GEOLOGY, GEOCHEMISTRY, AND GENESIS OF THE BRAZIL LAKE PEGMATITES, YARMOUTH COUNTY, NOVA SCOTIA

by

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ABSTRACT

The Brazil Lake pegmatites, located about 25 km northeast of Yarmouth, intrude amphibolites and orthoquartzites of the White Rock Formation on the eastern flank of the Yarmouth syncline. The pegmatites are of igneous origin and were forcefully injected into fractures subparallel to the strongly developed regional schistosity. The following mineralogy was determined for the lithium-rich pegmatites: quartz, albite, microcline, spodumene, muscovite, beryl, tourmaline, zircon, apatite, columbite, tantalite, biotite, epidote and cassiterite.

Three distinct chemical/mineralogical/textural phases are recognized within the pegmatite. The three phases are asymmetrically distributed in zones. These zones, in order of emplacement, are: zone A - a coarse-grained, K-rich microcline-quartz-muscovite phase; zone B - a very coarse-grained, Li-rich spodumene-quartz-muscovite phase; and zone C - a Na-rich aplitic albite-quartz phase. The strong partitioning of the alkali elements Li, Na and K, is interpreted to have resulted from differential rates of element transport and crystallization, owing to the presence of a fluid phase coexisting with the silicate magma. Metasomatic effects from the pegmatite resulted in tourmaline and holmquistite (a rare Li-rich amphibole) being emplaced in the host quartzite rocks.

A K-Ar date of 333 ± 7 Ma was determined for the pegmatites, and this is interpreted as a cooling age, possibly resulting from thermal overprinting. This date is in agreement with dates from other southern Nova Scotia plutons, including the Brenton, which is just 2 km southwest of the Brazil

Lake pegmatites. These other plutons all record a Late Carboniferous tectonic or thermal event dated at about 320 Ma.

The genetic evidence available is inconclusive, but it is very unlikely that the Brazil Lake pegmatites, which contain an average of 1.16% Li_2O, were derived from the nearby Brenton pluton, which is, in fact, depleted in lithium (averaging 71 ppm Li), when compared to other southern Nova Scotia plutons.

ACKNOWLEDGEMENTS

The advice and support of Dr. G. K. Muecke throughout this project is gratefully acknowledged. Mr. S. Parikh performed the wet chemical analyses and Dr. P.H. Reynolds and Mr. Keith Taylor provided the K-Ar dates. I am very grateful to both of them. Dr. P.E. Schenk kindly allowed me to use his camera and microscopic equipment. I thank Mr. Bob MacKay for his patient advice and help with the microprobe analyses and computer calculations.

Mr. Dave McAslum and Mr. Roger Cornish, both of Shell Canada Resources, kindly gave their permission for access to Shell's data on the Brazil Lake project. The information and advice of Mr. Vicente Palma and Mr. Paul Sinclair was invaluable during the summer field work at Brazil Lake. Finally, I would like to express my gratitude to Mrs. Dianne Crouse for patiently typing the manuscript.

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CHAPTER 1

INTRODUCTION

1.1 LOCATION

Brazil Lake is located about 25 km northeast of the town of Yarmouth (Figure 1.1) at 44°00'N latitude and 66°00'W longitude. Access to the area is excellent. Highway 340 has a good secondary road which runs from Pleasant Valley westward to a paved road leading from Gardeners Mill south to the Brenton intersection. The community of Brazil Lake is located at the intersection of this secondary road and the paved road. The map area studied is located about 0.5 km north and south of the secondary road, near the Brazil Lake intersection.

1.2 PHYSIOGRAPHY

The southwest mainland of Nova Scotia is generally flat-lying, with abundant lakes and marsh land. Elevation rarely exceeds 100 m. Outcrop, except along the coast, is poor because of a thick glacial till and softwood cover. The thickness of the till averages 5 to 10 m in the general study area, but locally may reach a depth of 25 to 30 m (from general knowledge of drilling area). Outcrop in the map area is relatively good, however, with at least two or three exposures of each major rock type. Within the map area, the swamp and marsh lands generally overlie the garnet-mica and staurolite-mica schists, whereas the rounded hills and uplands are underlain by the more resistant metabasites and meta-

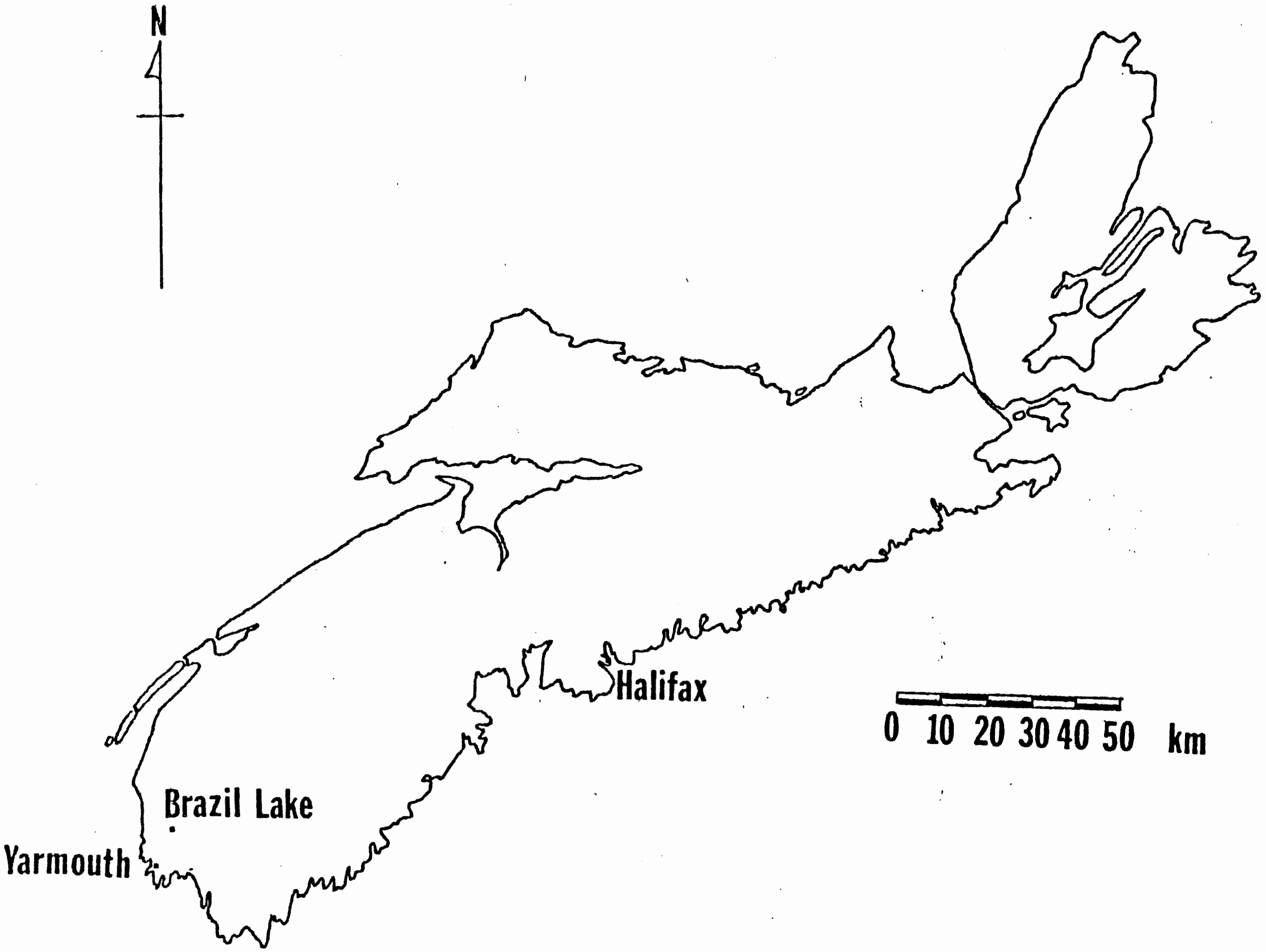


Figure 1.1– Location Map

quartzites (geological map back cover).

1.3 PREVIOUS WORK

E. R. Faribault (1918) mapped most of western Nova Scotia for the Geological Survey of Canada. Subsequent reconnaissance mapping by the G.S.C. includes work by Crosby (1962), Smitheringale (1960, 1973), and Taylor (1965, 1967, 1969). O'Reilly (1976) studied the petrology of the Brenton pluton (the closest granitic body to the pegmatites) and Sarkar (1978) produced a detailed study of the petrology and geochemistry of the White Rock metavolcanic suite (the host rock for the pegmatite).

G.S.C. Map Sheet 1186A (1967) by F.C. Taylor shows the geology of the Shelburne map area at a scale of 1 inch = 2 miles (1:126,720) and includes the spodumene-bearing Brazil Lake pegmatite occurrence. In the accompanying report (G.S.C. Memoir 349), Taylor includes a sketch map of the pegmatite area, at a scale of 1 inch = 2000 feet (1:24,000). Included also, is a modal analysis of the mineralogy of the major pegmatite outcrop.

The main pegmatite body at Brazil Lake has been drilled within the last twenty years. The exploration company involved failed to file a report with the Department of Mines, however, so no record of the geology encountered in the drillhole exists.

1.4 SCOPE, OBJECTIVES AND ORGANIZATION OF RESEARCH

Field work was carried out in the month of August, 1981, during summer employment with Shell Canada Resources Ltd. Approximately ten days were spent mapping the pegmatite area and collecting samples for thin section study, age dating, and chemical analysis of the material.

The main aim of this study is to describe the petrology and mineralogy of the pegmatitic bodies and their host rocks, and to devise a petrogenetic history for the area using all available chemical, mineralogical, structural, and age data.

The work was divided into a number of sections. Four bulk samples, representative of the different zones within the main pegmatite were collected, using a wire grid to ensure a statistically random sample. The grid covered 1.44 m^2 total area (1.2m x 1.2m) with 30 cm centres. A fist-sized sample of pegmatitic material was collected, using a chisel and hammer, at each of the 25 intersections on the grid. Thus, each of the four bulk samples covered an area of 1.44 m^2 and weighed approximately 3-4 kg before crushing.

Part of these four bulk samples were crushed, with a ceramic swing mill, and submitted for whole rock wet chemical analysis. A portion of each of the four powders was also sent to a commercial lab for assaying. The remainder of the bulk samples were crushed in a tungsten-carbide swing mill, homogenized, and sieved into four grain size fractions for heavy mineral separation. The fraction retained on the -40 +60 mesh was run through an electro-magnetic separator to isolate magnetic mineral grains from quartz, feldspar and spodumene.

The magnetic grains were then separated with a heavy liquid

($CHCl_3$, specific gravity = 3.32, using CCl_4 as a solvant) into three fractions; heavy minerals (S.G. > 3.32), intermediate (S.G. < 3.32, > 2.90, determined by presence of abundant muscovite, S.G. = 2.90) and lighter grains (S.G. < 2.90). These grains were scanned with a binocular microscope and unknown specimens were selected, mounted in resin, and analyzed by the electron-microprobe.

Thirty hand samples were selected for thin section study and description. Subsequently, ten polished sections of both pegmatite and country rock were prepared and analyzed with the electron-microprobe.

Fresh, large flakes of muscovite collected from the pegmatite were cut, pulverized and analyzed by wet chemical methods. Muscovite samples were also submitted for K-Ar dating.

CHAPTER 2

REGIONAL GEOLOGY AND SETTING OF THE PEGMATITE

2.1 STRATIGRAPHY

The Brazil Lake pegmatites occur within the White Rock Formation, of Ordovician or Silurian age (Lane, 1975), which is underlain by the Meguma Group metasediments, of Cambro-Ordovician age (Schenk, 1971). The White Rock Formation is composed of diverse rock types including sedimentary, metasedimentary and metavolcanic rocks, often exhibiting little stratigraphic continuity. Outcrops of the White Rock Formation occupy the axis and flanks of regional south-west trending synclines, in a 230 km long belt which parallels the Fundy coastline of southwestern Nova Scotia.

The stratigraphic thickness of the White Rock Formation shows an increase from east to west in the Annapolis Valley. It increases from 100 m in the Wolfville map-area to 1000 m in the Digby map-area, reaching a maximum thickness of 4950 m in the Yarmouth area (Taylor, 1967, 1969). In the Yarmouth area, the top of the section is not exposed. Lane (1980) and Sarkar (1978) reinterpreted the stratigraphy of the White Rock Formation based on correlations of individual sections. In good exposures along the coast, it was recognized that parts of the stratigraphic section are repeated along vertical faults which parallel the regional synclinal axis. A minimum thickness of 3000 m has been determined for the White Rock Formation from these studies.

The stratigraphic thickening of the White Rock Formation towards the Yarmouth area is accounted for by the presence of the metavolcanic rocks which make up 50% of the section at Yarmouth. The dominant metavolcanic rock types are the metabasites (85%), with the metafelsites comprising the remainder (15%).

Accurate correlation, mapping and thickness determination of the White Rock Formation is made difficult by pervasive stratigraphic discontinuity. Taylor (1967) concluded that the only characteristic rock type of the White Rock Formation is the white to grey massive quartzite. Despite these difficulties however, good coastal exposures allowed Sarkar (1978) to determine a general stratigraphy of the White Rock Formation for the Yarmouth area.

The formation was divided into two Members. The Lower Member (400-500 m thick) is composed of a basal feldspathic quartzite with minor schists, followed by a thick pelitic schist with subordinate micaceous quartzite and feldspathic quartzite and a 1.5 - 5 m thick garnet-biotite schist with metabasite sills. The Upper Member (160-570 m thick) is composed of grey to white orthoquartzite with thick metabasite sills and dykes; overlain by a metabasite of flow origin, a thick metafelsite and metamafelsite near the stratigraphic top.

The contact of the White Rock Formation with the underlying Halifax Formation has been the topic of considerable debate in recent years. The controversy has centered particularly on the exposure of the contact at Cape St. Mary. Here, the contact exhibits axial plane cleavage which is almost parallel to the stratification in the Halifax Formation. In another outcrop at Cape St. Mary, the upper few metres of the Halifax Formation show isoclinal folds with axial planes almost parallel to the stratification in the underlying undeformed parts of the formation and the overlying White Rock (Schenk, 1972). These observations have been variably interpreted as (1) a high angle unconformity of local significance (Taylor, 1965), (2) a thrust fault (Keppie, 1980), and (3) a structurally modified but conformable contact (Lane, 1980).

2.2 INTRUSIVE ROCKS

The major episode of igneous intrusion in southern Nova Scotia was the emplacement of the South Mountain batholith during Late Devonian time. A mean age of 367 Ma has been determined for the South Mountain batholith and the northern stocks whereas the southern satellite plutons (Figure 2.1) yield an apparent age of 300-320 Ma (Reynolds et al., 1981). The composition of the batholith is granodioritic to adamellitic (McKenzie and Clarke, 1975). McKenzie and Clarke have also shown, chemically, that the various rock types of the batholith are representatives of a single comagmatic suite, probably related by fractional crystallization. Albuquerque (1977), however, suggested that the southern plutons were not the product of differentiation, but rather a result of partial melting of the metasedimentary rocks in the orogenic belt, based on geochemical affinities such as high Na/K and K/Rb ratios and REE abundance patterns.

Abundant evidence has defined a strong correlation between the occurrence of late stage differentiates and concentrations of certain

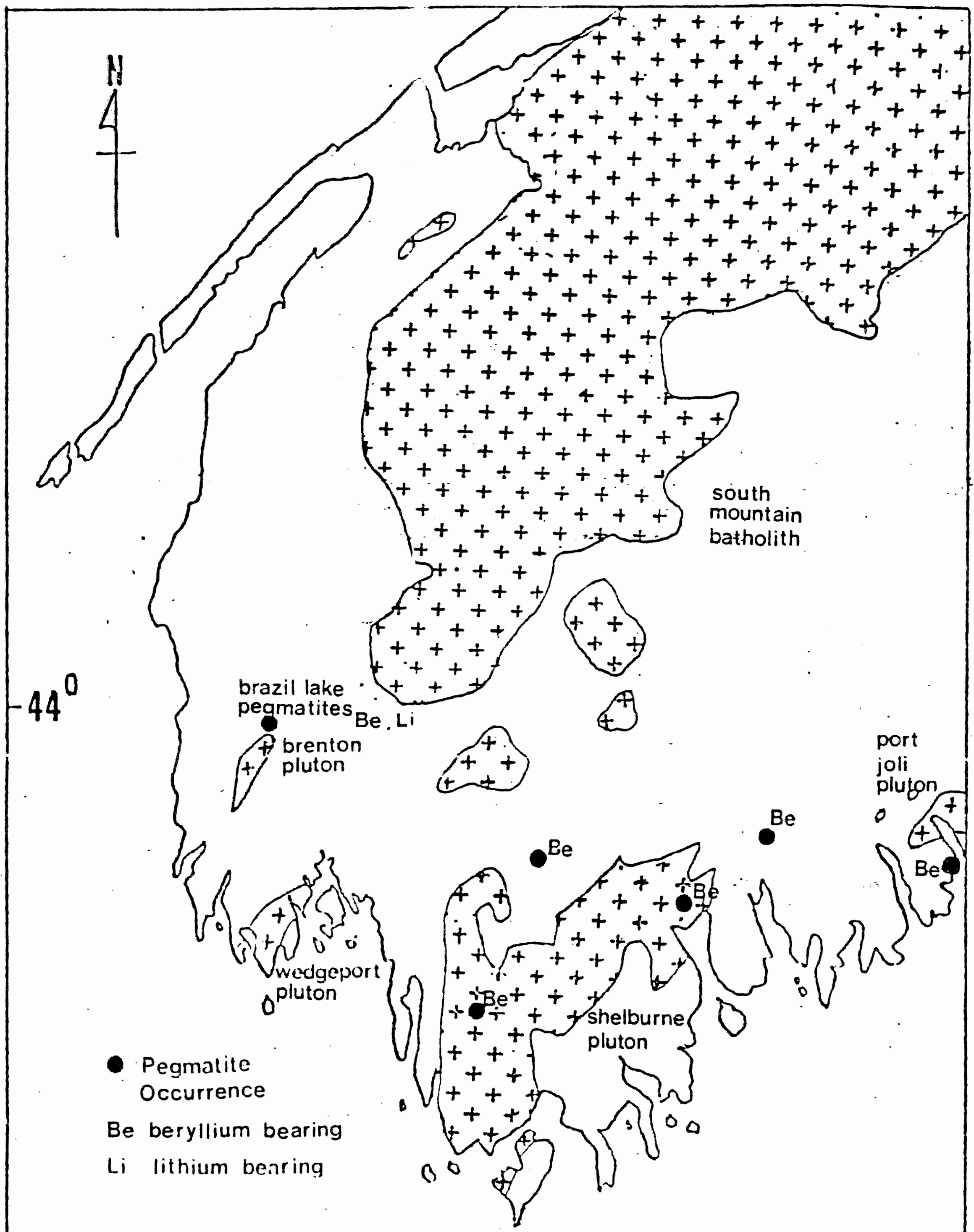


Figure 2.1 – Distribution of Igneous Intrusives in Southwestern Nova Scotia (from Geol. Map of the Prov. of N.S., comp. by J. D. Keppie, 1979)

elements of economic interest in the South Mountain batholith. In the New Ross area, successively later stage intrusives consisting of granodiorite, adamellite, aplite dykes, leucoadamellite, late aplites, pegmatites and quartz veins host Li, Be, P, F, As, Zn, Mn, and Nb-Ta mineralization (Charest, 1976). The mineralization is restricted to late stage aplites, pegmatites and veins, but most concentrated in greisenized zones. The nearby Walker-Turner prospect, located within the New Ross-Vaughan complex, hosts As, Zn, Cu, Sn, W and U mineralization, and is also greisenized. The greisenizing fluid is interpreted to be the end product of differentiation of the granitic melt. The fluid was rich in volatiles, incompatible elements and rare metals (Farley, 1979).

