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Zr-Nb-Y-REE MINERALIZATION IN THE CROSS HILLS PLUTONIC SUITE

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Mineral Deposits Section

ABSTRACT

Minor Zr-Nb-Y-REE mineralization occurs in peralkaline granitic rocks of the Cross Hills Plutonic Suite. The suite consists of spatially and genetically related gabbro to diabase, granodiorite, biotite granite, peralkaline granite and minor syenite intrusions, which outcrop over 260 km² in the Terrenceville map area of southeast Newfoundland.

Euhedral and botryoidal, zoned, hydrothermal zircon is disseminated in narrow aplite veins and concentrated in tuffisite and along fractures in the peralkaline granite. The mineralized samples are significantly enriched in Zr, Y, Nb, Sn, Th, Ce and heavy REE. Assays have returned values of up to 20,000 g/t Zr, 2968 g/t Y, 2334 g/t Nb, 1550 g/t Ce, 725 g/t Th and 240 g/t Sn.

Scanning electron microscopy reveals a variety of Zr-, Nb-, Y- and REE-bearing minerals associated with the zircon. Baddelyite, fergusonite and thorite have been tentatively identified, along with thorium oxide and additional unidentified minerals.

The mineralogy of the occurrences and the distribution of mineralization in aplite dykes, tuffisite and fractures indicates a magmatic—hydrothermal origin. The peralkaline granite provided a source for the mineralizing elements. Concentration and mobilization of these elements was aided by the prevalence of oxidizing, alkaline and possibly carbonate-rich fluids.

INTRODUCTION

The Cross Hills Plutonic Suite (Bradley, 1962; Tuach, 1984, *in preparation;* O'Brien *et al.*, 1984) consists of a group of spatially and genetically related gabbro to diabase, granodiorite, biotite granite, peralkaline granite and minor syenite intrusions, which outcrop over 260 km² in the Terrenceville (1M/10) map area of southeast Newfoundland (Figure 1). In 1983, mapping and sampling was focused on an area of about 20 km² to the northwest of Grand Le Pierre (Figure 2). The peralkaline granite in this area is host to minor Zr-Nb-Y-REE mineralization.

Preliminary results of field work were presented in Tuach (1984) and the first draft of a report, documenting major and trace element data, petrographic observations and geological interpretations has been completed (Tuach, *in preparation).* This present paper summarizes the geology, geochemistry and mineralization of the Cross Hills Plutonic Suite and provides details of scanning electron microscopy (SEM) of mineralized samples and results of REE analyses of six peralkaline granite samples.

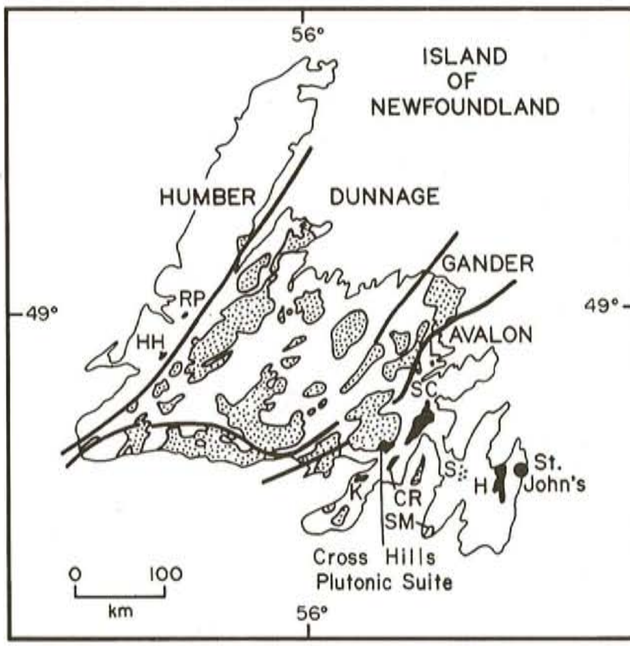

Figure 1. *Location of the Cross Hills Plutonic Suite in Newfoundland; also shown are the major tectonostratigraphic subdivisions in Newfoundland, and location and distribution of Paleozoic (stippled) and Eocambrian to Cambrian plutonic rocks (black). RP—Round Pond, HH—Hare Hill, L—Louil Hills, SC—Swift Current, CR—Cape Roger Mountain, K—Knee Granites, S—Spreadeagle, SM—Saint Marys Diabase, H—Holyrood.*

