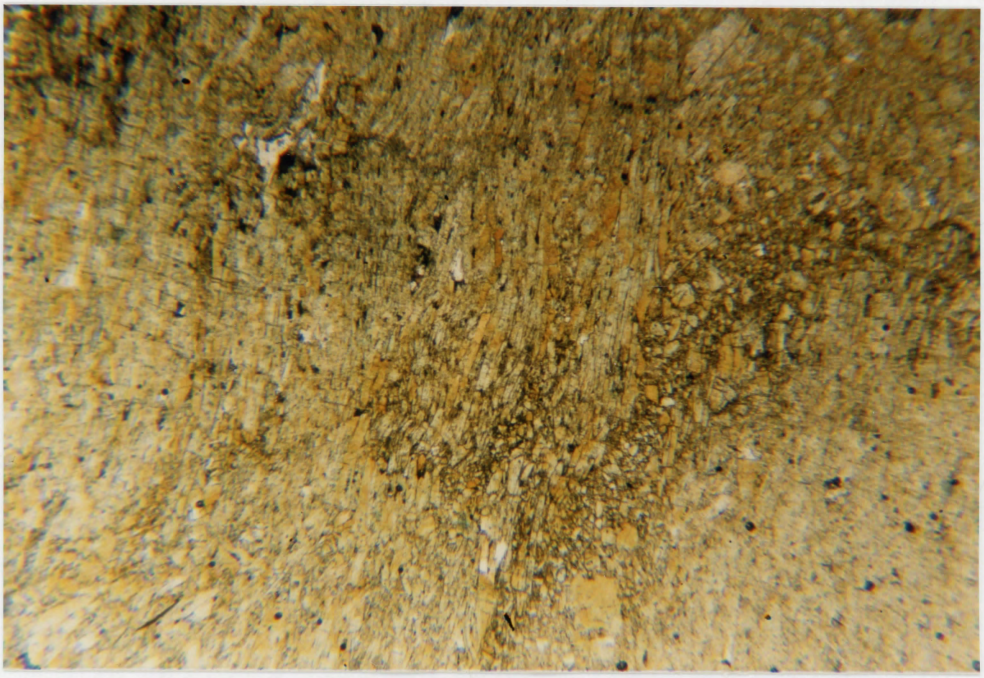


Plate 5. Jumbo Vein 1: tourmaline veins filling fractures in a quartz vein (Jumbo Vein) with minor sulphides (2.5X, ppl, field of view = 5 mm).

Plate 6. Jumbo Vein 2: bladed massive brown tourmaline in a quartz vein (10X, ppl, field of view = 1.5 mm).



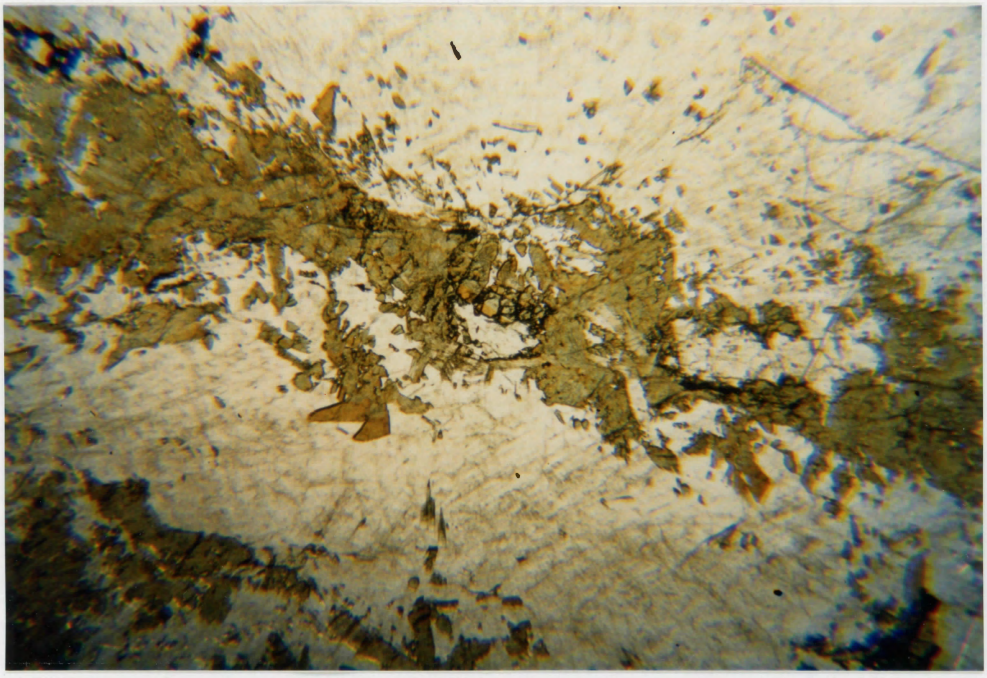


Plate 7. Walker Deposit: dark blue tourmaline grains showing a cross-cutting relationship, the grains are highly fractured (2.5X, ppl, field of view = 5 mm).