Charest (1976) suggests that sufficient degrees of chemical evolution to produce high concentrations of certain elements occurred only in the thickest part of the batholith, where cooling was slowest and fractional crystallization most efficient. He suggests that other areas remote from New Ross, which is near the centre of the batholith, have low potential for mineralization. Muecke and Clarke (1981) however, have shown that the importance of fluid transport relative to fractional crystallization probably increased during the cooling of the South Mountain batholith. The recent discovery of many local concentrations of certain elements near the South Mountain batholith - country rock contact, associated with greisenized zones, supports this concept. Geochemical expressions of the late-magmatic stage, fluid-enriched processes in the South Mountain batholith include enrichment in the alkalis (Li, Rb, Cs), Sn, Ta and F and low K/Rb and Th/U ratios (Muecke and Clarke. 1981).

One unusual trend observed in the South Mountain batholith is the fact that Nb does not vary significantly with differentiation (Charest, 1976) and the REEs decrease (Muecke and Clarke, 1981).

An economic tin deposit is located about 25 km east of the Brazil Lake area, near the community of East Kemptville. It is hosted by strongly greisenized leucoadamellite and the ore mineral is cassiterite, which is disseminated throughout the rock and localized in veins. The deposit is located just inside the Davis Lake pluton-Meguma metasediment contact.

The Brenton pluton is a "true" granite in chemical composition, being more siliceous and potassic than surrounding igneous bodies. It is also unique in that it has a strong foliation and cataclastic texture (O'Reilly, 1976). Some outcrops of the Brenton however, do exhibit a massive equigranular texture (Reynolds _et al._, 1981). Also minor, local areas of foliation do exist within the other southern plutons, but generally they are not strongly foliated.

Pegmatitic bodies have been described in association with other southern Nova Scotia plutons and are relatively common (Figure 2.1). Virtually all of the pegmatites on the southwestern shore of Nova Scotia are mineralogically simple. Most are beryllium-bearing, while many contain tourmaline, and some are garnetiferous (Kent, 1962). There are no other pegmatitic occurrences which contain lithium-bearing minerals in southwestern Nova Scotia other than the Brazil Lake pegmatites, to the writer's knowledge.

2.3 METAMORPHISM

All of the Lower Paleozoic, pre-granitic rocks of southern Nova Scotia have been regionally metamorphosed (Taylor, 1969), and locally overprinted by contact metamorphism and intrusive phases. This period of regional metamorphism took place during early to middle Devonian time (Keppie and Muecke, 1979). The pattern of regional metamorphism developed in southwestern Nova Scotia can be seen in Figure 2.2, showing the highest grade (sillimanite) zone centered near Shelburne, flanked by progressively lower grade amphibolite and greenschist zones to the east and west. The general metamorphic facies of the study area around Brazil Lake is middle greenschist to lower amphibolite.

2.4 STRUCTURE

The dominant structural feature of the Lower Paleozoic rocks of southern Nova Scotia is the north to northeast trending folds in the sedimentary rocks, resulting from the (Devonian) Acadian Orogeny. The structural grain developed around the Yarmouth area is not concordant with the rest of mainland Nova Scotia. The fold axes are much more steeply dipping northward, whereas they are oriented in more of an east-westerly direction in the rest of the Meguma massif.

Fyson (1966) reported minor cross folds (F_2 and F_3) in addition to the more pervasive north to northeast trending (F_1) folds in the Halifax Formation. The Yarmouth syncline is one of the major (F_1) folds, and is important because it has preserved the Upper Ordovician to Lower

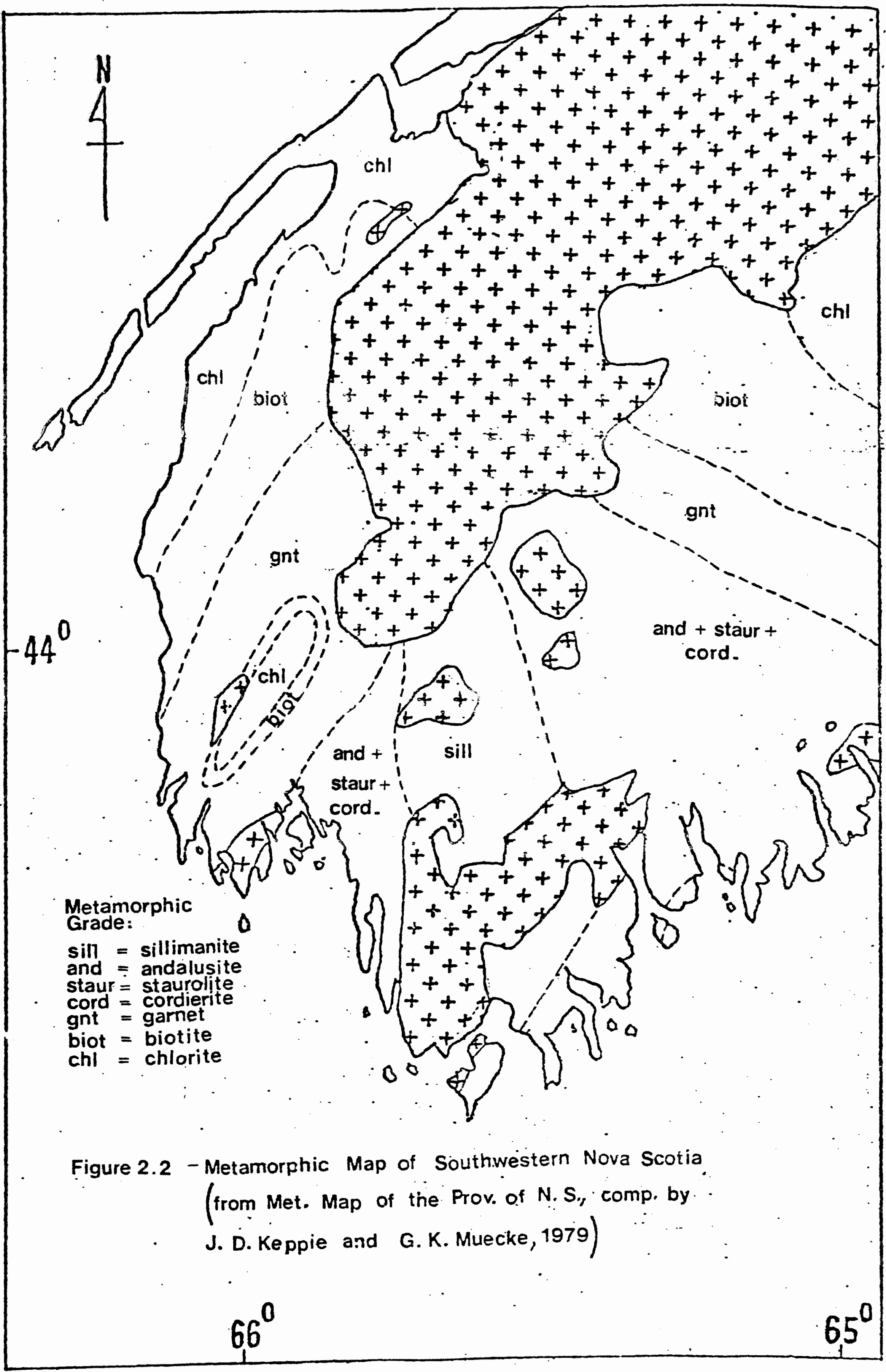


Figure 2.2 – Metamorphic Map of Southwestern Nova Scotia (from Met. Map of the Prov. of N. S., comp. by J. D. Keppie and G. K. Muecke, 1979)

Silurian strata from erosion.

The Brenton pluton is chemically and structurally distinct from the South Mountain batholith (O'Reilly, 1976). It is strongly foliated and the strike of the foliation is coincident with that of the country rocks. O'Reilly suggests local faulting to explain the rare, minor deviations in the foliation direction, although no direct evidence of faulting is observed. The Brenton pluton is unique in that none of the other southern plutons in the area show the pervasive foliation characteristic of the Brenton. The extent and significance of faulting in this area is still uncertain. Taylor (1967) however, concluded that faults are scarce in the area and with rare exceptions, of local significance only. Lane (1980) and Sarkar (1978) however, recognized major repetitions in the White Rock stratigraphy and mapped vertical faults parallel to the Yarmouth syncline.

CHAPTER 3

PETROGRAPHY OF THE PEGMATITE

3.1 INTRODUCTION

Four discrete outcrops, representing two pegmatitic bodies, are exposed within the map area (geological map, back cover). The best exposed outcrop occurs south of the dirt road and consists of a continuous elongate mass of rock about 24 m long and 4 m wide, which has been exposed by preferential erosion of the less resistant host rocks. The linear mass of pegmatite rises about 1.5 m above the ground and the only direct contact with the country rock is observed in a small patch on the southeast face. North of the road, three poorly exposed pegmatite outcrops occur along a linear ridge, striking roughly parallel to the southern pegmatite body. This is believed to constitute a separate, but contiguous, pegmatite dyke.

One pegmatite body was examined outside of the map area, within the Brenton pluton. The exposure is found along a cut power line and consists of foliated granite which is crosscut by quartz-tourmaline veins and pegmatite dykes of simple mineralogy (quartz + feldspar + mica ± tourmaline). There appears to be a concentric zonation pattern developed around the pegmatite dykes which consists of simple quartz veins, quartz-tourmaline veins, and finally, pegmatite dykes ± tourmaline within a 200-300 m radius of the exposed pegmatites. Many boulders of pegmatite material are located around the exposure and some of them show undeformed pegmatites crosscutting the pervasively developed foliation in the Brenton granite.

3.2 INTERNAL ZONATION PATTERNS

The southern pegmatite outcrop was mapped in detail to determine a possible mineralogical pattern. A general distinction is made between "simple" (quartz-feldspar ± tourmaline, mica) pegmatites and "complex" (rare-metal) pegmatites by most workers, and one feature of the complex type is some sort of internal zonation pattern. In order to be of economic interest, generally, rare-metal pegmatites must be zoned to some degree. It is, however, recognized that all gradations exist from complete, symmetrical zones to partially developed zones, and pods or lenses that occur only on one side of the pegmatite (Cameron et al., 1949).

A modal analysis of the pegmatite was performed using a wire grid for point counting, with 30 cm centres. A total of 758 points were counted. The results were recalculated to 100% and appear in Table 3.1. A copy of Taylor's (1967) modal analysis of this outcrop is included, and compares favourably with the present results, except that Taylor did not distinguish between albite and microcline. The points were colour coded for different minerals and zones rich in particular minerals were delineated as shown in Figure 3.1. The modal points were recalculated to 100% for each of the three zones defined, and the results appear in Table 3.1.

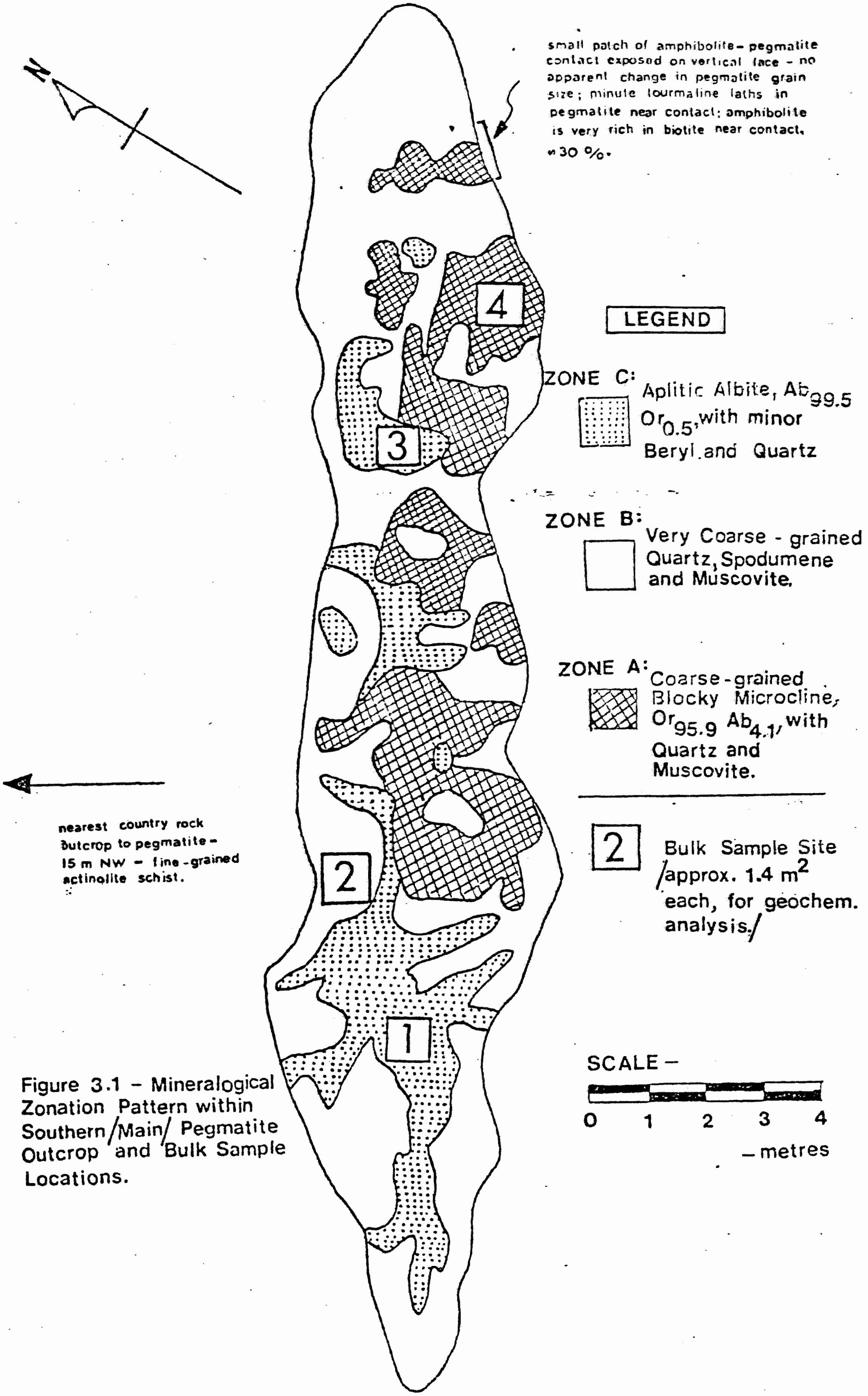


Figure 3.1 - Mineralogical Zonation Pattern within Southern/Main/ Pegmatite Outcrop and Bulk Sample Locations.

TABLE 3.1 - Modal Analysis of Southern (Main) Pegmatite Outcrop, Brazil Lake - Volume %, Overall Total, based on 758 points, Taylor's (1967) Modal Analysis, and Modal Analysis of the Three zones defined in Figure 3.1.

(This Study, 1982)		(Taylor, 1967)	
Microcline ($Or_{95.9}$)	26.0%	Feldspar	52.4%
Albite ($Ab_{99.5}$)	22.0%	Quartz	34.0%
Quartz	35.4%	Spodumene	10.7%
Spodumene	13.6%	Mica	2.6%
Mica	2.5%	Beryl	0.5%
Beryl	0.5%		
Total	100.0%	Total	100.2%

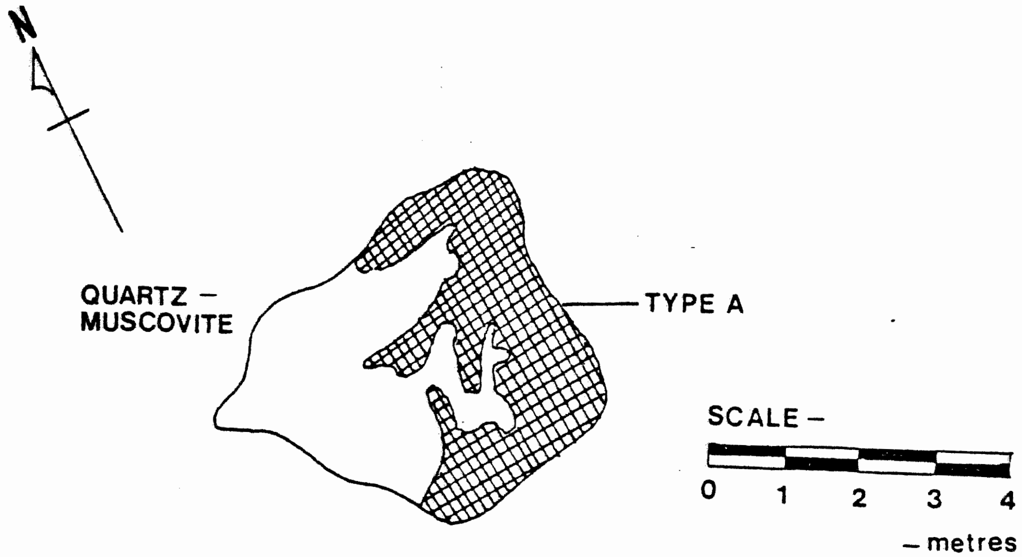
Zone A (This Study, 1982)		Zone B (This Study, 1982)		Zone C (This Study, 1982)	
Microcline($Or_{95.9}$)	58.5%	Quartz	44.0%	Albite($Ab_{99.5}$)	64.0%
Quartz	35.8%	Spodumene	38.5%	Quartz	22.3%
Spodumene	2.2%	Albite($Ab_{99.5}$)	7.7%	Beryl	1.8%
Muscovite	2.5%	Muscovite	5.3%	Microcline($Or_{95.9}$)	11.9%
Albite	1.0%	Microcline($Or_{95.9}$)	4.5%		
Total	100.0%		100.0%		100.0%

Three distinct mineralogical/textural zones were recognized in the Brazil Lake pegmatite. Although the three pegmatitic phases are somewhat sporadic in their distribution, a gross pattern of mineralogical segregation is evident in Figure 3.1, and the term zone will be used because this is common in the literature. An outer rim of very coarse-grained quartz-spodumene intergrowth with abundant green muscovite is characterized by giant spodumene crystals up to 60 cm long. A zone of coarse, blocky microcline, quartz and muscovite is developed on the southeast face of the outcrop. The third zone is irregularly distributed throughout the core and fingers into the outer zones. It is composed of a uniquely textured saccaroidal aplite, consisting of almost pure albite.