GENERAL GEOLOGY

The following is summarized from Tuach (1984 and *in preparation).* The high-level, posttectonic Cross Hills Plutonic Suite intrudes late Hadrynian, subaerial, low-grade, metavolcanic rocks (Belle Bay Formation) and metasedimentary rocks (Anderson's Cove Formation) of the Long Harbour Group (Williams, 1971; O'Brien and Nunn, 1980; O'Brien *et al.*, 1984). The Belle Bay and Anderson's

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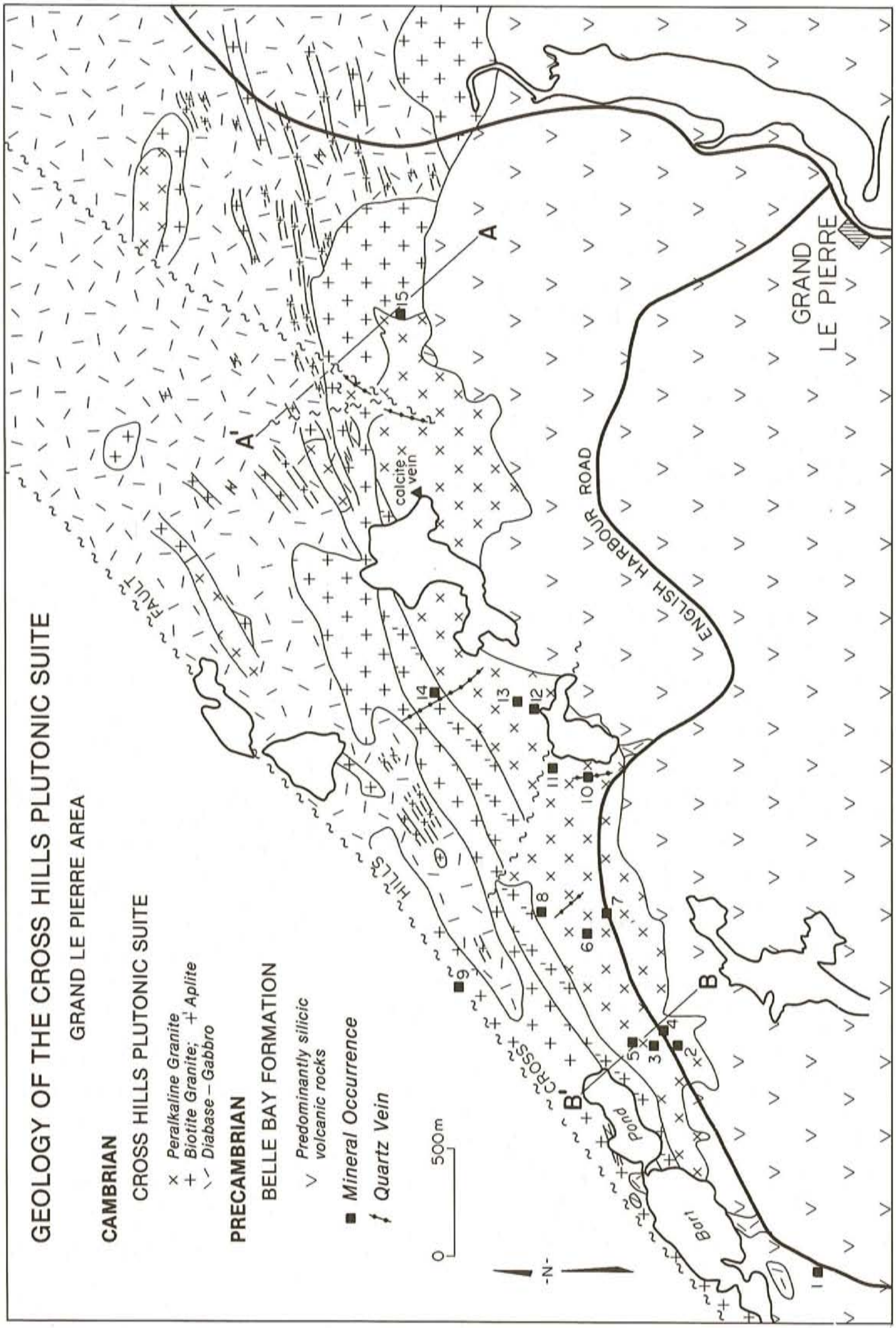