Plate 8. Walker Deposit: as in Plate 7, note core replacement by quartz and feldspar (2.5X, ppl, field of view = 5 mm).

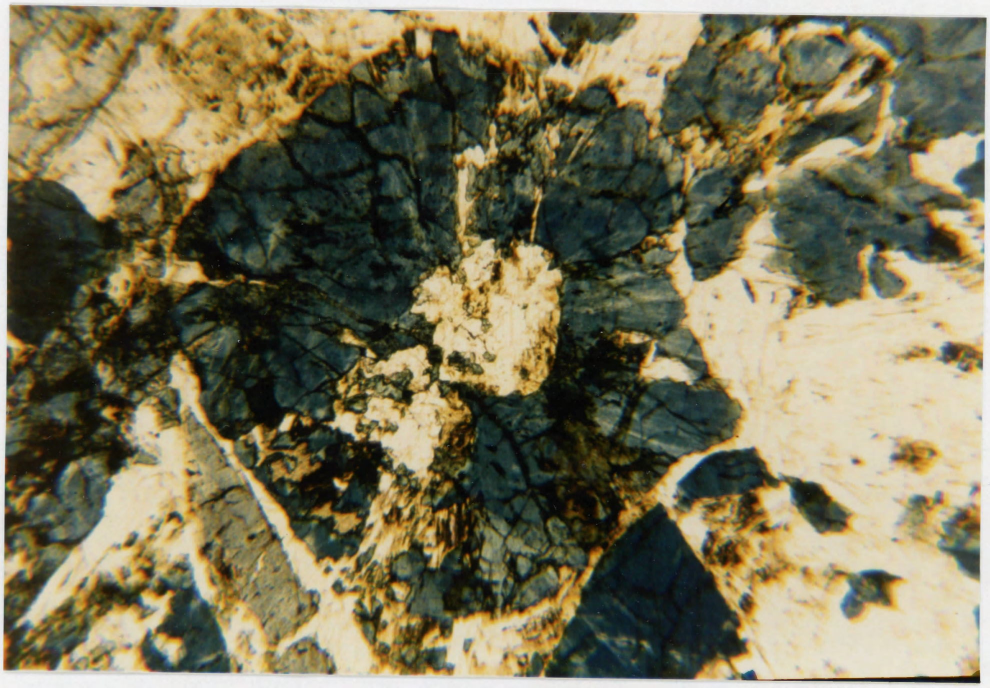
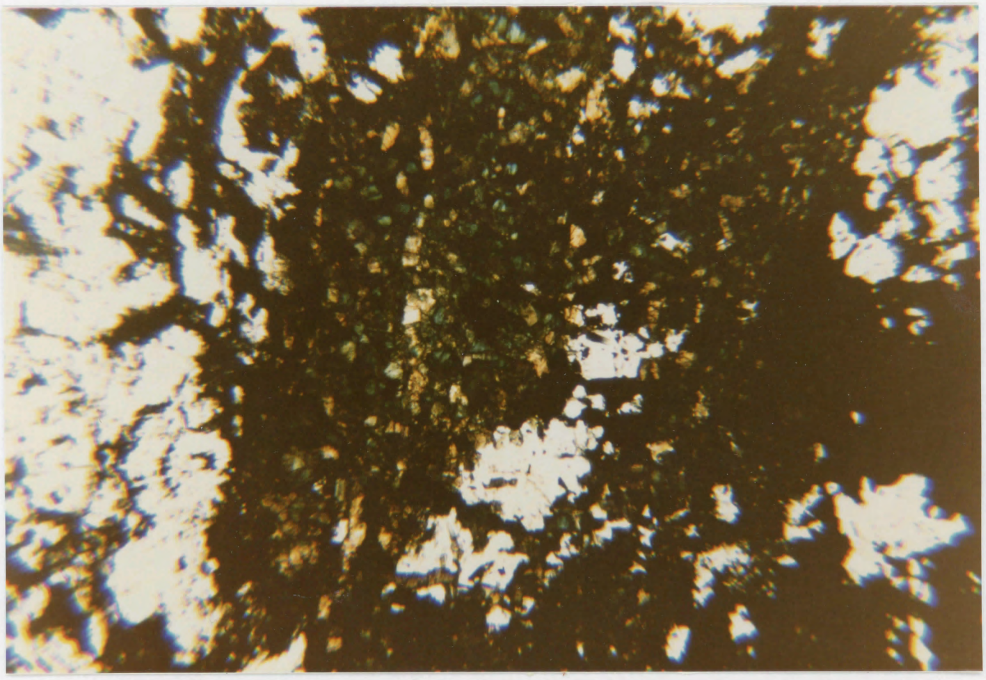
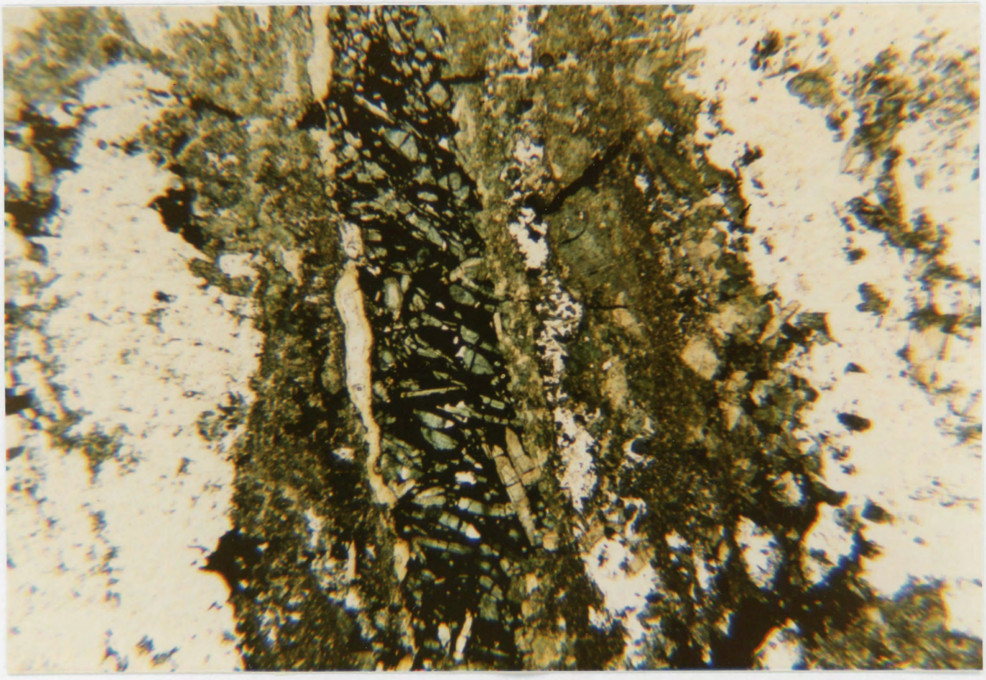