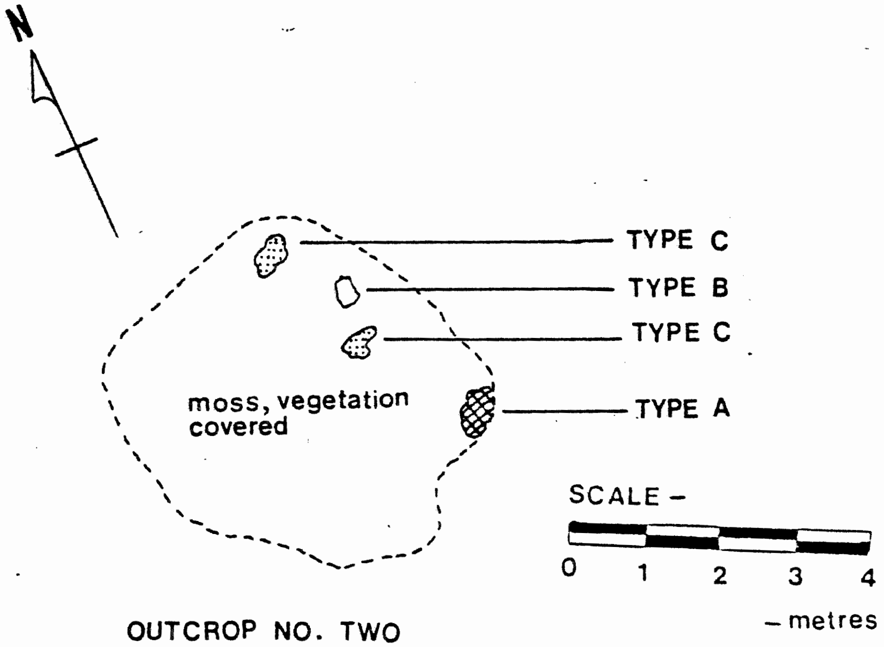
Although the three pegmatite outcrops north of the road are poorly exposed, certain mineralogical segregations were observed within them (Figure 3.2). The textures and mineralogy developed in these pegmatite exposures are very similar to those observed in the southern body, and therefore will be discussed together as zones A, B, and C. The three northern outcrops will be referred to as outcrop numbers 1, 2 and 3 from most southerly to most northerly (see geological map, back cover for relative locations).

3.3 ZONE A; MICROLINE-QUARTZ

A zone of blocky, off-white to grey microcline is asymmetrically distributed in the main outcrop (Figure 3.1). It is restricted to the southeastern side and upper half of the body. Weathered, blocky microcline crystals (3-5 cm diameter) are associated with veins, 2-4 cm wide,



OUTCROP NO. ONE



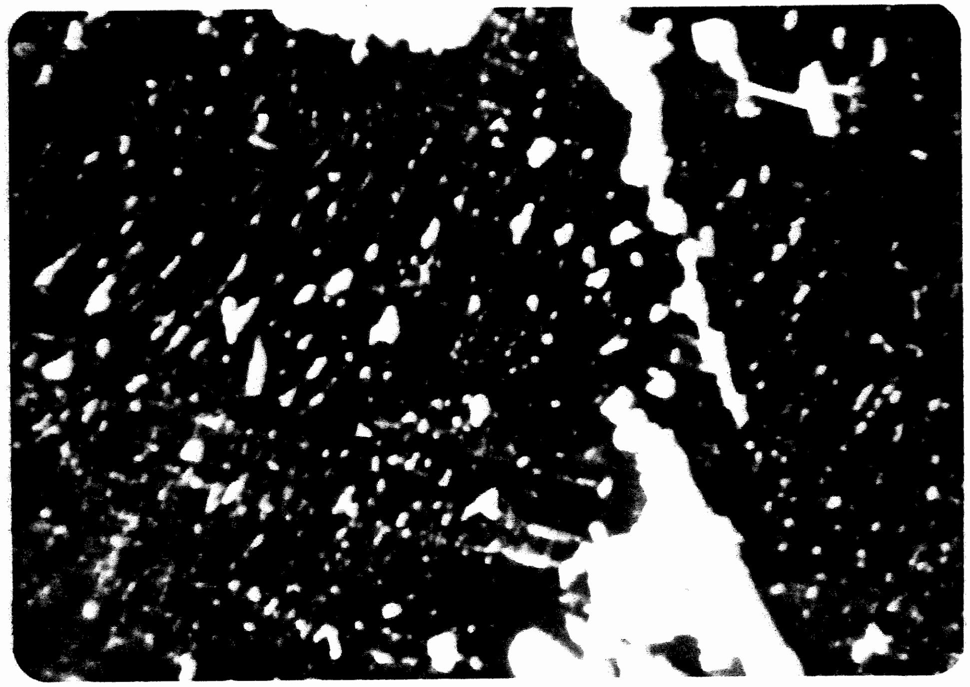
OUTCROP NO. TWO

Figure 3.2 – Mineralogical Zonation Pattern in Two Northern Outcrops. No country rock contacts were observed. Refer to Fig 3.1 for description of pegmatite types A, B, C.

of clear quartz and light green muscovite books, 1-2 cm in diameter. Clear to smokey quartz also occurs as nodular grains, 1-3 cm in diameter, intergrown with the feldspar.

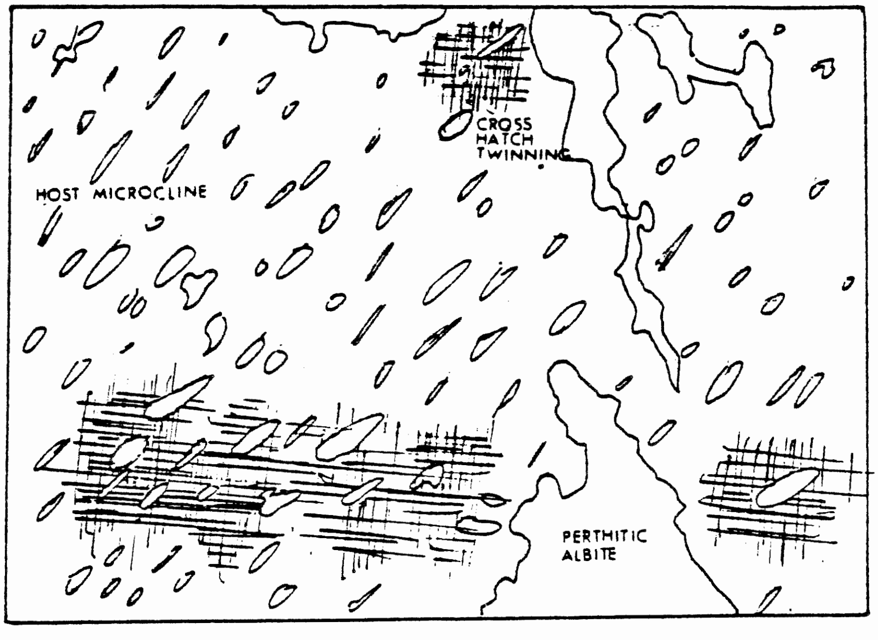
Outcrop #1 of the northern exposures shows a large segregation of zone A-type pegmatite, (microcline and quartz) again, on the southeastern face (Figure 3.2) of the exposure. Here, the blocky, 3-5 cm diameter, microcline is more pink to flesh-coloured and appears fresher than that from the southern outcrop. The quartz is more concentrated in fractures (1-2 cm wide) and microfractures (< 0.5 cm) in this outcrop, which cross-cut individual crystals of feldspar randomly. The quartz veins also carry abundant books of coarse-grained, 2-4 cm diameter, green muscovite. The northwestern side of this outcrop is made up largely of clear to smokey, coarse-grained, 5-10 cm diameter, nodular quartz grains and coarse-grained books of green muscovite. No spodumene was observed in association with the quartz.

A well developed micro-perthitic texture is seen in thin sections of the blocky microcline from the southern and northern #1 outcrops. In the southern one, patchy perthitic albite occupies cross-hatch twinning planes in the host microcline. In the #1 northern outcrop, however, microcline occurs with "flame-type" micro-perthite stringers which diagonally cut the cross-hatch twinning (Plate 3.1). This is somewhat unusual in that "flame-type" perthites most frequently follow cross-hatch twinning planes in microcline (Augustithis, 1974). A metasomatic origin is generally invoked to explain perthites which follow cross-hatch twinning or other intracrystalline directions of penetrability.



XN, X 10

Plate 3.1. Micro-perthitic albite stringers cross-cutting cross-hatch twinning in host microcline, from northern #1 outcrop.



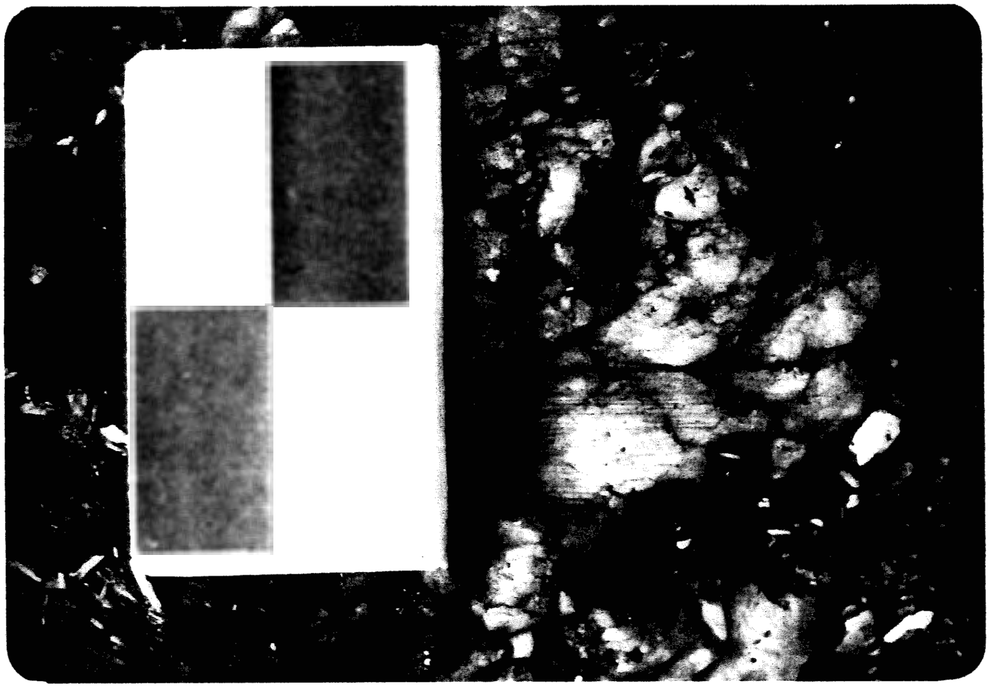


Plate 3.2. Massive quartz with imprint of weathered-out spodumene crystal in lower left hand corner, showing deeply striated face.

The micro-texture of both outcrops is further complicated by the presence of relatively unaltered subhedral albite laths, poikiloblastically enclosed in the microcline.

The northern #1 microcline outcrop, however, contains microfractures, and locally, small stringers of perthite can be observed originating from the fractures and penetrating the microcline. Here then, the perthite-forming process was probably, at least in part, the result of mechanical stress on the microcline. It should be mentioned that few perthites form solely by one process. Smith (1974) classifies perthites under four modes of formation; exsolution, replacement, filling of voids and simultaneous growth. He qualifies the classification by stating that it is usual for more than one process to act simultaneously. He cites the example of infiltration cracks in K-feldspar by Na-rich solutions inevitably being accompanied by some replacement. A further qualification should be placed on "replacement" to imply material coming from a considerable distance, as opposed to local replacement as in exsolution (Smith, 1974).

The blocky microcline is replaced, along fractures and zone boundaries (zone A/zone C contacts) by the aplitic albite phase. Patchy areas of white to cream coloured albite are observed replacing the coarser-grained pink microcline.

A small patch of contact with the wall rock occurs on the southeast corner of the main outcrop (Figure 3.1). Here tiny, 0.5-1.0 cm long, tourmaline laths are developed just inside the pegmatite-amphibolite contact and aligned parallel to it. No apparent change in the grain size of the blocky microcline is observed at the contact.

Zone A appears to be best developed in the northeastern corner of the northern number two outcrop (Figure 3.2). Here it is again associated with quartz and green muscovite, and minor (< 5%) spodumene occurs with the microcline-quartz.

3.4 ZONE B: SPODUMENE-QUARTZ

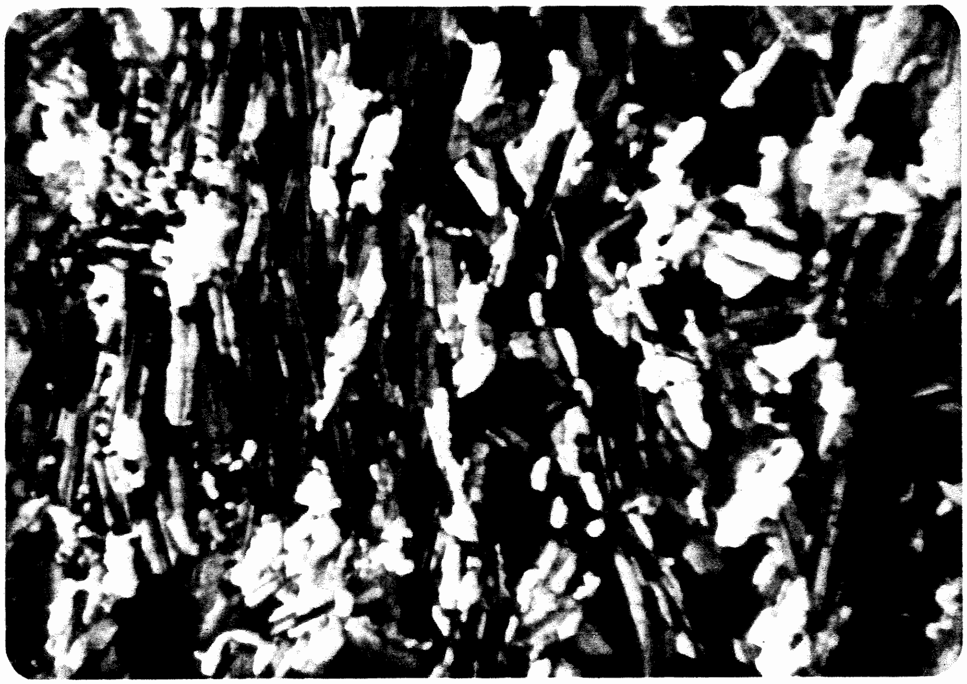
Zone B, the quartz-spodumene zone, is the lithium-rich zone of the Brazil Lake pegmatite, and is characterized by giant crystals of spodumene up to 60 cm long. Taylor (1967) reported spodumene crystals up to 4 feet in length from this outcrop, but mineral collectors have scavenged the area since that time. The coarse spodumene crystals average 4-5 cm in length and have well developed crystal faces which are usually striated parallel to the long axis of the mineral. The beige to off-white spodumene crystals are intimately associated with nodular clear to smoky quartz grains, 1-5 cm in diameter. Occasionally, the quartz is observed as inclusions in the larger spodumene crystals. The intimate intergrowth of these two minerals is evident from the impressions of striated faces left in quartz where spodumene crystals have weathered out (Plate 3.2). Coarse-grained, 2-3 cm diameter books of green muscovite are also strongly associated with the quartz veins and nodular masses in zone B.

Zone B appears to be developed in the outer rim of the northern #2 outcrop as well (Figure 3.2). On the extreme southeastern edge of the poorly exposed outcrop, spodumene crystals, up to 15 cm in length, are intimately associated with clear quartz and green muscovite.

No apparent mineral lineation was observed in zone B, on visual or microscopic inspection of the southern pegmatite. A detailed statistical analysis of the orientation of the giant spodumene crystals might show a slight preferred orientation, but this is not readily observable in outcrop. The orientation of the various minerals in different zones may, however, have been altered since the initial crystallization of the body as a result of fracturing or displacement due to the introduction of new material.

3.5 ZONE C: APLITIC ALBITE

The aplitic albite phase, zone C, shows a striking contrast in texture and mineralogy compared to zones A and B which are much more coarse-grained. It is composed of fine-grained (< 0.5 mm) laths of almost pure albite ($Ab_{99.5}$). The distinct granular, or saccaroidal texture and uniform grain size make this phase very easy to recognise. In thin section, the texture appears as prismatic, twinned albite laths with minor anhedral quartz and subhedral beryl (Plate 3.3), which usually occurs in clusters or pods of crystals. In hand specimen, these beryl prisms are observed to be aligned perpendicular to the long axis of the pegmatite, apparently as a result of having grown from a cooling face parallel to the wall rock contact, inward. Evidence of minor deformation is observed in rare deformation twins in albite and slightly bent laths.



XN, X 10

Plate 3.3. Aplitic albite phase (zone C), from southern pegmatite outcrop.

The texture of zone C is not unlike that of a typical anorthosite with the feldspar laths being albite rather than anorthite (Plate 3.3). The rock may be termed an albitite.

This phase is irregularly distributed in the main pegmatitic body (Figure 3.1). It typically fingers into the other two zones and locally albite is observed replacing the microcline of zone A. A very similar distribution of zone A is seen in the northern outcrop #2 (Figure 3.2). Here, the aplitic albite occurs in two exposures between exposures of zones A and B, and thus it is probably exhibiting a similar interfingering type of irregular distribution pattern as is observed in the main pegmatite.

An exposed face in the southwestern corner of the main pegmatite reveals a patch of aplitic albite rich is biotite. This is the only place where biotite is observed in any of the pegmatite outcrops, and probably represents a partially assimilated xenolith of country rock.