Figure 2. *Geology of the Cross Hills Plutonic Suite in the Grand Le Pierre area.*

Cove formations are possibly facies-equivalent and are unconformably overlain by peralkaline ash flows of the Mooring Cove Formation. The latter has been interpreted as the extrusive equivalent of the peralkaline granite phase of the Cross Hills Plutonic Suite (O'Brien *et al., in press)*. The Early Cambrian Cross Hills Plutonic Suite has provided imprecise Rb-Sr ages of around 560 ± 30 Ma (Tuach, *in preparation)*. The northern boundary of the suite is cut by the Sage Pond phase of the Ackley Granite suite. The Sage Pond phase has provided $^{40}Ar/^{39}Ar$ ages between 368.4 ± 4.2 Ma and 371.4 ± 5.4 Ma (Kontak *et al.,* 1988).

The Cross Hills Plutonic Suite is one of several Eocambrian to Cambrian plutonic bodies, commonly of alkaline to peralkaline affinity, which are found in both the Humber and Avalon zones of Newfoundland (Figure 1). It has been divided into five map units on the basis of field and geochemical data (Table 1). These are: 1) a mafic unit consisting of gabbro and diabase; 2) granodiorite; 3) biotite granite; 4) peralkaline granite, and 5) minor syenite. The following descriptions are summarized from Tuach *(in preparation)*.

Mafic unit

The mafic unit contains a variety of dark green, to grey, to black gabbro, diabase and minor dioritic rocks that are intruded by numerous veins and dykes of biotite granite. Small roof pendants and xenoliths of silicic volcanic rocks occur locally, and are common to the east of Grand Le Pierre. Gabbro is medium- to coarse-grained with local pegmatite patches. Diabase is fine- to medium-grained with an ophitic texture. Fine-grained aphyric and plagioclase- and pyroxene-phyric varieties of diabase also occur. Xenoliths of earlier gabbroic and diabase phases are seen in some exposures of the mafic unit. Diorite is the most abundant lithology at the Southeast Bight Hills and at Nine Mile Hill (O'Brien and Nunn, 1980).

Granodiorite

Mottled, purple to orange, massive, equigranular, medium- to coarse-grained hornblende–biotite granodiorite outcrops over a large area to the east of Grand Le Pierre. Abundant felsic and mafic volcanic and diabase xenoliths are common. The granodiorite is locally cut by diabase and aplite dykes, which are up to a metre wide.

Biotite granite

This is an orange, miarolitic, equigranular granite containing up to 5 percent mafic minerals. Although most of the granite is fine- to medium-grained, it is characterized by zones of aplitic texture, and an important mappable subunit of aplite of similar mineralogy and composition, occurs along the southern boundary of the biotite granite to the northwest of Grand Le Pierre (Figures 2 and 3). Locally, fine- to coarse-grained pegmatite is present. Related, thin, felsic granite dykes that locally intrude the mafic rocks, grade from an aplitic margin to a pegmatitic core. Xenoliths of felsic volcanic and mafic intrusive rocks are common in exposures to the northeast of Grand Le Pierre. North and west of Grand Le Pierre, silicic volcanic xenoliths are rare, and xenoliths of mafic intrusive rocks occur only in close proximity to contacts with the main bodies of mafic rocks. Epidote veins and fractures are common, particularly near faults and lineaments. Networks of quartz-filled fractures and veins are locally common, and quartz veins occur up to one metre wide and 100-m long.

Peralkaline granite

The peralkaline granite is purple-brown, miarolitic, fine- to medium-grained and is characterized by Na-amphibole, which is partly to completely replaced by chlorite. Granophyric intergrowths can commonly be recognized in hand-specimens, and small pegmatite patches occur locally. Tuffisite, indicative of gas streaming, is common and small peralkaline aplite veins occur. Several small, mineralized, peralkaline aplite veins intrude peralkaline granite at mineral occurrence 12 (Figure 2, Table 2). Hematite staining is common, particularly around fractures and tuffisite. Clay alteration occurs in association with fractures near the southern contact between the granite and the silicic volcanic rocks. Quartz vein networks and quartz veins up to a metre wide occur and are locally continuous with those in the biotite granite.