Plate 9. Coxheath: tourmaline vein associated with sulphide mineralization, note that bladed grains occur within sulphides (2.5X, ppl, field of view = 5 mm).

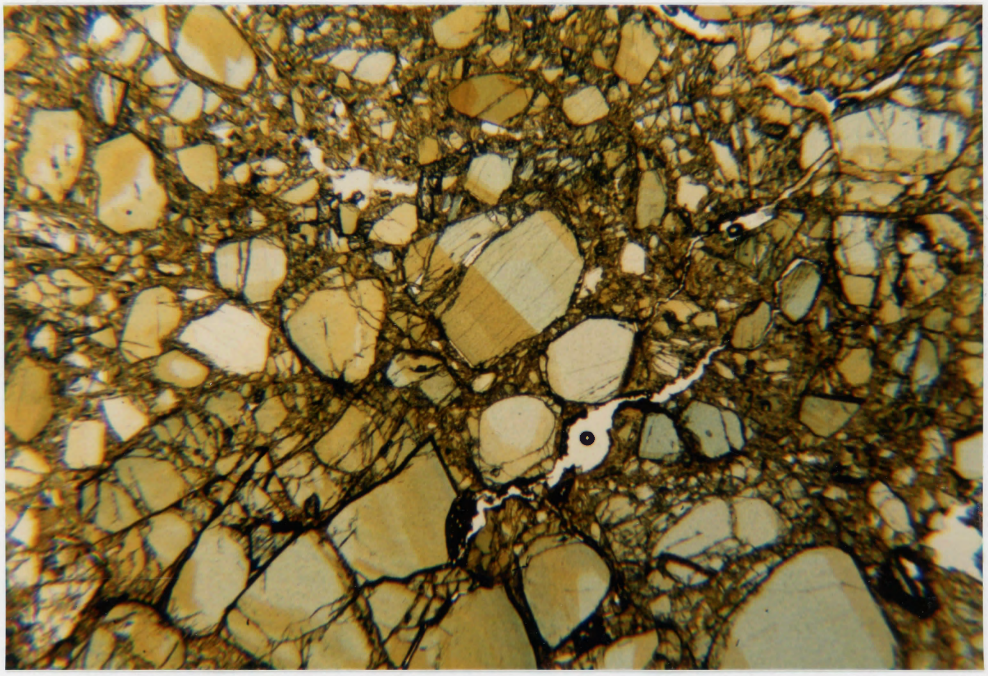
Plate 10. Coxheath: as Plate 9 (2.5X, ppl, field of view = 5 mm).