The aplitic albite phase sporadically grades into a coarser-grained (0.5-2.0 cm) cleavlandite phase. Another interesting feature of the distribution of zone C is the fact that it preferentially occurs where closed fractures in the pegmatitic body are found (c.f. Figure 3.1 and 3.3). This may imply that the aplitic albite is a late-stage, fracture filling phase. Alternatively, the pegmatitic body may have been entirely consolidated before fracturing occurred, and the fractures developed in the aplitic phase simply because it was less resistant than the very coarse-grained quartz-spodumene phase. Whatever the case, it appears

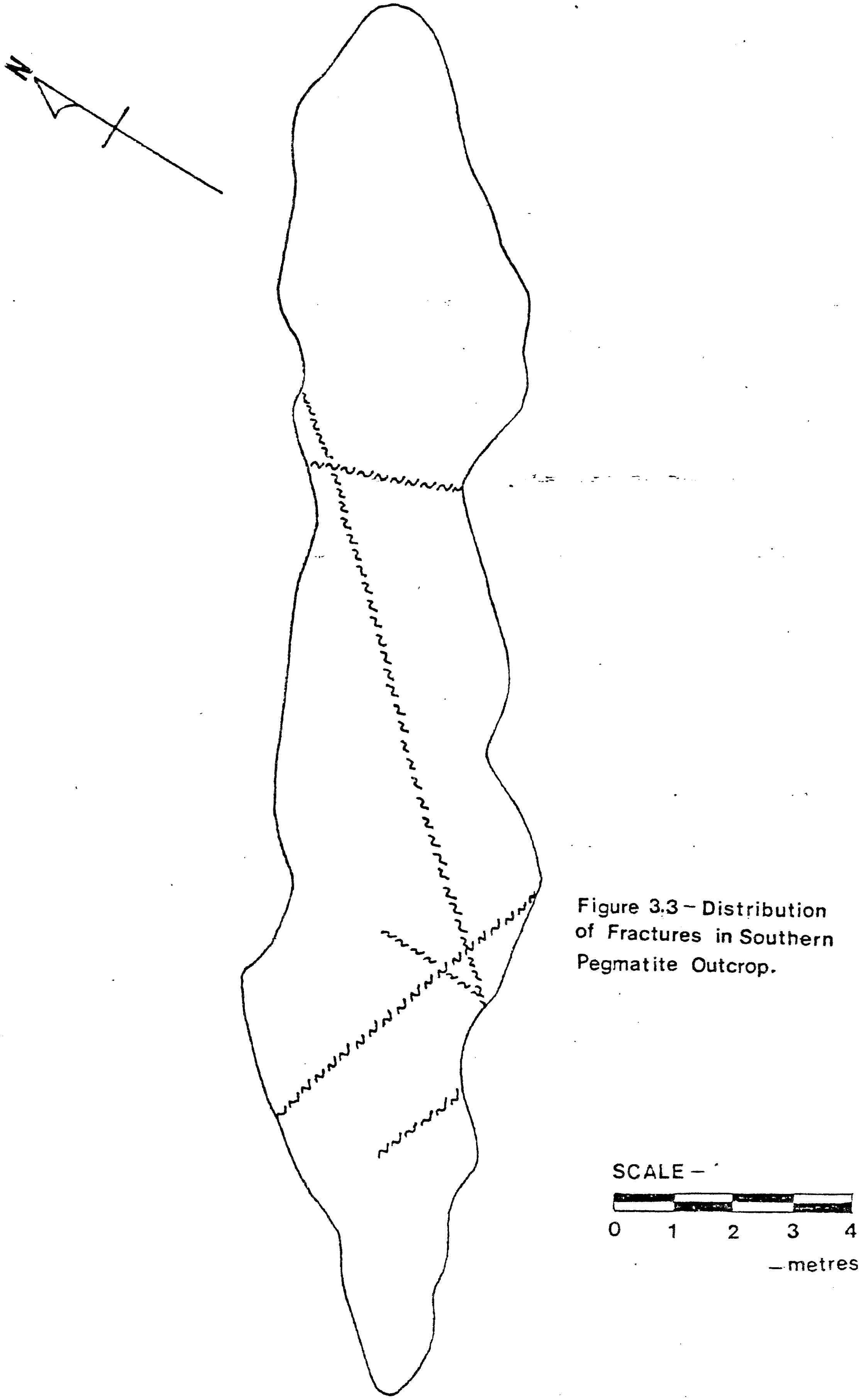


Figure 3.3 – Distribution of Fractures in Southern Pegmatite Outcrop.

that the aplitic albite phase, zone C, was emplaced relatively later than zones A and B.

As seen in Figure 3.3, the fractures are oriented roughly at 45° to the long axis of the pegmatite. This is in accord with a regional stress ellipsoid with the principle stress axis aligned in a northwest-southeasterly direction, and is probably related to the tectonic event which deformed the Yarmouth syncline.

The northern #3 pegmatite outcrop is poorly exposed. The following mineralogy was determined however; quartz (clear), albite (saccaroidal, locally showing a blue tint), microcline (buff), muscovite (light green), spodumene (off-white to buff with crystals up to 15 cm long), beryl (deep green), tourmaline (black), and apatite (dark green).

CHAPTER 4

PETROGRAPHY OF THE COUNTRY ROCKS

4.1 PELITIC SCHISTS

Garnet and staurolite-bearing schists occur about 200 m southeast of the pegmatite outcrops. These rocks are stratigraphically the oldest exposed rocks in the map area. They form part of the Lower Member of the White Rock Formation as described by Sarkar (1978) (see section 2.1), as do all of the exposed country rocks in the Brazil Lake map area. No extensive pelitic schists are described in the Upper Member of the White Rock Formation in the Yarmouth area, therefore the observed rocks must belong to the Lower Member. The Lower Member is divided into Submembers 1 and 2 however. Submember 1 consists of feldspathic quartzite with subordinate schists, orthoquartzite and metabasite sills and dykes (total thickness, 300-330 m). Submember 2 consists of a thick pelitic schist with subordinate feldspathic quartzite, metabasite and a 1.5-5 m thick garnet and/or biotite schist (total thickness, 100-180 m).

The pelitic schists probably represent the subordinate schists of Submember 1, with overlying quartzites and metabasites, because the total thickness of 300-330 m is occupied, in the Brazil Lake, area by the succession of these strata. They may however be correlated with the thick pelitic schist of Submember 2, because they appear to occupy a substantially thick succession, as inferred from the low topography.

Tectonic deformation has produced many distinct textural features in these rocks. Rotated garnets (Plate 4.1), mica envelopes around porphyroblasts, quartz pressure shadows, kink banding in biotite (Plate 4.2), undulose extinction and crystallographic preferred orientation, all atest to at least one period of intense deformation and, probably, more than one. The staurolite-biotite schist, in thin section, shows a discordant internal foliation (S_i) with respect to the external foliation (S_e). Most of the rotated garnets, in thin section, also show a planar S_i which is discordant to the S_e. Clear evidence of two distinct foliations is observed in pelitic schists which outcrop nearby, just east of the Brenton pluton (G.K. Muecke, pers. comm.).

4.2 FELSIC METAVOLCANIC ROCKS

One outcrop of this rock type was found about 120 m east of the northern most pegmatite outcrop (number 3). The rock has a distinct light grey colour on a fresh surface and is rusty brown where weathered. It is composed of 75% quartz, 15% feldspar (An_{10}), 2-3% muscovite and biotite, and minor opaques, chlorite and garnet.

The rock has a porphyroblastic texture with rounded xenoblasts, 2-3 mm in diameter, of quartz and feldspar which are surrounded by envelopes of minute muscovite and biotite laths, in a fine-grained (0.1-0.2 mm) matrix of quartz and feldspar. Minor ($<$ 1%) garnet occurs as small (0.5 mm) idioblasts with abundant randomly oriented quartz and biotite inclusions.

A weakly developed schistosity, defined by biotite and muscovite,

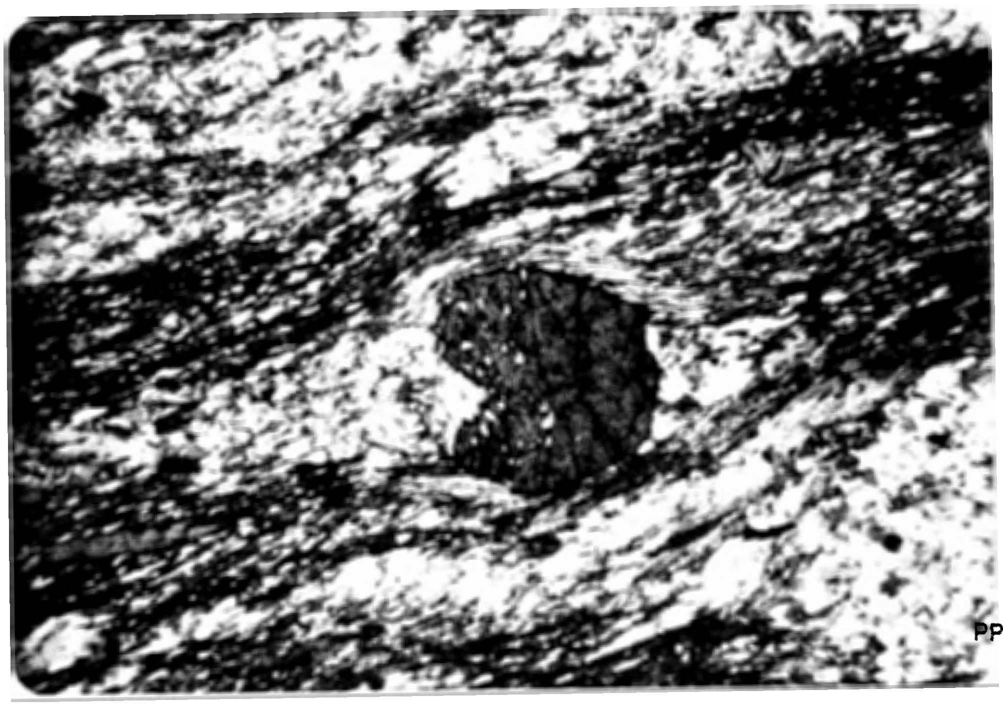


PLATE 4.1. Rotated garnet in garnet-biotite schist, from outcrop on dirt road. Note internal foliation (S_i), defined by quartz inclusions, is discordant with external foliation (S_e), defined by biotite. Note also the well developed quartz filled pressure shadows.

PLATE 4.2. Kink banding in biotite, from staurolite-biotite schist outcrop near felsic metavolcanic unit.

is best observed on a weathered surface. Quartz veins, 2-5 cm wide, are abundant throughout the rock.

Sarkar (1978) did not recognize the felsic metavolcanic unit, or metafelsite, in the Yarmouth area, as described by Taylor (1967) and Lane (1975). It has been placed, by Taylor and Lane, however, at the base of the Lower Member of the White Rock Formation. It does not appear in Taylor's (1967) map above, or northeast of, the Brenton pluton, but the occurrence of this outcrop confirms its lateral continuity northeast of the Brenton pluton, and its stratigraphic position within the Lower Member of the White Rock Formation.

4.2 ORTHOQUARTZITES

The quartzites studied in the map area are all of the type described by Taylor (1967) as the characteristic rock type of the White Rock Formation. They are massive, white to grey orthoquartzites, composed predominantly of quartz grains (> 90%) with minor impurities, usually micaceous material, giving the rock its off-white or dirty appearance.

The quartzites also belong to the Lower Member. Sarkar (1978) describes feldspathic quartzites near the base of the Lower Member and micaceous quartzites near the top. The Brazil Lake quartzites probably occur closer to the higher level, micaceous quartzites than the feldspathic ones.

Evidence of strong deformation is observed in the texture of the quartzites. In thin section, well developed sutured grain boundaries and deformation lamellae in quartz grains are common. Where biotite and other micaceous minerals make up to 5 to 7% of the rock, a strong preferred orientation and planar foliation is developed. Crystallographic preferred orientation is moderately well developed in the quartzites as well.

Tourmaline is found in the White Rock quartzite outcrops and boulders within about a 150 m radius of the pegmatite bodies. The tourmaline crystals locally may reach lengths of 4 to 5 cm, but generally, they are fine-grained (1 to 5 mm) and exhibit a strong preferred orientation, giving the rock a banded appearance with alternating dark layers and white, barren quartzite bands (Plate 4.3). In Lane's (1975) and Sarkar's (1978) descriptions of the orthoquartzites of the White Rock Formation, micaceous material, feldspar and subordinate phyllosilicates are the only constituents other than the quartz noted in the mineralogy of these rocks. No mention of tourmaline is made in any description of the quartzites. Hence, the tourmaline within the orthoquartzites at Brazil Lake must be the result of a metasomatic introduction of material into the rock. A tourmalinization process, resulting from the emplacement of the pegmatites is probably responsible.

An outcrop 80 m southwest of the main pegmatite exhibits a dirty colour, caused by dark-coloured impurities which are aligned in a strongly developed preferred orientation, paralleling regional schistosity. In thin section, the mineral causing the dark colour occurs as euhedral,

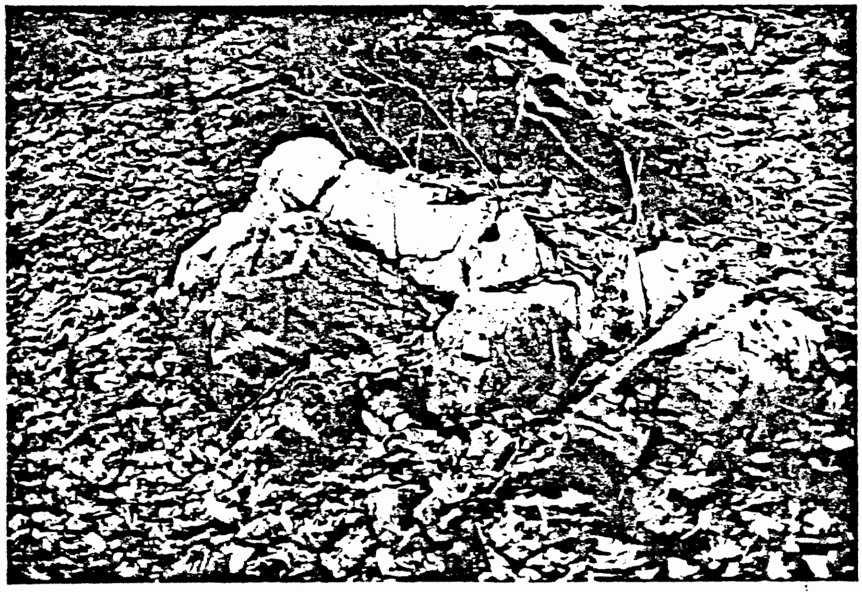


PLATE 4.3. White Rock quartzite outcrop about 20 m southeast of the main pegmatite outcrop. The lower half of the outcrop is pervasively tourmalinized.

prismatic laths, 0.5 to 1.0 mm long, showing a blue to violet pleochroism (Plate 4.4). The mineral has parallel extinction and a small optic axial angle. The mineral was analyzed with the electron microprobe and the results are found in Table 4.1. The mineral is apparently an amphibole, based on its optical properties, cleavage and crystal habit. The chemical analyses show a strong depletion of CaO, Na_2O and K_2O. The only other probable element which could occupy the alkali site in the amphibole structure is lithium. The mineral is identified as holmquistite, a rare lithium-rich amphibole.

Holmquistite is restricted in occurrence almost solely to contact rocks near lithium-rich pegmatites (Deer, Howie, Zussman, Vol. 2, pp. 230-233, 1967). Its occurrence has been ascribed to lithium metasomatism in all cases. Holmquistite has never been described from Nova Scotia previously, to the writer's knowledged.

4.4 ACTINOLITE GNEISSES AND SCHISTS

The mafic metavolcanic rocks in the study area are readily identified both in hand sample and thin section. They are dark, greenish-grey to black, fine to medium-grained and have a well developed mineral lineation, and in some cases, foliation. The mineralogy consists of amphibole (60-90%), plagioclase, An_{10-30} (2-20%), quartz (5-15%), biotite (up to 20%), white mica (up to 15%), and minor (< 5%) chlorite, epidote, sphene, zircon and apatite. Opaques, principally ilmenite and magnetite, are generally minor (< 5%) but locally constitute up to 20% of the rock.

TABLE 4.1 - Microprobe Analyses of Holmquistite from a White Rock Quartzite Outcrop, 80 m southwest of the Main Pegmatite.

	Average of four analyses from one thin section	Range in four analyses	Average of six holmquistite analyses (from Deer, Howie, Zussman, 1967, p. 231)	Range in six samples, (Deer, Howie, Zussman, 1967, p.231)
SiO_2	55.43	54.49-56.41	58.40	55.48-59.73
TiO_2	0.00	0.00	0.22	N.D. - 0.64
Al_2O_3	12.44	11.87-12.66	10.98	7.19-14.64
Fe_2O_3	N.A.	N.A.	4.06	1.80- 5.72
FeO	19.43	19.11-19.94	9.50	4.88-13.04
MnO	0.09	0.00- 0.17	0.28	tr.- 0.65
MgO	5.38	5.19- 5.53	9.40	8.82-11.66
CaO	0.03	0.00- 0.11	0.64	0.06- 1.32
Na_2O	0.55	0.44- 0.63	0.49	0.11- 1.24
K_2O	0.00	0.00	0.26	0.00- 0.74
Li_2O	N.A.	N.A.	2.97	2.40- 3.56
H_2O^+	N.A.	N.A.	2.36	1.87- 3.16
H_2O^-	N.A.	N.A.	0.04	N.D.- 0.12
F	N.A.	N.A.	0.28	tr.- 0.91
Total	93.35	N/A	99.62	N/A

* N.D. - not detected
N.A. - not analyzed for
N/A - not applicable
tr. - trace

PPL, X 100

PLATE 4.4. Thin section of White Rock quartzite from outcrop approximately 80 m southwest of main pegmatite. The acicular, euhedral mineral is holmquistite, a rare lithium-rich amphibole, found only at the country rock contacts of lithium-rich pegmatites.

Amphibole occurs as acicular, idiomorphic to subidiomorphic grains, rarely exhibiting a poorly developed patchy zonation pattern. The pleochroic scheme of the amphiboles indicates that they are probably actinolitic hornblendes with occasional actinolite cores (Sarkar, 1978). A spectacular texture consisting of radial clusters of actinolitic hornblende is observed in a few outcrops. Relict vesicles are marked by the presence of coarse-grained radiating acicular amphibole and local concentrations of quartz and chlorite.

Plagioclase occurs as streaks or gneissic bands, lenses and pods (Plate 4.5), which stand out in strong contrast to the much darker amphibolites. Some of the pegmatitic pods are highly enriched in platy, idiomorphic ilmenite crystals up to 1.5 cm long, which are generally aligned parallel to the schistosity.

Epidote, apatite, and zircon are relatively minor constituents and occur as subidiomorphic crystals in the groundmass together with the amphiboles. Sphene is also generally a minor phase within the groundmass, but also occurs as coarse (up to 1 cm) idioblasts (Plate 4.6).

Stratigraphically, these amphibolites, or metabasites, also must lie within the Lower Member, because they are generally relatively thin, sill-like bodies, typical of the Lower Member, whereas the Upper Member is characterized by much thicker flows (Sarkar, 1978).

PLATE 4.5. Actinolite schist about 600 m northwest of southern pegmatite outcrop, showing pod of coarse grained plagioclase (An).

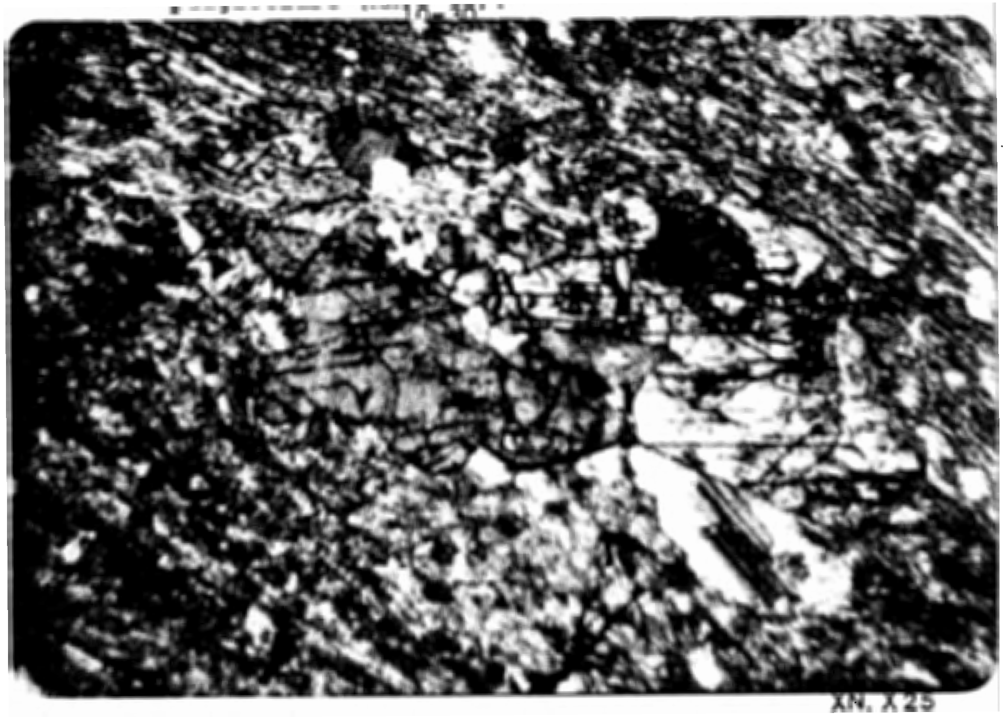


PLATE 4.6. Thin section of actinolite schist, showing idioblast of sphene.