Syenite

A 50-m-long outcrop of purple, manganese-stained Na-amphibole-bearing syenite was found on the Grand Le Pierre road and a small outcrop of orange, alkali feldspar granite was noted 1.5 km to the south. These rocks are medium- to coarse-grained and equigranular. Two 50-m-wide, east-northeast-trending, subvertical dykes of fine-grained, red–brown, quartz-poor trachyte, outcrop approximately 1 km to the west of the main exposure of the Cross Hills Plutonic Suite. They exhibit high-background radioactivity and are tentatively correlated with the alkalic and peralkaline phase of the Cross Hills Plutonic Suite.

MINERALIZATION AND ALTERATION

The peralkaline granite and immediately adjacent rocks are host to numerous small mineral occurrences, many of which were located by Saarberg Interplan (Hopfengaertner, 1982). These are described by Tuach *(in preparation)* and are known as occurrences 1 to 15 (Figure 2, Table 2).

The most significant occurrences (11 and 12) are anomalous concentrations of Zr-Nb-Y-REE minerals. Radioactivity is 4 to 5 times above background levels at the mineralized locations, with spot highs up to 10 times above background levels. Other similar radioactive occurrences are listed in Table 2.

Table 1. Summary of geochemical data from the Cross Hills Plutonic Suite, Sage Pond–Grand Le Pierre area.

	GABBRO <52% SiO_2		BIOTITE GRANITE		APLITE		GRANODIORITE*		PERALKALINE GRANITE		SYENITE		MINERALIZED PERALKALINE	
	$\bar{x}$	$\bar{s}$	$\bar{x}$	$\bar{s}$	$\bar{x}$	$\bar{s}$	$\bar{x}$	$\bar{s}$	$\bar{x}$	$\bar{s}$	$\bar{x}$	$\bar{s}$	JT-067	JT-124
SiO_2	47.9	2.78	74.4	1.22	75.1	0.56	69.4	0.92	76.6	0.54	65.1	2.55	74.3	73.8
Al_2O_3	16.3	1.47	12.6	0.38	12.4	0.19	14.3	0.23	11.0	0.37	16.1	0.72	8.75	8.00
Fe_2O_3	3.64	1.74	0.73	0.14	0.68	0.15	1.08	0.22	1.88	0.45	2.38	0.93	6.14	5.80
FeO	6.96	1.70	0.76	0.26	0.70	0.18	1.67	0.25	0.45	0.18	2.36	1.08	0.41	0.11
MgO	7.23	1.26	0.26	0.16	0.15	0.04	0.79	0.16	0.05	0.03	0.11	0.08	0.16	0.08
CaO	9.02	1.08	0.62	0.47	0.45	0.06	2.59	0.21	0.09	0.07	0.44	0.27	0.06	0.13
Na_2O	2.85	0.42	3.70	0.22	3.89	0.18	4.06	0.12	3.75	0.21	6.01	0.58	1.65	1.75
K_2O	1.07	0.65	5.16	0.40	5.16	0.26	2.63	0.16	4.57	0.29	5.14	0.79	5.15	4.62
TiO_2	1.75	1.01	0.28	0.05	0.25	0.04	0.36	0.01	0.18	0.03	0.37	0.21	0.36	0.57
MnO	0.19	0.06	0.03	0.01	0.03	0.01	0.09	0.01	0.04	0.03	0.13	0.06	0.06	0.19
P_2O_5	0.29	0.18	0.03	0.01	0.02	0.01	0.06	0.01	0.02	0.01	0.05	0.04	0.02	0.03
LOI	2.30	0.64	0.71	0.13	0.54	0.11	1.28	0.18	0.49	0.11	1.07	0.42	0.93	0.79
CO_2	0.072	0.042	0.072	0.034	0.047	0.027	0.127	0.107	0.075	0.072	0.128	0.133	-	-
Li	36	9.7	11	2.8	8.1	1.9	13	2.5	8.8	6.5	13	4.8	10	8
Be	1.8	0.5	5.7	5.5	5.3	0.6	1.9	0.1	8.5	2.2	7.8	7.7	43.8	51.9
F	449	254	165	77	394	246	-	-	79	71	1196	1427	54	141
V	276	129	16	6.5	11	2.2	38	7.5	6	1.9	6.8	5.9	10	15
Cr	136	36	1.9	2.4	0.6	1.1	2.7	2.1	2	2.2	0.3	0.8	0	0
Ni	72	39	1.7	0.08	1.2	0.5	1	0	1	0	1	0	-	-
Cu	62	23	3.8	0.07	3.8	0.8	8.7	5	12	16	3	1	-	-
Zn	99	27	50	19	54	23	51	4.6	115	86	147	78	149	162
Ga	20	5	20	2.4	22	1.19	16	1.5	27	1.8	35	7	26	11
Rb	51	30	175	22	167	8.4	86	4.7	193	21	141	43	309	279
Sr	352	108	47	26	33	5.5	180	8.5	11	5.7	38	27	0	4
Y	35	13.7	83	27.5	97	12	31	4.4	150	59	123	74	1619	2968
Zr	136	68	231	19	259	28	154	3.1	690	234	996	612	6800	19208
Nb	9.6	2.9	30	5.3	35	2.7	13	0.6	65	28	244	176	809	1860
Ag	0.1	0	0.1	0	0.1	0	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1
Sn	1	-	1	0	2	1.6	-	-	5.2	3	7	5.2	40	90
Ba	164	173	307	84	248	88	647	62	73	64	387	377	47	220
La	11.7	6	46	13	62	15	18	2.3	34	22	124	95	33	190
Ce	109	51	194	41	222	29	84	13	200	67	351	224	762	1550
Pb	2.7	2.5	13	4.4	15	9.1	7.3	2.5	18	13	18	22	33	44
Th	2.8	3.4	25	2.9	27	2.9	13	1	31	13	32	23	364	725
U	0	-	4.1	1	4.8	0.6	-	-	6.2	2.7	6.5	3.7	64.2	112.5
n**	12		20		9		3		22		6		1	1