<u>Plate 11.</u> Wedgeport WP2: felted aggregate of tourmaline needles at quartz grain boundaries (2.5X, ppl, field of view = 5 mm).

<u>Plate 12.</u> Kehoe Hill Greisen SMB14: brecciated and irregularily zoned tourmaline in a matrix of fine-grained tourmaline (2.5X, ppl, field of view = 5 mm).



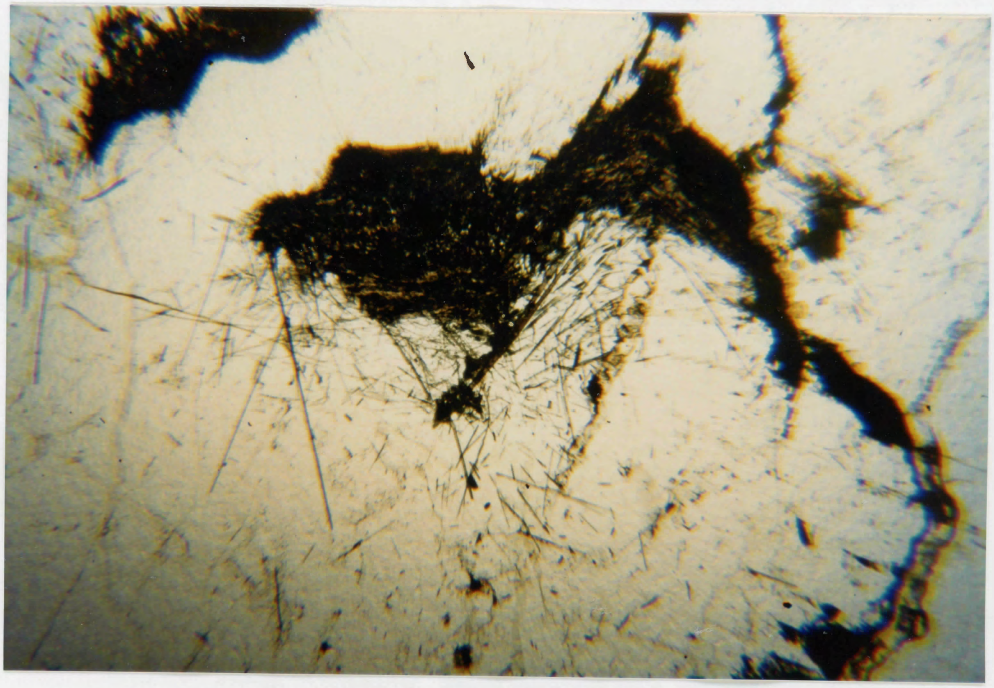
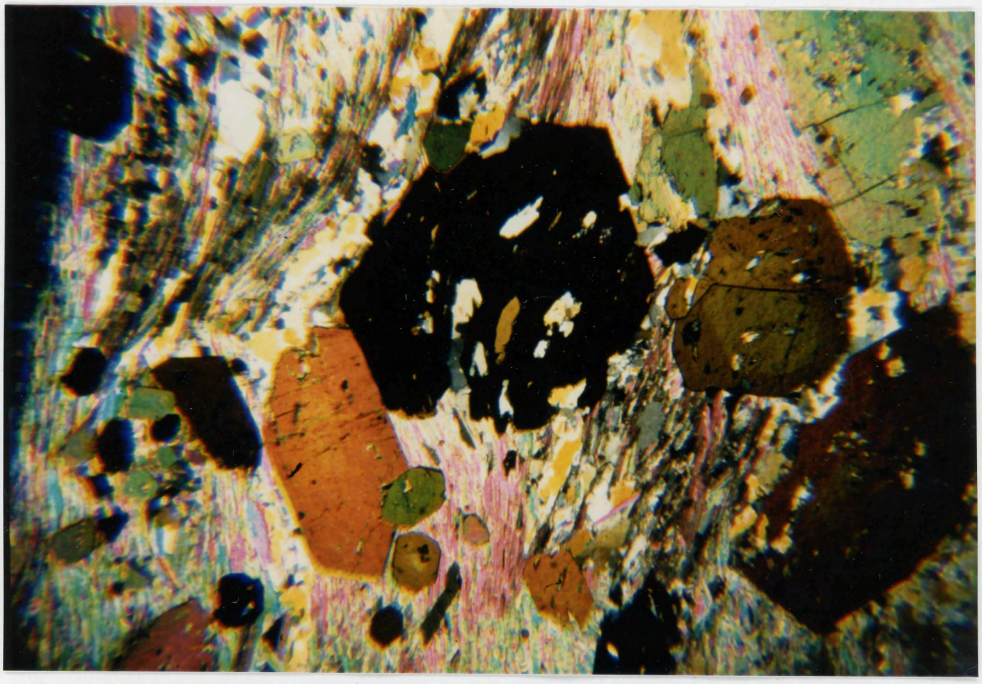
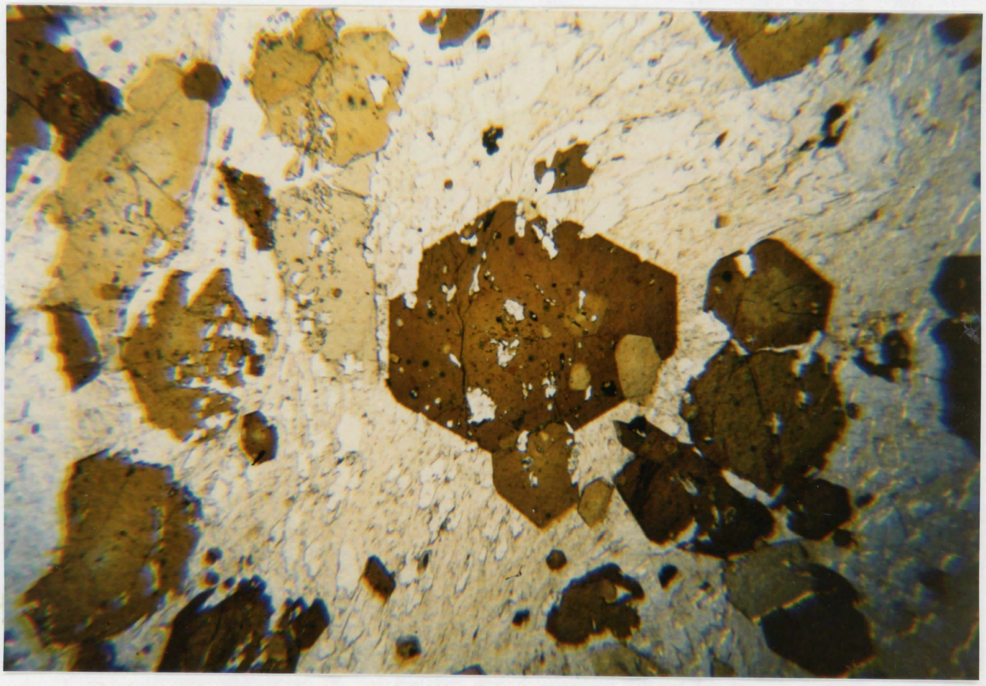


Plate 13. Forest Hill: synmetamorphic euhedral zoned poikilitic brown tourmaline showing inclusion trails (2.5X, ppl, field of view = 5 mm).

Plate 14. Forest Hill: as in Plate 13, note syndeformational relationship (2.5X, xn, field of view = 5 mm).





<u>Plate 15.</u> Pearl Lake: zoned cassiterite closely associated with amber and green tourmaline (10X, ppl, field of view = 1.5 mm).

<u>Plate 16.</u> Brazil Lake: multiple zoning in subhedral to euhedral tourmaline within the Brazil Lake Pegmatite (2.5X, ppl, field of view = 5 mm).