CHAPTER 5

GEOCHEMISTRY AND MINERALOGY OF THE PEGMATITES

5.1 NORMATIVE MINERALOGY AND CHEMICAL COMPARISON WITH OTHER INTRUSIVES

Whole rock analyses were performed on powders from the four bulk samples shown in Figure 3.1. The results are presented in Table 5.1. Also included are trace element analyses. All phases of the pegmatite are extremely depleted in MgO, FeO, and CaO, indicating that the magma from which the Brazil Lake pegmatites crystallized was very highly evolved. Samples 1 and 3 represent the aplitic albite phase, zone C, and hence have 9.44% and 6.54% Na_2O respectively. Sample 2 represents the quartz-spodumene phase, zone B, and therefore is the most enriched in SiO_2 (82.08%) and Li_2O (2.08%): Sample 4 comes from the microcline phase, zone A, and contains 5.17% K_2O.

C.I.P.W. norms were calculated from these four analyses using a modified scheme which takes account of the presence of lithium as a major element in some of the rocks (Table 5.2). The quartz-orthoclase-albite values were recalculated to 100% and plotted on a modal triangle which encompasses the major phase relationships encountered in highly evolved granitic systems (Figure 5.1). Sample 4, representative of zone A, plots in the true granite field and is probably the only sample of the four that is representative of the original silicate fluid from which it crystallized, without simultaneous or subsequent

TABLE 5.1 - Whole Rock Chemical Analyses of Four Bulk Samples, Representing Three Zones from the Southern Pegmatite Outcrop.

Bulk Sample Number (see Fig. 3.1 for Location)	1	2	3	4
ZONE	C	B	C	A
SiO_2	68.60	82.08	73.97	74.26
Al_2O_3	19.09	11.56	17.08	15.32
Fe_2O_3	0.27	0.04	0.09	0.02
FeO	0.00	0.05	0.03	0.09
MgO	0.04	0.03	0.02	0.02
CaO	0.12	0.00	0.05	0.00
Na_2O	9.44	1.41	6.54	2.77
K_2O	0.66	0.57	0.53	5.17
TiO_2	0.06	0.06	0.05	0.06
MnO	0.06	0.02	0.02	0.02
P_2O_5	0.12	0.00	0.04	0.07
Li_2O	0.21	2.08	1.27	1.07
H_2O^+	0.08	0.33	0.19	0.24
H_2O^-	0.14	0.12	0.10	0.08
Total	*98.89	*98.35	99.98	99.19
Trace Analyses (ppm)				
Li	980	9700	5900	5000
Cu	3	1	1	4
Zn	29	21	10	12
Ni	6	3	5	4
V	6	6	5	0

* Low total in sample 1 may be accounted for by the presence of 2-3% beryl in the bulk sample; beryllium was not analyzed for. Minor beryl (< 1%) also present in sample 2.

TABLE 5.2 - Calculated Normative Mineralogy for Four Bulk Samples from the Southern Pegmatite Outcrop.

Bulk Sample (zone)	1(C)	2(B)	3(C)	4(A)
Quartz	10.97%	69.62%	32.70%	37.24%
Orthoclase	3.90	3.34	3.13	30.58
Albite	79.78	11.90	55.27	23.41
Corundum	2.13	1.56	1.42	1.52
Spodumene	1.30	12.90	7.87	6.63
Hypersthene (enstatite)	0.11	0.07	0.01	0.00
Magnetite	0.39	0.05	0.00	0.03
Hematite	0.00	0.01	0.08	0.00
Ilmenite	0.11	0.11	0.09	0.11
Apatite	0.66	0.00	0.08	0.00
Total	99.35%	99.56%	100.65%	99.52%

* Norms were calculated according to Cox, Bell and Pankhurst (1978, pp. 408-412), with the following modification. After 4C (formation of anorthite from Al_2O_3 and CaO), spodumene is calculated from excess Al_2O_3 and total Li_2O, with excess Al_2O_3 going to the formation of corundum (as in 4d).

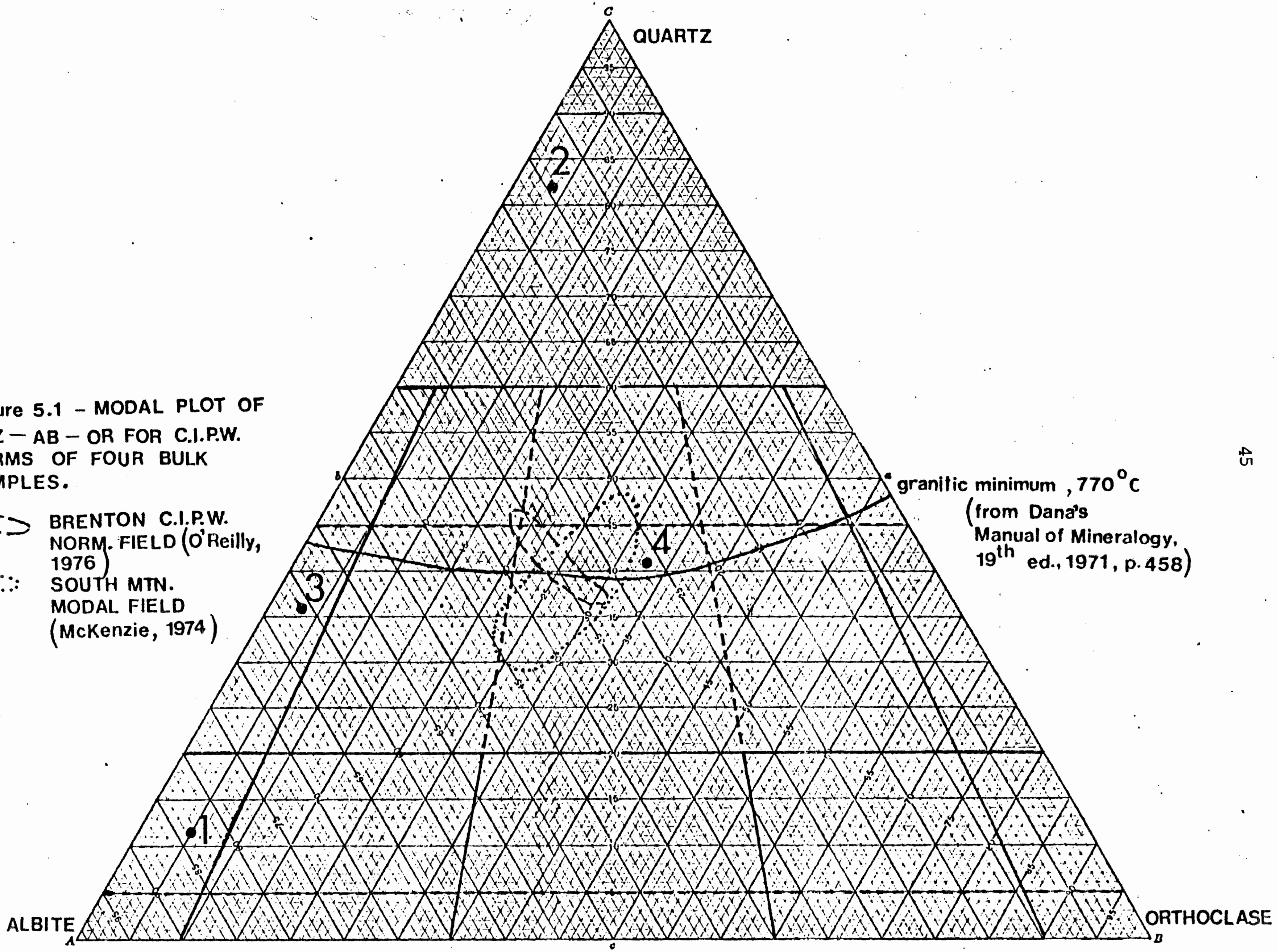


Figure 5.1 - MODAL PLOT OF QTZ — AB — OR FOR C.I.P.W. NORMS OF FOUR BULK SAMPLES.

BRENTON C.I.P.W. NORM. FIELD (O'Reilly, 1976)

SOUTH MTN. MODAL FIELD (McKenzie, 1974)

alteration by various melt or aqueous phases. All other zones plot far from known minima and eutectics in the granite system and cannot simply represent the products of crystal fractionation from a granitic melt.

The chemical analyses and C.I.P.W. norms were compared to those from the Brenton pluton (O'Reilly, 1976). Although broadly similar in normative mineralogy, no particular similarities are observed that would suggest a genetic link between the two igneous bodies. Both data sets are very low in FeO, TiO_2, MgO, CaO and P_2O_5, but this is common in such highly fractionated rocks. Both data sets are corundum normative, but all of the granitoid rocks of southern Nova Scotia are peraluminous and corundum normative.

A critical geochemical parameter is the lithium content of the Brenton pluton. If indeed, the Brazil Lake pegmatite is genetically related to the Brenton pluton, one would expect the Brenton pluton to be somewhat enriched in lithium, compared to other granitoid bodies.

Seven samples of the Brenton pluton, collected by O'Reilly, were analyzed for the trace elements Li, Cu, Zn, Ni, V, Rb, Sr, Zr and Nb. The results appear in Table 5.3. The mean lithium content of the Brenton pluton is 71 ppm. This shows, in fact, a depletion rather than an enrichment in lithium when compared to other southern Nova Scotia plutons. The next most proximal granitoid body to Brazil Lake, after the Brenton pluton is the Davis Lake pluton (20 km east), which hosts an economic tin deposit. In an average of 12 samples from the

TABLE 5.3 - Trace Element Geochemistry of Seven Samples from the Brenton Pluton (O'Reilly, 1976).

Sample No.	74-42	74-45	74-46	74-47	74-50	74-59	74-69
* Li (ppm)	70	108	80	63	64	47	62
* Cu (ppm)	17	10	2	17	6	6	3
* Zn (ppm)	97	120	58	76	80	74	101
* Ni (ppm)	4	4	5	6	4	4	3
* V (ppm)	0	0	0	2	4	4	0
Rb (ppm)	217	234	243	195	209	173	180
Sr (ppm)	40	15	7	46	129	56	86
Zr (ppm)	79	90	93	145	293	180	191
Nb (ppm)	23	26	27	26	29	28	26

* The Li, Cu, Zn, Ni and V were analyzed from O'Reilly's samples, in January, 1982

Davis Lake leucoadamellite, a mean lithium content of 191 ppm Li was determined (Chatterjee, 1980). Charest (1976), in his study of the mineralized aplite and pegmatite area of New Ross, found a mean lithium content of 124 ppm in the granodiorite (the least evolved rock in the area), 294 ppm Li in the adamellite, and 513 ppm Li in the leucoadamellite. Thus the Brenton pluton, with its mean lithium content of 71 ppm, seems a very unlikely source for the lithium-rich Brazil Lake pegmatites.

Similarly the Rb values show a depletion relative to other southern Nova Scotia plutons and the Nb values are only slightly enriched. The mean Rb value for the Brenton pluton is 207 ppm. The Davis Lake pluton, however, yields a mean of 734 ppm Rb. Although the zones in the Brazil Lake pegmatite have not yet been analyzed for Rb, the presence of 0.55 weight % Rb_2O in the muscovites of zone A and B indicates a very strong Rb enrichment. The Brenton and Davis Lake plutons yield average Nb concentrations of 26 ppm and 12 ppm.

The Wedgeport pluton is located about 25 km south of the Brazil Lake area is associated with Sn, W, Mo, Cu, Zn and U mineralization. This granitoid body represents another possible, but more distal source for the Brazil Lake pegmatites.

5.2 FELDSPARS

Microprobe analyses of the aplitic albite laths in four thin sections from the southern and northern #2 outcrops are very consistent, yielding an average composition of $Ab_{99.5}Or_{0.5}$ (Table 5.4). Analyses

TABLE 5.4 - Average Albite Analyses (Probe) from Southern and Northern #2 Outcrops.

	1	2	3	4
	(Southern)	(Southern)	(Northern #2)	(Northern #2)
	* n = 4	n = 4	n = 5	n = 3
SiO_2	69.08	68.76	68.83	68.64
Al_2O_3	19.61	19.29	19.38	19.49
TiO_2	0.00	0.00	0.00	0.00
FeO	0.00	0.05	0.11	0.00
MnO	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00
CaO	0.00	0.00	0.00	0.00
Na_2O	11.67	11.84	11.91	11.67
K_2O	0.14	0.00	0.09	0.10
Total	100.50	99.94	100.32	99.90

						Average
Molecular %	Ab	99.2	100.0	99.5	99.4	99.5
	An	0.0	0.0	0.0	0.0	0.0
	Or	0.8	0.0	0.5	0.6	0.5

* n - number of grains analyzed per thin section

TABLE 5.5 - Average Microcline Analyses (Probe) from Southern and Northern #1 Outcrops.

	1 (Southern) * n = 4	2 (Southern) n = 3	3 (Northern #1) n = 4
SiO_2	64.46	64.34	63.93
Al_2O_3	18.30	18.29	18.31
TiO_2	0.00	0.00	0.00
FeO	0.00	0.00	0.00
MnO	0.00	0.00	0.00
MgO	0.00	0.00	0.00
CaO	0.00	0.00	0.00
Na_2O	0.43	0.53	0.37
K_2O	15.53	15.40	15.90
Total	98.72	98.56	98.51

					Average
Molecular %	Or	95.9	95.0	96.7	95.9
	An	0.0	0.0	0.0	0.0
	Ab	4.1	5.0	3.3	4.1

* n - number of grains analyzed per thin section

of the blocky microcline from the southern and northern #1 outcrops are also very consistent. The microcline is highly potassic, averaging 15.58% K_2O. The average composition of the microcline is $Or_{95.9}Ab_{4.1}$ (Table 5.5).

The consistent chemical analyses and uniform purity of the end members in these feldspars must reflect a very efficient mechanism of segregation of the K and Na components within the crystallizing melt.

5.3 SPODUMENE AND MICAS

The spodumene from the Brazil Lake pegmatite varies very little from its ideal formula $LiAlSi_2O_6$ (Table 5.6). It is relatively pure with minor substitution of Fe for Al, and Na for Li. The crystals vary extensively in size, from less than 1 cm up to 60 cm. They are off-white to grey with a pinkish hue and have a very smooth texture on well developed faces, occasionally showing deep striations.

Light green muscovite is ubiquitous within zone B and very abundant in zone A, where it is localized in quartz veins and pods. It is very rare in zone C, and generally fine-grained. In zone B, the muscovite is locally concentrated in pods and ovoid segregations. Large masses of coarse-grained, 2-5 cm diameter, books of muscovite may be removed with one's fingernails from these areas. A number of pegmatitic boulders north and south of the main pegmatite contain significantly more muscovite (up to 15%) and suggest the presence of a higher vertical zone, rich in muscovite (± cassiterite and garnet) which has been removed during Pleistocene glaciation.

Table 5.6 - Average Spodumene Analyses from the Southern Pegmatite.

	1 (Southern Outcrop, Zone B) n = 3	2 (Average Spodumene analyses from Deer, Howie and Zussman Vol. 2, p. 93) n = 6
SiO_2	63.41	64.24
Al_2O_3	27.21	27.21
Fe_2O_3	N.A.	0.68
FeO	0.23	0.06
MnO	0.15	0.06
MgO	0.00	0.00
CaO	0.00	0.01
Na_2O	0.07	0.88
K_2O	0.00	0.18
*Li_2O	N.A.	6.45
H_2O^+	N.A.	0.37
H_2O^-	N.A.	0.05
Total	91.32	100.19

*N.A. - not analyzed; Li analyses are not feasible with the microprobe

The wet chemical analyses (Table 5.7) show that these are normal muscovites with minor Fe and Mg substituting for Al, giving them the greenish tint. Two significant features are noted in the analyses. First, they contain almost no lithium, and secondly, they are very enriched in rubidium. One would expect the muscovites to be enriched in lithium, because the usual association with spodumene pegmatites are lithium-rich micas, such as zinnwaldite or lepidolite. The lepidolite zone in most lithium-rich pegmatites however, is generally separated from the spodumene-quartz zone, and located in the structurally higher part of the pegmatite (Foldvari-Vogl, 1978). The lepidolite zone of the giant Tanco pegmatite at Bernic Lake, Manitoba, has been interpreted as a late-stage metasomatic body (Crouse and Cerny, 1972). Late greenish muscovite is reported in assocation with the microcline-rich zone in the Tanco pegmatite as well.

The question which must be answered regarding the Brazil Lake pegmatites, is why the lithium was so strongly partitioned into the spodumene and rejected by the muscovite, within the crystallizing fluid. The great abundance of rubidium probably provides the answer. With an average of 0.55% Rb_2O in the muscovites, there must have been an excessive amount of rubidium in the melt at the time of crystallization. The ionic radius of K^+ is 1.68Å , in 12-fold coordination. Rb^+ has an ionic radius of 1.81Å, in 12-fold coordination, whereas Li^+ has a radius of only 0.82Å, in 6-fold coordination. It is relatively easy for one element to substitute for another if the ionic radii are within 10% of each other. Hence, if abundant Rb^+ were present, it would fit into the muscovite structure, substituting in the K^+ site,

TABLE 5.7 - Wet Chemical Analyses of Two Composite Muscovite Samples, from Southern and Number 1 Outcrops.

	(Southern Pegmatite Zones A and B)	(Northern #1 Pegmatite Outcrop)
SiO_2	45.15	45.29
Al_2O_3	35.91	36.23
Fe_2O_3	0.00	0.00
FeO	0.84	0.88
MgO	0.12	0.03
CaO	0.00	0.00
Na_2O	0.70	0.72
K_2O	10.57	10.43
TiO_2	0.07	0.07
MnO	0.07	0.07
P_2O_5	0.00	0.00
Li_2O	0.08	0.07
H_2O^+	3.77	4.30
H_2O^-	0.10	0.06
Rb_2O	0.57	0.54
Total	97.95	98.69

infinitely better than the Li^+ would. The physico-chemical conditions were, presumably, ideal for all of the Li^+ to be partitioned into the spodumene structure.

Grice et. al. (1972) described greenish and white muscovite in association with the quartz-spodumene zone of the Tanco pegmatite. The chemical analyses of these micas show that they are very poor in Li, but also their Rb and Cs values are among the lowest found in any of the Tanco pegmatite micas, some of which contain up to 3.93% Rb_2O. Some of these high Rb muscovites also contain 3-4% Li_2O. Hence, it would seem that the concentration of these elements in various mineral phases depends on very local chemical conditions and equilibria.

Biotite is extremely rare, and restricted to a one square metre patch on the northwest side of the main pegmatite. This probably indicates that it is a partially assimilated piece of country rock or a cluster of xenocrysts.