* These samples are from the Cross Hills Plutonic Suite–east of Grand Le Pierre.

** Maximum number of samples. For some elements, i.e., F, Ni, Cu, Sn and U, n may be lower.

$\bar{x}$–mean; $\bar{s}$–standard deviation; major elements and CO_2 in percent, trace elements in g/t; (-) not analyzed.

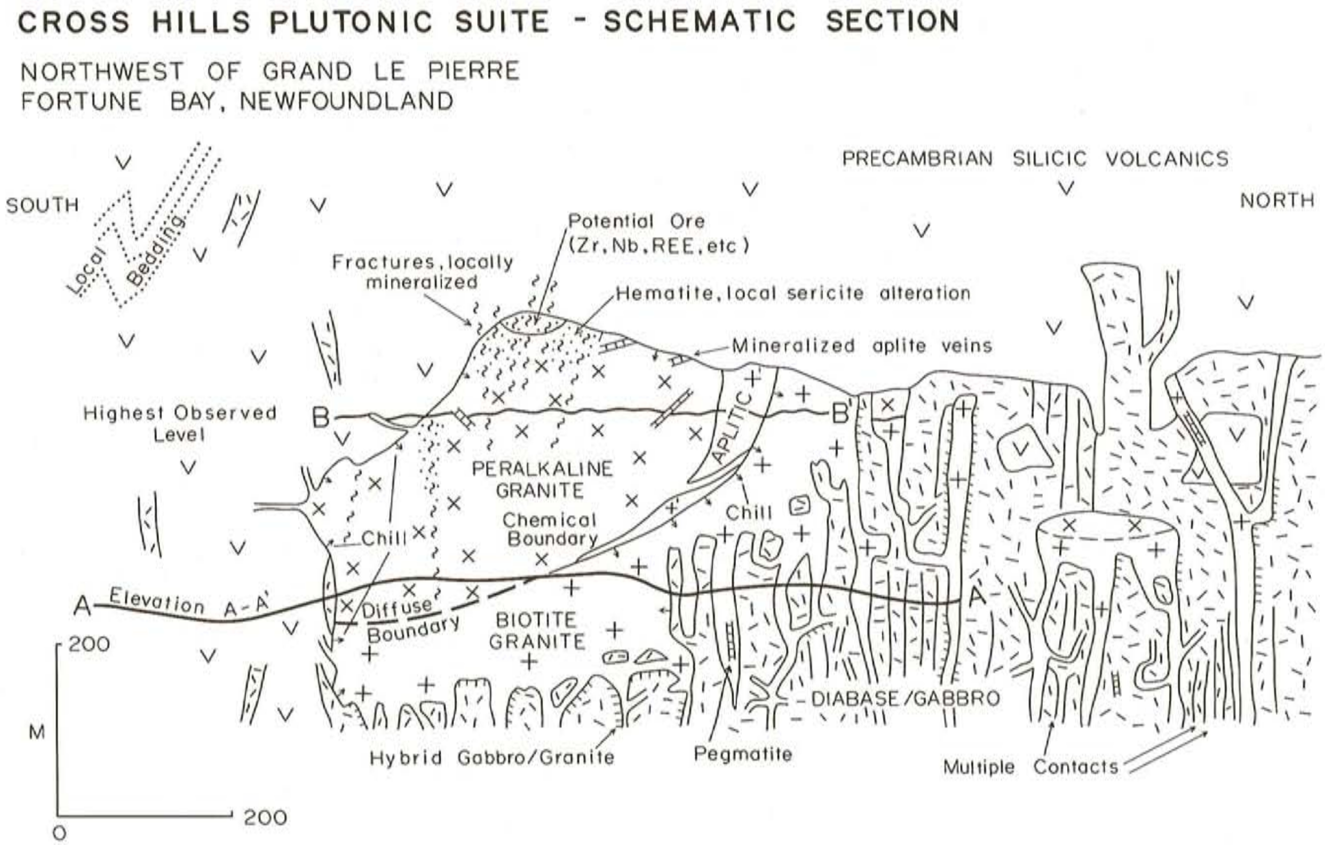

Figure 3. *Schematic (composite) geological section across the Cross Hills Plutonic Suite in the area to the northwest of Grand Le Pierre; level of sections shown on Figure 2 and denoted by A-A', B-B'.*

The highest assay results were obtained from chips of small aplite veins that intrude peralkaline granite exposed in a 3- by 2-m-trenched outcrop at occurrence 12 (Plate 1). The outcrop contains 5 to 10 percent, gently-dipping, up to 5-cm-wide, sheeted aplite veins; the host granite has weak anomalous radioactivity and did not give anomalous analytical values. A selected sample of vein material (JT-124) assayed 19208 g/t Zr, 2968 g/t Y, 1860 g/t Nb, 1550 g/t Ce, 725 g/t Th and 90 g/t Sn. Similar values were obtained by Hopfengaertner (1982). Abundant fine-grained (less than 0.1 mm), euhedral zircon is disseminated in the aplite matrix and is concentrated in tuffisite and fractures in the veins. It is commonly intergrown with hematite (Plate 2). SEM analysis reveal a variety of Zr-, Y-, Nb- and REE-bearing minerals. These include traces of baddelyite (ZrO_2) and possible fergusonite ($YNbO_4$) (Figure 4a). Additional unidentified Nb- and REE-bearing minerals were found (e.g., Plate 3 and Figure 4b, c and d).