5.4 MINOR AND ACCESSORY MINERALS

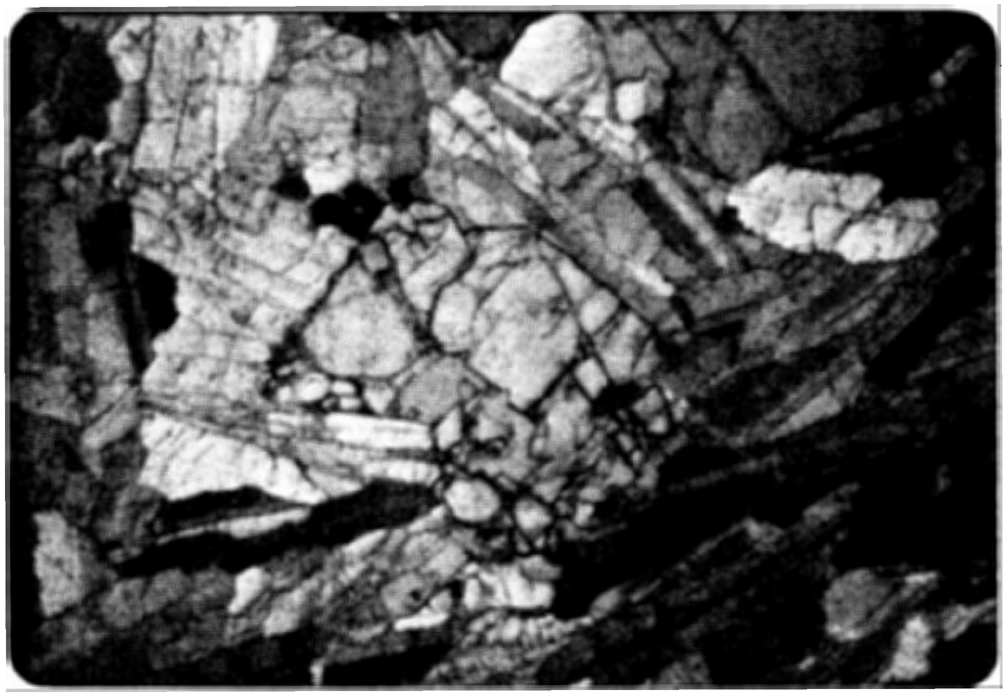
Minor (< 5%) and accessory (< 1%) minerals of the Brazil Lake pegmatite include, in decreasing abundance: beryl, zircon, tourmaline, apatite, ilmenite, columbo-tantalite, epidote and cassiterite. Most of these minerals were not observed in hand specimen or thin section, and were isolated after crushing the bulk samples, running them through an electro-magnetic separator, and further separating them with heavy liquids. The various specific gravity fractions from the different zones were then observed through a binocular microscope and minerals were described, abundances noted, and samples selected for microprobe analysis.

Beryl crystals are found, usually in clusters, within the albite zone, commonly dark emerald-green and 3 to 5 mm in diameter (Plate 5.1). Most of the beryl crystals have their long axis oriented perpendicular to the wall rock contact. Within the aplitic albite zone (C), beryl may constitute 1-2% of the rock, but the whole outcrop averages 0.5% beryl (Table 3.1).

Zircon is greenish-grey to brown and occurs in minute (< 1 mm) euhedral crystals, most abundantly in zone C, and to a lesser extent in zone A.

Tourmaline is most abundant in the metasomatic aureole developed around the pegmatitic bodies, and is most easily observed in the White Rock quartzite (Plate 4.3). In the aureole, it varies in grain size from 1 mm laths to 5 cm megacrysts (Plate 5.2). Within the main pegmatite, tourmaline is observed, only in a small patch of wall rock contact exposed in the southeast side of the outcrop. Just a few millimetres into the pegmatite from the contact with the amphibolite, tiny 2-4 mm, black tourmaline laths are oriented parallel to the wall rock contact.

Two distinct generations of tourmaline were recognized. Black (Fe and Mg-rich) tourmaline, or schorl, is most abundant, in the aplitic and quartz-spodumene zones (B and C), whereas clear to pale green



XN, X25

Plate 5.1. Subhedral beryl crystal in aplitic albite phase, from main pegmatite.

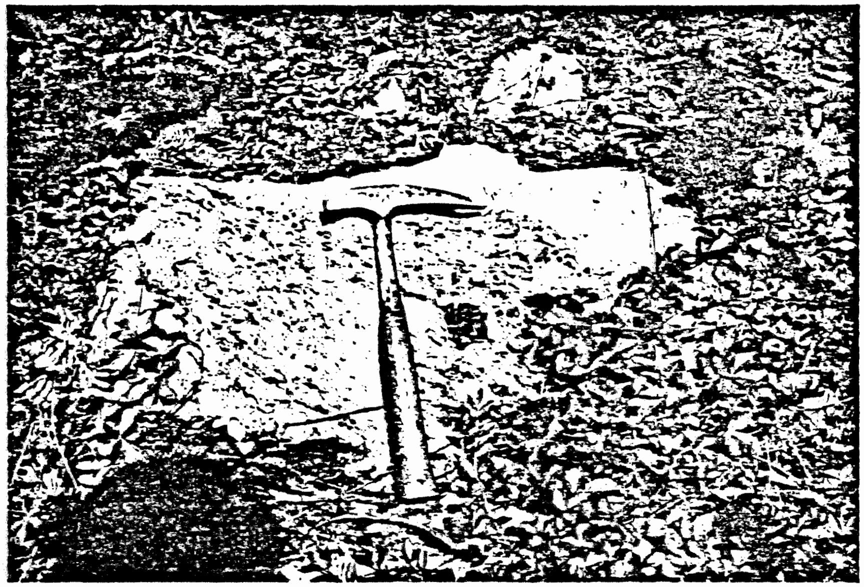


Plate 5.2. Large megacryst of tourmaline in boulder of pegmatite from the Brenton pluton.

(Li-rich) tourmaline, or elbaite, is more abundant in the microcline zone (A), but occurs in the quartz-spodumene zone (B) as well.

Apatite is rare and was only observed in the aplitic albite zone (C). Crystals up to 2 cm long are found in the middle northern pegmatite but are smaller and more scarce in the main, southern outcrop.

Ilmenite is also quite rare within the pegmatite itself, where it is developed as minute acicular laths within zones A and B. It is much more abundant in the pegmatitic pods which intrude the amphibolites, surrounding the pegmatic bodies, where it occurs as large, 1-2 cm, platy crystals associated with feldspars. Ilmenite analyses from the lowermost northern pegmatite are seen in Table 5.8.

Epidote crystals are very scarce. They are anhedral, rounded dark green grains. A typical chemical analyses of the epidote is found in Table 5.9. The Fe and Al end members, pisticite and Al-epidote, were calculated and compare very favorably with an average of analyses of epidotes from the White Rock metavolcanics (Sarkar, 1978). The pegmatitic epidote yielded an average analysis of 25.2% Pistacite and 74.8% Al-epidote, whereas Sarkar's average for the White Rock was 28.0% Pistacite and 72.0% Al-epidote, based on 17 samples. The epidote in the pegmatite is believed to be xenocrystic, probably picked up from the metabasites by the intruding pegmatitic fluids.

TABLE 5.8 - Average of Three Ilmenite Analyses from Zone A of Pegmatite Outcrop Number 1.

	Average of 3 grains	Range in Values
SiO	0.00	0.00
TiO_2	52.62	51.95 - 53.07
Al_2O_3	0.00	0.00
FeO	44.03	43.97 - 44.46
MnO	1.30	1.20 - 1.41
MgO	0.02	0.00 - 0.05
CaO	0.00	0.00 - 0.00
Na_2O	0.00	0.00 - 0.00
K_2O	0.00	0.00 - 0.00
Total	97.97	

* Both Ta and Nb can substitute for Ti in various minerals, and after biotite, ilmenite is the most favoured species for Nb concentrations (Foldvari-Vogl, 1978). This may account for the low totals.

TABLE 5.9 - Average of Three Epidote Analyses from Zone B, Southern Pegmatite.

	(Average of 3 grains, zone B)	
SiO_2	37.83	
Al_2O_3	24.71	
Ti_2O	0.00	
FeO	10.64	
MnO	0.00	
MgO	0.00	
CaO	22.99	
Na_2O	0.00	
K_2O	0.00	
Total	96.17	
Si	2.961	*
Al	.038	3.000
Al	2.247	*
Fe^{3+}	0.761	*
Ti	0.000	3.008
Mn	0.000	*
Mg	0.000	*
Ca	1.934	1.992
Na	0.000	
O	13.000	

$Ca_2Fe_3Si_2O_{12}(OH)$ = Ps = 25.2%

$Ca_2Al_3Si_3O_{12}(OH)$ = Epi = 74.8%

5.5 HEAVY MINERAL GRAINS (Sn, Ta, Nb MINERALS)

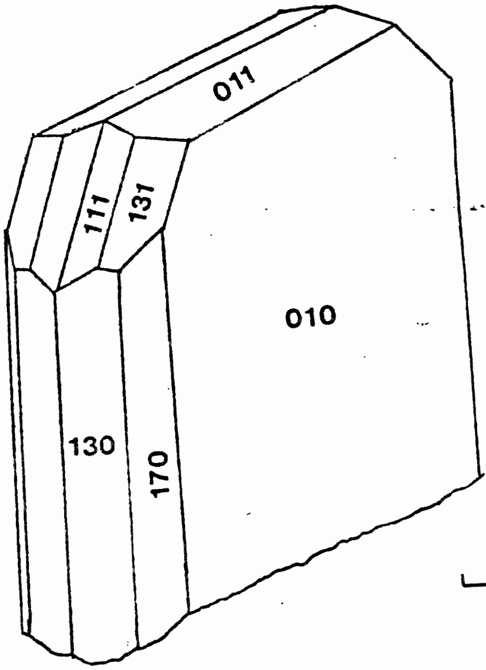
Heavy mineral grains (> 3.32 S.G.) were observed under a binocular microscope and representative specimens were isolated for microprobe analysis. The niobium and tantalum-bearing minerals were readily identified by their euhedral, tabular habit and occasional twinning (Figure 5.2).

One reddish-brown grain from zone C was probed and found to be 99.98% SnO, essentially pure cassiterite. Grains similar in appearance were observed under the binocular microscope but they are very scarce, and restricted to zone C.

The microprobe analyses of the Nb-Ta minerals are quite variable (Table 5.10). The Ta/Nb ratio is extremely variable. Samples 1, 2 and 3, from zones A and C, are richer in Ta than Nb and thus are columbo-tantalites. Samples 4, 5 and 6, all from zone C, are richer in Nb than Ta, and are therefore tantalo-columbites. The MnO content is relatively constant whereas the FeO content is highly variable. Indeed, with an average MnO content of 13.55%, these minerals may be termed mangano-tantalites and mangano-columbites.

The whole rock analyses of the pegmatite are extremely low in MnO (averaging 0.03%), and MgO and FeO as well. Therefore, these mafic oxides must have been very strongly concentrated in the late-stage fluids, into these accessory oxides.

A general increase in the Ta/Nb ratio during the crystallization process of a pegmatite is described from many localities (e.g. Grice



Crystal System and Class:
ORTHORHOMBIC; 2/m 2/m 2/m

scale = 0.2 mm

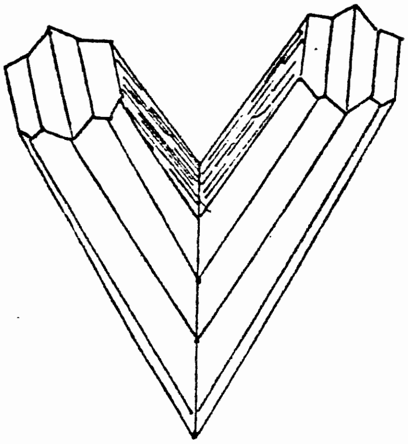


Figure 5.2 - Columbite – Tantalite Crystals as observed under the binocular microscope. Euhedral, platy crystal and heart-shaped twin with striations on the {010} face. Twinned on {201}.

TABLE 5.10 - Nb-Ta Mineral Analyses (Probe) from the Southern Outcrop.

	1	2	3	4	5	6
	Zone A	Zone A	Zone C	Zone C	Zone C	Zone C
Nb_2O_5	20.84	20.18	36.13	64.95	70.26	45.43
Ta_2O_5	61.63	61.05	46.04	16.89	11.24	36.96
FeO	3.38	3.23	6.83	9.30	5.82	1.04
MnO	14.01	13.21	12.56	12.10	15.21	14.21
Total	99.86	97.68	101.56	103.23	102.54	97.64

* Analyses were reclaculated using the EMPADR VII computer program

et al., 1972). The aplitic albite zone in the Tanco pegmatite is enriched in Ta, Fe, Sn and Ti minerals, all interpreted to be late-stage products associated with the crystallization of the sodic melt (Grice et al., 1972). The cassiterite is located in the structurally highest parts of the Tanco pegmatite and the ilmenite occurs in close association with amphibolite wall rock contacts, just as the ilmenite at Brazil Lake is most common in pegmatitic pods within the amphibolite country rock. Thus many similarities in the chemistry and distribution of minerals can be drawn between various pegmatitic bodies suggesting strongly that the basic processes involved in their formation must be similar.

A decrease in the Mn/Fe ratio is described from the Tanco pegmatite, but this is unusual, for an increase in Mn during the evolution of pegmatites is well known from other areas (Ginzburg, 1960). The six samples from Brazil Lake were plotted on an FeO/FeO + MnO versus Ta_2O_5 /Ta_2O_5 + Nb_2O_5 diagram to determine any possible correlation between the Fe/Mn and Ta/Nb ratios (Figure 5.3). Samples 1, 2 and 3, the tantalites, show a decrease in FeO content with increasing Ta_2O_5, whereas samples 4, 5 and 6, the columbites, show an increase in FeO with increasing Ta_2O_5. Thus, samples 1, 2 and 3 follow the Mn enrichment trend, and 3, 4 and 5 follow the opposite trend.

Niobium and tantalum do not act exactly alike in pegmatitic processes, although their atomic radii and other properties are very similar. Tantalum prefers earlier, higher-temperature assemblages, whereas niobium is more abundant in late-stage, lower-temperature ones

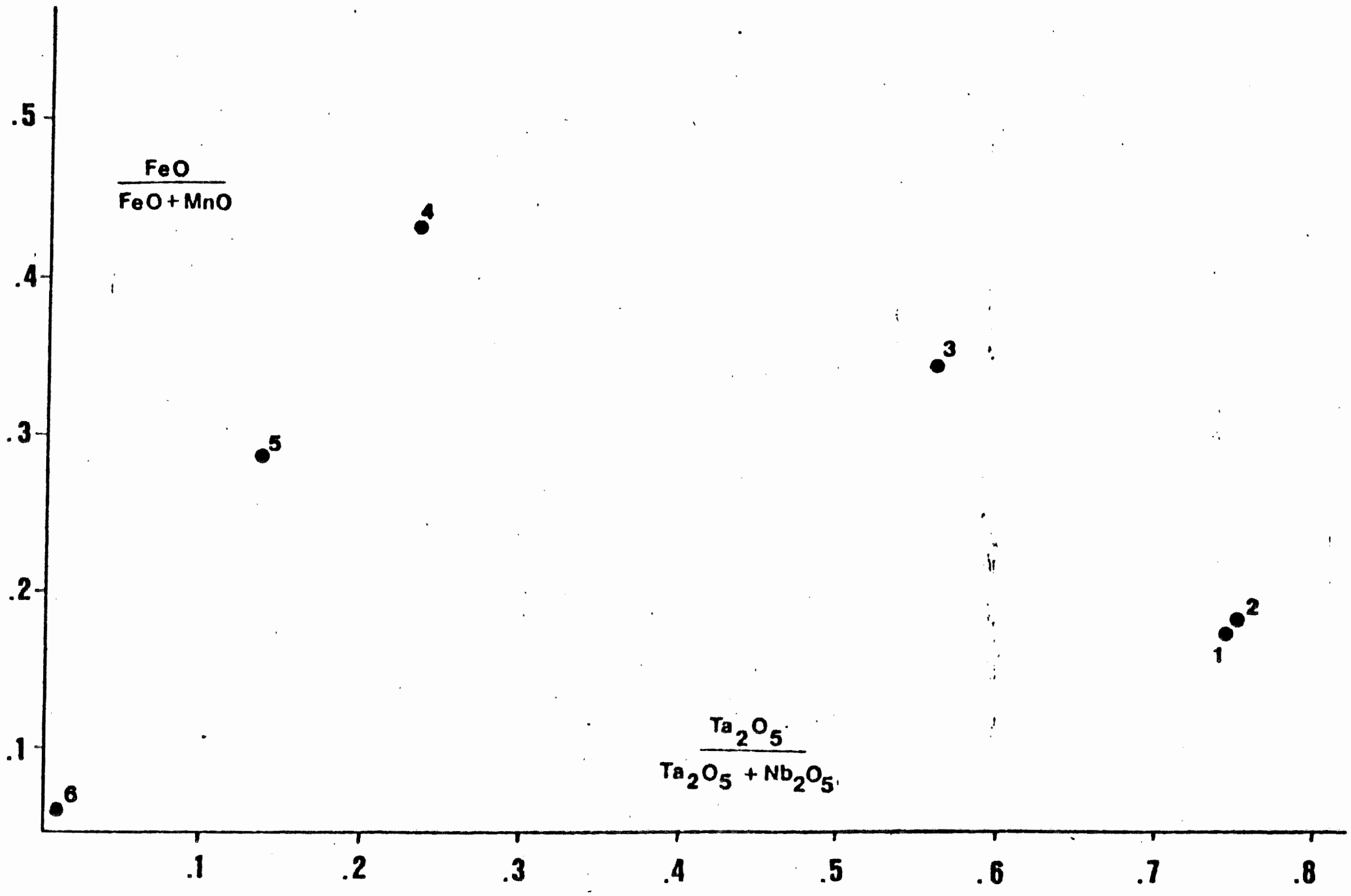


Figure 5.3 – The FeO/FeO + MnO Ratio Plotted Against the $Ta_2O_5/Ta_2O_5 + Nb_2O_5$ Ratio For the Brazil Lake Columbites and Tantalites

(Foldvari-Vogl, 1978). This observation seems to be born out for the Brazil Lake pegmatites. Samples 1 and 2 occur in the microcline zone (A) and are enriched in Ta, but samples 4, 5 and 6 are Nb-rich and occur in the albite zone (C), which is inferred to have crystallized at a later-stage.

Thus, the solid solution series of columbo-tantalite minerals must have crystallized over a considerable range of temperatures during the crystallization of the Brazil Lake pegmatites.

CHAPTER 6

AGE RELATIONS OF THE PEGMATITE

6.1 RELATIVE AGES

As discussed in Chapter 2, the Brenton pluton is structurally and texturally anomalous in comparison with other southern Nova Scotia plutons. It has a cataclastic, foliated texture, indicating that it was subjected to a period of intense shear stress which the other satellite plutons and the South Mountain batholith apparently were not. Thus, it may have been emplaced before the others and sheared either during emplacement, or, alternatively, after emplacement, during a shearing event which predated the emplacement of the other plutons. The other possibility is that it was emplaced synchronously with the other plutons (or post-dates them), and records a later tectonic event during which it was subjected to local shearing which the other plutons did not record.

An outcrop of quartz-feldspar-tourmaline pegmatite was observed within the Breton pluton. The outcrop is surrounded by many angular boulders of pegmatite and foliated granite. One boulder shows a contact between massive, undeformed pegmatite and strongly foliated granite (Plate 6.1). The foliation is cross-cut by the pegmatite, indicating that the pegmatites are younger than the Brenton pluton and the shearing event which affected the Brenton.

6.2 RADIOMETRIC AGES

A sample of concentrated muscovite was separated from the four bulk samples which were collected from the southern pegmatite, using the heavy liquid method described in Chapter 1. A composite sample of muscovite was also taken from the three northern pegmatite outcrops, and this was physically separated by hand. Both samples were scanned for flakes containing zircons and other impurities, and these were discarded.

The two samples, representing the two pegmatitic bodies at Brazil Lake, were dated by the K-Ar method. The two dates obtained were 332.3 ± 7 Ma and 334.0 ± 7 Ma, for the southern and northern pegmatites, respectively. In sample M-1, from the northern body, K_2O = 10.43 ± 0.21 wt. %, Ar^{40} (radiogenic) = 1.23520 scc/g, and the air correction was 9%. In sample M-2, from the southern body, K_2O = 10.51 ± 0.20 wt.%, Ar^{40} (radiogenic) = 1.24502 scc/g, and the air correction was 8%.

In a recent compilation of all the available K-Ar and $^{40}Ar/^{39}Ar$ dates of granitoid rocks in southern Nova Scotia (using biotite and muscovite extracts), Reynolds _et al._ (1981) reported a mean age of 367 ± 8 Ma for the South Mountain batholith and the northern satellite plutons. The southern satellite plutons (see Figure 2.1) yielded an average age of 300 - 320 Ma. Among the southern satellites, the age of the Brenton pluton was consistently dated at 320 ± 8 Ma. Thus, the average K-Ar date of 333 ± 7 Ma obtained for the Brazil Lake pegmatites in this study, agrees well with those of the regional plutons, or the southern satellites.

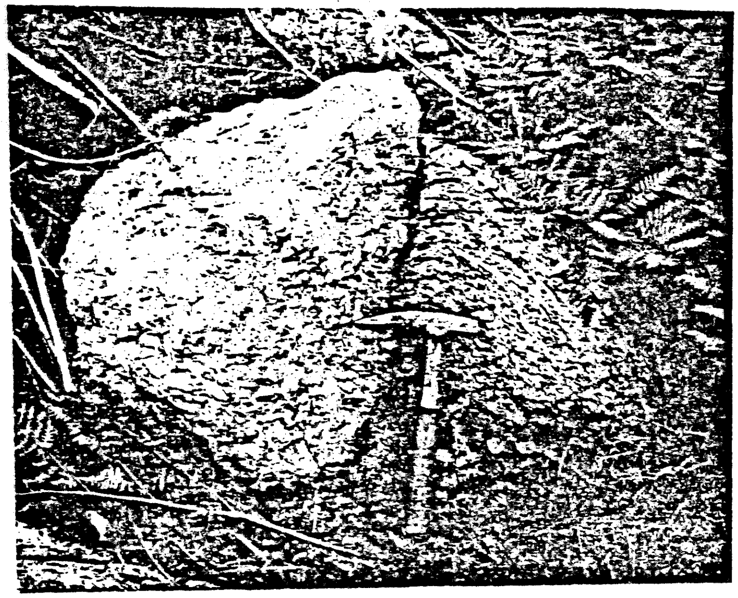
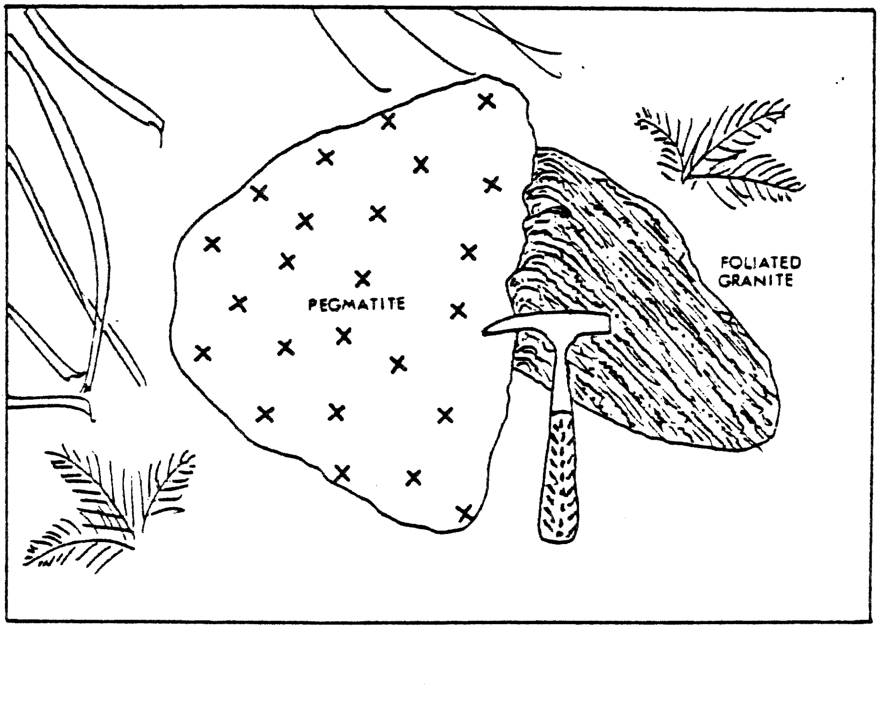


Plate 6.1. Boulder of pegmatite/granite from Brenton pluton, showing bending of foliation in granite at contact with pegmatite, suggesting forceful intrusion.



Three possible models were considered by Reynolds et al. (1981) to account for the younger apparent ages (300-320 Ma) of the southern satellite plutons: (1) these satellite plutons were intruded significantly later in time than the South Mountain batholith, or (2) they are time-synchronous with the South Mountain, but took much longer to cool to the argon retention temperatures, or (3) they were affected by a later thermal or tectonic event which partially degassed the minerals, giving younger apparent ages.

Various lines of evidence led Reynolds et al. to conclude that the apparent ages for the southern satellite plutons are not original igneous ages, but reflect a later degassing effect, thus favouring model (3). O'Reilly (1976) also suggests that the apparent dates he obtained for the Brenton pluton reflect a partial or complete overprinting, or argon loss, yielding a cooling or metamorphic age. The muscovites in the Brenton pluton are very strongly deformed into gneissic textures, whereas the muscovite in the Brazil Lake pegmatites is totally fresh and undeformed. The fact that both muscovites yield the same age confirms the premise that the age obtained is not an original igneous age.

O'Reilly (1976) interpreted the Brenton pluton as a pre- or syntectonic intrusion on the basis that the foliation in the pluton parallels the regional schistosity. The pluton was clearly emplaced into hot country rocks because of the very narrow contact aureole surrounding the body. Similarly, the effect on the country rocks surrounding the Brazil Lake pegmatites was minimal except for the late stage metasomatic effects, resulting in tourmaline and holmquistite formation in the host rocks. The blocking temperature of muscovite for radiogenic argon may be extremely low (about 200°C) in regional metamorphic rocks (Clark and Jaeger, 1969). Therefore, the young apparent dates of the Brenton and other southern plutons in general, may reflect a long period of slow cooling, indicating that these plutons were emplaced at considerable depth and remained hot for a long period of time. The evidence for a Late Carboniferous tectonic and/or thermal event in Nova Scotia is manifold. Poole (1967) called the tectonic event, which resulted in regional faulting and shearing around the Minas Basin and southern New Brunswick, the Maritime Disturbance. Late Carboniferous low-angle, large-scale, thrust faulting has been described from Cape Breton by Milligan (1970) and Currie (1977). Reynolds et al. (1981) speculate that locally observed deformational features in Devonian plutons probably reflect this tectonism.

Evidence for at least two distinct tectonic events around the Brazil Lake area is found in the two foliation directions observed in the garnet-biotite schists. The regional metamorphic grades (Figure 2.2) are also indicative of a post-South Mountain batholith thermal event. The highest grade (sillimanite zone) is centered near the town of Shelburne. The metamorphic zones are not continuous around the Brenton pluton area however. Just east of the Brenton pluton, low grade rocks of chlorite and biotite metamorphic grade are found. Just north of this area, high-grade amphibolite-facies metabasites and staurolite-biotite schists are found. This suggests some large scale displacement in the area which has not yet been identified. The regional folding in the Yarmouth syncline area is also discordant with the rest of the Meguma massif, suggesting a tectonic event which affected this area to a much greater extent than the rest of mainland Nova Scotia.

Thus it is clear that the Brazil Lake pegmatites were emplaced later than the Brenton pluton was emplaced and acquired its cataclastic texture, through shearing. It is also evident that the dates obtained for the Brenton pluton and the Brazil Lake pegmatites are not original igneous ages, but reflect a later overprinting effect. The age of regional metamorphism which affected most of the Paleozoic rocks of Nova Scotia resulting in the present regional metamorphic zonation pattern, is approximately 400-415 Ma (Reynolds, et al., 1979).

The following relative time frame can be drawn for the Brazil Lake area, between the 400-415 Ma regional metamorphic event and the inferred 320 Ma tectono-thermal event: (1) 400-415 Ma - regional metamorphism, (2) approximately 367 Ma - emplacement of South Mountain batholith, (3) some time between regional metamorphism and pegmatite emplacement - emplacement of Brenton pluton, (4) shearing of Brenton pluton, (5) Brazil Lake pegmatite emplaced, (6) 320 Ma - tectono-thermal event resulting in cooling or overprinting of Brenton pluton and Brazil Lake pegmatites.

CHAPTER 7

INTERPRETIVE ASPECTS OF PETROLOGIC OBSERVATIONS

7.1 MODE OF EMPLACEMENT

The nature of the pegmatite-forming process has been discussed by many workers, e.g. Schaller (1925), Cameron et al. (1949), Jahns, (1955), Chadwick (1958), Mulligan (1962), Jahns and Burnham (1969), Tikhomiuova (1972), Zasedatelev (1977), and Kremenetskiy et al. (1978). In a general consensus of opinion regarding the origin and emplacement of pegmatite rocks, three possible mechanisms are generally considered: fluid emplacement (crystallization and differentiation in a "restricted" system), replacement bodies (pegmatitic material replaces pre-existing rock), and metamorphic or metasomatic segregation (pegmatitic material is derived from the country rocks). Evidence for each of these processes has been described in the literature and various pegmatite bodies have been attributed to one or more of these mechanisms.

In the study of pegmatite genesis, it is generally agreed that structural and textural features are better indicators of fundamental igneous processes than "key minerals" or assemblages. Structural relationships and textural features of the Brazil Lake pegmatite strongly indicate a fluid emplacement origin.

The following observations were interpreted as evidence of fluid emplacement by Hutchinson (1959) in his study of the Bernic Lake, Manitoba spodumene pegmatite, and all of these features were observed in the Brazil Lake pegmatite as well. (1) the development of an internal structure and mineralogical zonation, (2) sharp wall rock contacts, suggestive of intrusive relationships, especially between rocks of such different composition as amphibolite and pegmatite, (3) wall rock alteration of limited extent (amphibolites within 10 m of the Brazil Lake pegmatite appear similar to those hundreds of metres away); and (4) the nature of the wall rock alteration is in accord with fluid emplacement (e.g. tourmaline and holmquistite formation in the quartzite).

The fact that most rare-metal pegmatites exhibit grossly similar mineral assemblages and sequences of occurrence from wall rock inwards is supportive of a fluid emplacement mechanism, since metasomatism or replacement would not produce such consistant relationships (Varlamoff, 1972).

Replacement type pegmatites would probably be more homogeneous in texture than those formed by fluid emplacement. Furthermore, a metasomatic origin would be expected to produce much more pervasive wall rock alteration and a depletion in those elements which are enriched in the pegmatite. No such depletion was found in an unpublished Li-Cs-Rb lithogeochemical survey of the country rocks, conducted by Shell Canada Resources Ltd. Indeed, the reverse was observed, and local areas of enrichment of these elements were defined.

The distortion of foliation in the country rocks has been cited as a strong indication of dilation and fluid emplacement (e.g. Kretz, 1968). As seen on the detailed geology map (back cover), a local distortion of schistosity is observed in the country rock outcrops nearest to the Brazil Lake pegmatitic bodies.

Evidence of forceful injection, as opposed to passive emplacement, can be seen in an outcrop and boulder field of pegmatites within the Brenton pluton. A boulder consisting of half pegmatite and half foliated granite, displays at the contact, a local distortion or bending of the schistosity in the granite (Plate 6.1). Further evidence of forceful injection may be found in the irregular shape of the southern pegmatite outcrop (Figure 3.1) as well as the "pinch and swell" structure suggested by the occurrence of the three northern pegmatite outcrops.

7.2 INTERNAL STRUCTURE AND ZONATION

It is impossible to fully understand the internal zonation pattern of a pegmatite from a two-dimensional exposure. Hence, those pegmatite bodies which have been mined and excavated provide a wealth of information upon which models and patterns of internal zonation are based. It has become common to attempt to recognize and predict the downward distribution of additional zones not exposed at the surface.

The zonation patterns illustrated in Figures 3.1 and 3.2, therefore must be regarded as representative only of the particular level of present exposure, and the possibility of a vertical zonation pattern must also be considered. Certain textural and structural relationships exhibited by the zonal pattern can, nevertheless, be used to infer basic processes regarding their formation.

There are three distinct mineralogical zones within the southern outcrop at Brazil Lake; a coarse-garined, blocky, perthitized microcline zone (cut by quartz veins), a very coarse-grained quartz-spodumene zone, and a fine-grained, aplitic albite zone.

Jahns and Burnham (1969), in their experimental study of pegmatite genesis, make a clear distinction between coarse-grained, but otherwise normal, phaneritic igneous rocks (sometimes termed pegmatite, sometimes granite) and true pegmatites of igneous origin. The decisive difference in the formation of the true pegmatite is the appearance of a fluid phase, generally a supercritical aqueous fluid, in addition to the silicate melt.

Any theory of genesis for the Brazil Lake pegmatites must account for the following features:

1. Pronounced segregation of minerals.
2. Marked asymmetry in the zonal structure
3. Co-existing pegmatite and aplite within the same igneous body.
4. Distinct chemical and mineralogical differences between zones.

The following discussion draws freely from Jahns and Burnham's experimental model of pegmatite genesis. The first appearance of the fluid phase may be correlated with the first appearance of the giant crystals characteristic of true pegmatites. Diffusion of material along temperature gradients can occur much more rapidly in the aqueous phase than the relatively viscous silicate melt. The effects of this rapid diffusion include the development of coarse to giant sized crystals. If sufficient time is allowed, the aqueous fluid can migrate upward through the denser liquid and become segregated in the structurally highest parts of the solidifying pegmatitic body. Experimental research has shown that, although separation of constituents between the two fluids is never complete, a strong tendency exists for potash and lithium-bearing minerals to crystallize from the aqueous phase and soda-bearing minerals from the melt. Quartz seems capable of crystallizing simultaneously from both. Many workers have commented on the selectively more extensive transfer of potassium over sodium in aqueous phases. This is commonly expressed in the segregation of potash-rich mineral aggregates in the upper parts of pegmatitic bodies, usually in an asymmetric zone within the body.

The occurrence of the blocky microcline zone (A) on the southeastern side of the southern outcrop (Figure 3.1) and in the same relative position in the northern #1 outcrop (Figure 3.2) at Brazil Lake, may be explained in terms of the initial crystallization from a potassium-rich aqueous phase. Thus, the blocky microcline was emplaced probably along fractures in the country rock, as an early product from a potassium-rich fluid.

Generally, crystallization within the two fluid system described above yields relatively coarse-grained products from the aqueous phase and much finer-grained products from the melt. The aplitic albite phase within the Brazil Lake pegmatite may be attributed to a sudden reduction in confining pressure, resulting in a rapid loss of water from the silicate melt, through fractures in the country rock for example, and subsequent "quenching" of the melt. Aplite would result from this process. Alternatively, successive stages of residual silicate liquid progressively richer in water and other volatiles may have been injected into the crystallizing pegmatite. Decreasing amounts of the liquid would be available as time progressed, but segregation of pegmatitic material and increasing amounts of aplitic rocks would increase with time.

The texture of the aplitic phase, in thin section, resembles a cumulate aggregate of crystals, which would lead one to suspect that these albite laths crystallized slowly from a silicate melt and accumulated in some segregated section of the pegmatitic body. This theory would favour a slow diffusion of aqueous fluid through a simultaneously crystallizing silicate melt, as opposed to a rapid quenching mechanism.

Yet another possible explanation of the aplitic phase of the Brazil Lake pegmatite is a late stage replacement or fracture-filling body. On comparing Figure 3.1 with Figure 3.3, one can see that the fractures in the pegmatite preferentially follow, to a certain degree, the aplitic phase. It is believed, however, that the fractures occurred after solidification of the pegmatite and they simply followed the distribution of the aplitic material because it is less resistant than the much more consolidated, very coarse-grained quartz-spodumene phase.

Regardless of exactly which process or combination of processes formed the coexisting giant pegmatitic and aplitic textures, it has been experimentally and empirically observed that an increasing scale of asymmetry and internal segregation occurs with increasing coexisting giant pegmatite and aplite (Jahns and Burnham, 1969).

Finally, if the aqueous phase is effectively connected with the country rocks through grain boundaries or microfractures, transfer of material from the cooling pegmatite can lead to a metasomatic aureole around the body. This accounts for the tourmalinization and lithium metasomatism, resulting in holmquistite, found within the White Rock quartzite country rocks.

Thus, the three mineralogical/textural zones within the Brazil Lake pegmatite represent the segregation and partitioning of each of the three alkali elements Li, K, and Na. The mechanism which caused such a very efficient partitioning of these alkali elements seems to have involved the presence of an aqueous fluid, which served as a transport medium for particular elements at different times, during the crystallization of the pegmatite.

Ginsburg (1960) described a general pattern of evolution and mineralization of lithium pegmatites (Figure 7.1). An initial potassium (microcline) phase is followed by a lithium (spodumene) and Ca-Na (plagioclase) phase, which is not observed at Brazil Lake because the rocks are Ca-poor. This is followed by a K-rich (muscovite)phase and a Na-rich (albite) phase. Finally, another potassium (greisen) phase occurs and this is followed by a Cs-Rb-Li-K (lepidolite) phase, neither of which are observed at the exposed level of the Brazil Lake pegmatites, but may have been present at one time.

This general scheme fits the observed features of the Brazil Lake pegmatites very well. Evidence of the relative ages of the three zones

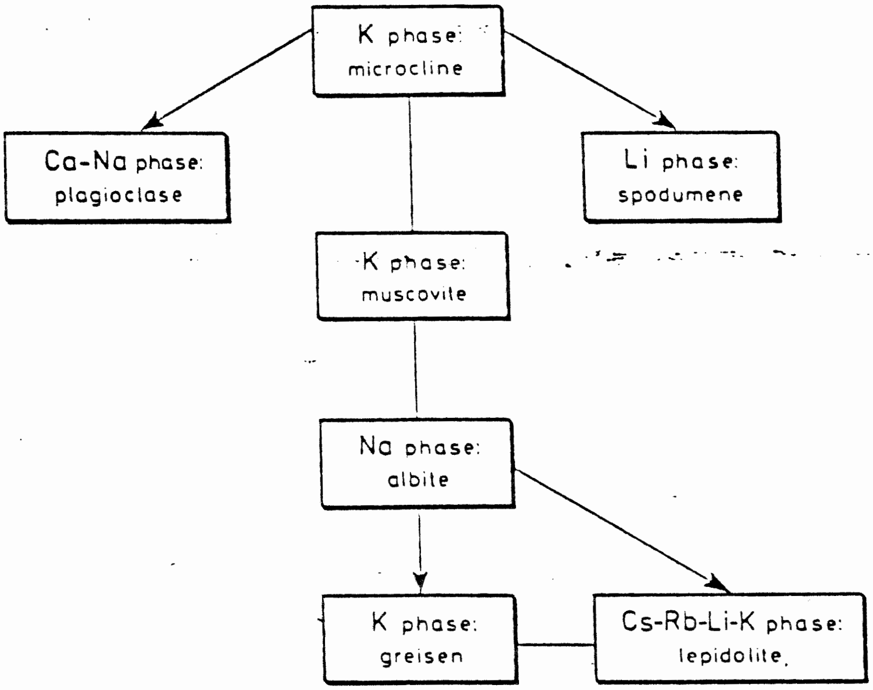


Figure 7.1— Phases of Pegmatite Formation, According to Ginsburg, 1960.

is seen in the textural and structural characteristics of the different zones and their contacts. The microcline zone (A) is inferred to have been emplaced first, from chemical data and textural relations, such as replacement of microcline by albite. Quartz must have crystallized simultaneously with the microcline and continuously throughout the spodumene crystallization phase, as it occurs in veins and massively, with muscovite, in both of these zones. The spodumene-quartz zone (B) was probably emplaced some time later than zone A (microcline), because of the irregular nature of the contact between these two zones. Similarly, the aplitic albite zone (C) shows intrusive-type contacts with zone B.

7.3 REGIONAL ZONATION

Varlamoff (1972) compared the mineralogy, internal zonation, and regional zonation patterns of African rare-metal pegmatites with those of the rest of the world. His conclusions were as follows. The rare-metal pegmatite forming process has remained the same throughout geologic time. The succession of pegmatite types remains the same, regardless of the types of rock in which they occur. The specific distribution of pegmatite types depends on the depth of crystallization of the granitic intrusion.

Thus the areal distribution of pegmatite types depends solely on the physico-chemical conditions under which the granitic magma differentiates and crystallizes. Varlamoff classified pegmatite types based on characteristic mineral assemblages and progressive distance from the granitic source. He recognized nine types. Types 1 to 3 are mineralogically simple (biotite, tourmaline, quartz and feldspar), and occur within the boundaries of the granitic body itself. Types 4 to 9 are mineralogically more complex, and occur progressively farther away from the igneous pluton, and stratigraphically higher in the country rocks.

The Brazil Lake pegmatite corresponds to Varlamoff's type 6, perhaps transitional to type 7. Type 6 is described as "zoned pegmatite, frequently with quartz core, and gigantic crystals of amblygonite and spodumene, pockets of big prisms of beryl, low contents of cassiterite, columbo-tantalite and microlite". Type 7 is described as "strongly albitized pegmatite with spodumene, muscovite, rare lepidolite, small prisms of white or greenish beryl, cassiterite and columbo-tantalite. The pegmatite which occurs within the Brenton pluton is of type 3, described as "muscovite, biotite and tourmaline, with graphic feldspar".

Four other pegmatite occurrences in southwestern Nova Scotia were studied by Kent (1962). Most of these were mineralogically simple and Kent classified them as type 5; "muscovite, microcline and quartz with a few small beryl crystals and first albitization". Most of these pegmatites occur within the source granitic pluton or very near the contact (Figure 2.1) and thus probably represent pegmatites of a stratigraphically lower position than the Brazil Lake pegmatites, which are mineralogically more complex and distal with respect to the source pluton.

Since the Brenton pluton most probably was not the source of the Brazil Lake pegmatites, they are indeed quite distant from their source, agreeing well with Varlamoff's classification. The two closest plutons to Brazil Lake, after the Brenton, are the Davis Lake pluton, 20 km east, and the Wedgeport pluton, 25 km south. The other possibility is that the source pluton for the Brazil Lake pegmatites is not exposed and lies at some depth, beneath the exposed pegmatites.

A typical regional zonation pattern has been described for the distribution of the rare elements Be, Li and Ta/Nb from many pegmatite districts (e.g. Hutchinson, 1955). The generally observed pattern is for Be to be enriched nearest to the source pluton, followed by Ta/Nb, and Li is generally found in the zone farthest removed from the source pluton. Although outcrop patterns and limited geochemical data do not allow a good picture of the regional distribution of rare-elements at Brazil Lake, one may infer that the two pegmatitic bodies represent a Lithium-rich zone (spodumene constituting 14% of the southern outcrop) and hence any greater enrichment in Be, Ta and Nb would probably occur at a greater stratigraphic depth, if the source pluton is not exposed, or either north or south of Brazil Lake, depending on which pluton is defined as the source. This discrimination would require very detailed geochemical comparisons of elements and ratios enriched in the Brazil Lake pegmatite.

The possible effects of late-stage alkali fluids or supergene fluids on the distribution of the rare-elements must also be considered. The present distribution may have been altered somewhat, and particular elements remobilized with respect to others within the pegmatitic body. Kraynov (1968) described a difference in the migration capacity between

Nb and Be in alkaline waters, depending mainly on the stability of anion complexes and pH of the fluids.

7.4 PETROGENESIS

Three distinct chemical/mineralogical/textural zones have been defined within the Brazil Lake pegmatitic bodies. They are zone A (a K-rich microcline-quartz phase); zone B (a Li-rich spodumene-quartz phase); and zone C (a Na-rich albite-quartz phase). Each of these three zones contains varying amounts of other minor and accessory minerals, generally not observed in hand specimen. The relative abundances of the various major, minor and accessory minerals within each of the three zones is illustrated in Table 7.1.

Most of the accessory minerals, such as apatite, zircon, columbo-tantalite, beryl and cassiterite are most strongly enriched in zone C, the aplitic albite phase. This association of Ta, Sn and Be mineralization with the aplitic albite phase is well known from other pegmatites (e.g. Crouse <u>et</u> <u>al.</u>, 1972). These minerals are inferred to have formed with this low-temperature, late-stage sodic-phase. The element enrichment in the residual melt phase may be partially the result of the absence of a suitable complexing agent in the aqueous phase. Fluoride commonly acts as a carrier of metal ions in magmatic systems, mobilizing certain metals and mineralizing areas where precipitation occurs. No fluorite was observed in the Brazil Lake pegmatites, whereas fluorite veining is very common in the greisenized areas of the Davis Lake pluton, about 20 km east of Brazil Lake, and is associated with Sn

TABLE 7.1 - Distribution of Minerals in the Three Internal Zones of the Brazil Lake Pegmatite.

Assemblages	zone A (microcline-quartz-muscovite)	zone B (spodumene-quartz-muscovite)	zone C (albite-quartz)
Minerals			
Quartz	++	++	+
Spodumene	-	++	-
Muscovite	+	++	+
Albite	-	-	++
Microcline	++	-	-
Tourmaline	+	+	+
(schorl)	-	+	+
(elbaite)	+	+	-
Beryl	-	+	++
Apatite	-	-	+
Zircon	+	-	++
Ilmenite	+	-	+
Columbo-Tanalite	-	+	++
Cassiterite	-	+	+
*Biotite	-	-	+
*Epidote	-	+	-

* probably xenocrystic

\- Relative abundances are expressed by the following symbols:

++ = abundant, usually readily observed in hand specimen
\+ = present, but scarce relative to other zones
\- = absent

mineralization.

The geochemical characteristics of the zones within the Brazil Lake pegmatite are similar to those observed in other lithium-rich pegmatites. Davies (1958) pointed out a generally observed antagonism between the occurrence of lithium and beryllium in granitic pegmatites. If both do occur within the same pegmatitic body, they are usually segregated in different zones, and beryllium tends to be most enriched in pegmatites low in lithium. This is born out for the Brazil Lake pegmatite where beryl is most abundant in the albite zone (C), and spodumene is restricted to zone B, which contains very little beryl. Beryl commonly tends to be enriched in later phases of pegmatite formation (Foldvari-Vogl, 1978).

The paragenesis of the pegmatites, as inferred from the various chemical data, and structural and textural observations, is presented in Figure 7.2.

The source of the pegmatite-forming fluid was most likely a highly differentiated granitoid magma. The fluid travelled, probably a considerable distance, perhaps along grain boundaries and microfractures, and was injected into a fracture system which cross-cuts the local stratigraphy and is sub-parallel to regional schistosity.

The presence of an aqueous fluid coexisting with the silicate melt is interpreted to be essential to the mineral segregations, textural variability and chemical partioning observed within the pegmatite. The microcline-quartz phase was emplaced first, mainly as a result of the

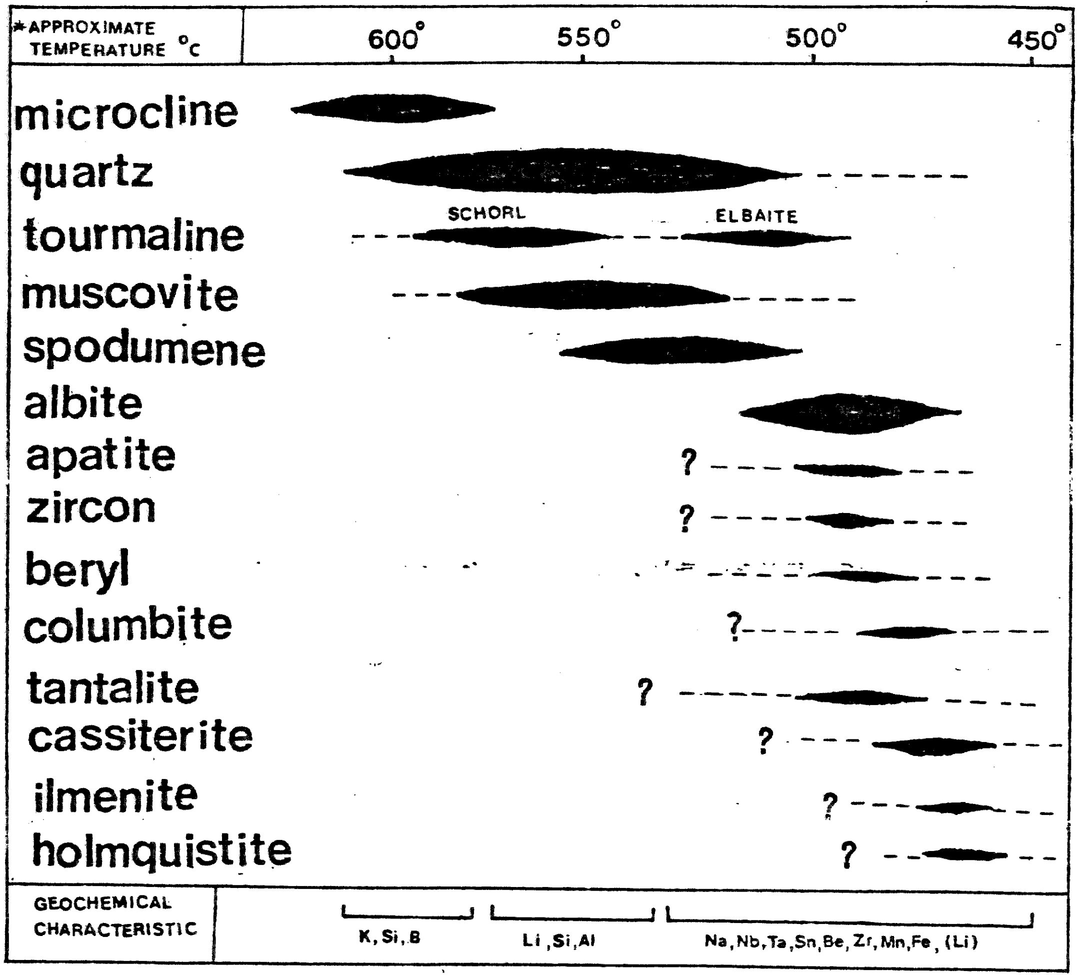


Figure 7.2 – PARAGENESIS OF THE BRAZIL LAKE PEGMATITES. (* approximate crystallization temperatures inferred from experimental evidence of Jahns and Burnham, 1969 and Földvári-Vogl, 1978, and a similar mineral assemblage described from the Congo, Africa in Mineralium Deposita, Vol. 2, 1967, pp. 119 – 130.)

upward migration of a K-rich aqueous fluid. The spodumene-quartz phase is also interpreted to have crystallized at least partially as a result of the aqueous phase, which perhaps acted as a medium of rapid transport of lithium ions through the silicate melt to the crystallization site of the giant-sized spodumene-quartz phase. A mechanism of sudden water loss, and subsequent quenching of the sodic melt may explain the cumulate-like texture of the aplitic albite phase. A resurgent boiling mechanism could account for the asymmetrical distribution of the coexisting aplitic and very coarse-grained phases. The cumulate texture, however, is distinctive and suggestive of a slow cooling and crystal settling process. Thus, the aqueous phase may have diffused through the silicate melt, forming K-rich, and later Li-rich, coarse-grained phases, while the silicate melt was simultaneously crystallizing Na-rich albite.

This late-stage aplitic albite phase was enriched in Be, Ta,Nb, Sn and Zr. Fluids rich in B and Li were also emplaced in the country rocks sometime during the crystallization sequence, resulting in tourmaline and holmquistite in the White Rock quartzite.

7.5 SUMMARY AND RECOMMENDATIONS

The Brazil Lake pegmatitic bodies are probably the product of a late-stage, highly evolved rare-metal enriched fluid. The source of the fluid is probably a considerable distance away from the pegmatites, either at depth and presently not exposed, or laterally distant, to the northeast or south of Brazil Lake.

It appears that the fluid was emplaced forcefully into fractures which cross cut the amphibolites and quartzites of the White Rock Formation, while these host rocks were still fairly hot.

The K-Ar data of 333 ± 7 Ma obtained for the Brazil Lake pegmatites is interpreted as a cooling age rather than an original igneous age, possibly overprinted by a Late Carboniferous tectonic or thermal event. It is clear that the pegmatites were emplaced after the emplacement of the nearby Brenton pluton and the tectonic event which resulted in the shearing of this body. This places the age of crystallization of the pegmatites somewhere between 400 Ma (oldest regional metamorphism) and 320 Ma (Late Carboniferous tectono-thermal event).

RECOMMENDATIONS FOR FUTURE WORK

1. From an economic view point, potential for Li, Be and Ta-Nb mineralization exists in the Brazil Lake area. The possibility of a vertical zonation pattern must be considered, and from the regional zonation patterns described from other areas, an enrichment in Be and Ta-Nb with depth seems possible for the exposed pegmatites. Also, the possibility of placer-type concentrations of heavy minerals, such as columbite-tantalite and cassiterite, must not be discounted in an area which has been so extensively glaciated. In many other pegmatite districts of the world, a large part of the ore is mined from placer deposits.

2. A much more detailed compilation and analysis of geochemical data on southwestern Nova Scotia granitoid plutons would provide the basis for a genetic correlation of the Brazil Lake pegmatites with a particular granitoid body or suite, and perhaps provide better exploration criteria with regard to the probable areal distribution of associated pegmatites. Tourmaline halos would provide a good exploration tool.
3. Detailed mapping of the structural geology in the Yarmouth syncline area might provide more evidence for the apparent Late Carboniferous tectonic or thermal event, and aid in the interpretation of the various textural and age relationships of the granitoid rocks in the area.

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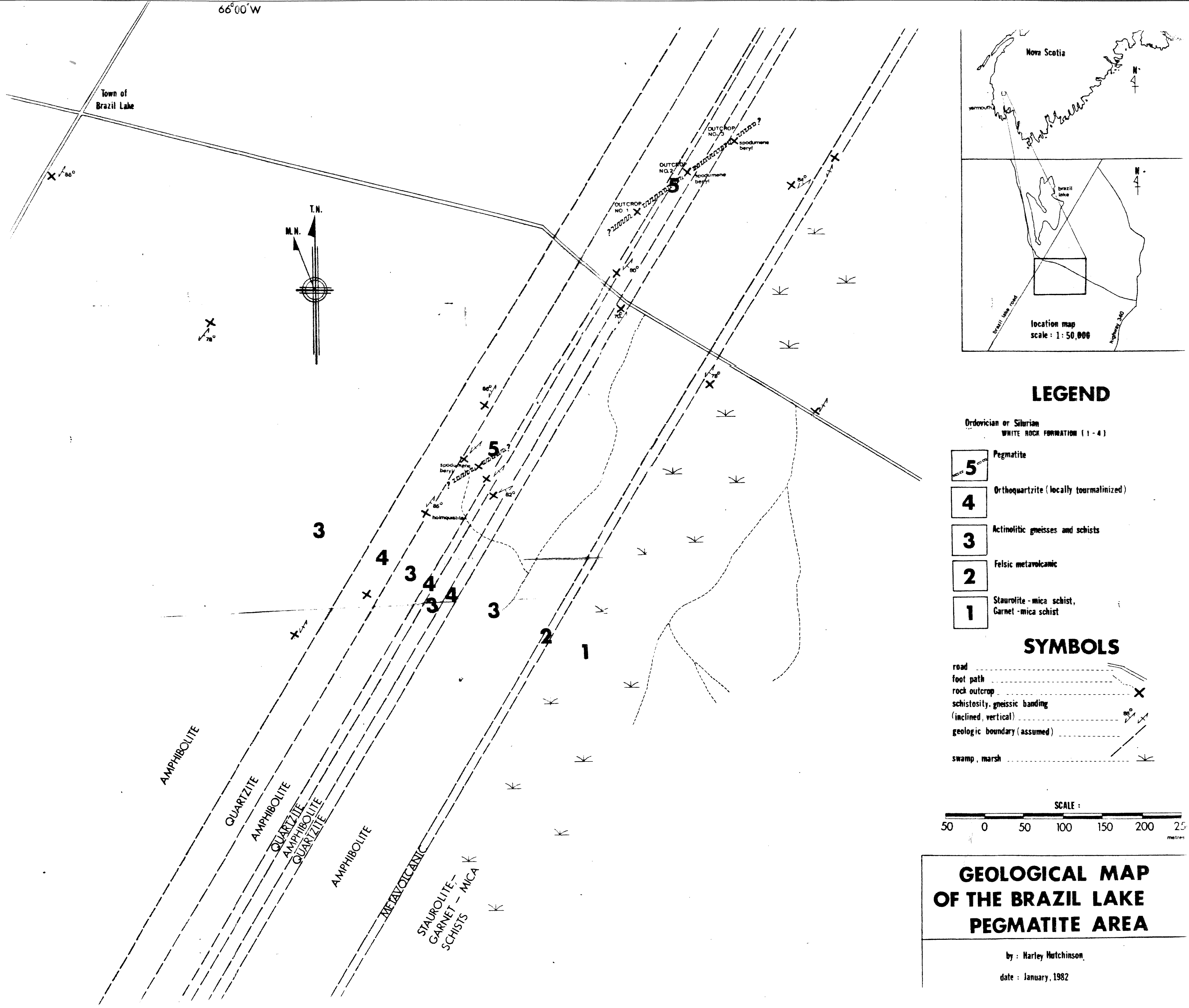

GEOLOGICAL MAP OF THE BRAZIL LAKE PEGMATITE AREA

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date : January, 1982