At occurrence 11 (Figure 2) a 10- by 5-m area of anomalous radioactivity (up to 5 times above background levels) occurs in a south-facing scarp. A selected sample (JT-067) of radioactive chips assayed 6800 g/t Zr, 1619 g/t Y, 809 g/t Nb, 762 g/t Ce, 364 g/t Th and 40 g/t Sn. Botryoidal, zoned zircon (Plate 4) is concentrated in tuffisite and fractures, and fills spaces between feldspar crystals (Plate 5). Zoning may be caused by variations in Fe and Mn content (determined by SEM analysis). Some zircons are cored by thorium silicate (Plate 6 and Figure 4e), which may be thorite ($Th[SiO_2]$). Thorium oxide is also common (Plate 6 and Figure 4f). This is isotropic and may be a metamict alteration product of thorium silicate; unidentified Th-Nb minerals were also found (Figure 4g and h).

The Cross Hills Plutonic Suite is also host to several minor base-metal occurrences. Red-brown, hematite- and limonite-stained peralkaline granite, containing 1 to 5 percent fine-grained disseminated pyrite is ubiquitous over an area of 1000 by 200 m along the English Harbour road; tuffisite zones in the granite contain abundant hematite grains. Traces of galena and up to 3 percent fine-grained disseminated and fracture-filling pyrite are found in subvertical 30- by 3-m zones of pervasive grey-green sericite alteration (occurrence 4). Small areas of malachite stain, in some instances associated with traces of chalcocite and bornite, occur in quartz veins that cut the biotite and peralkaline granites (occurrences 9, 10 and 14) and in sheared rhyolite (occurrence 1). Minor pyrite and galena are found in quartz veins, which cut the peralkaline granite (occurrence 5).

Table 2. Mineral occurrences in and adjacent to the Cross Hills Plutonic Suite. Assays are of selected grab samples.*

Occurrence No.	Mineral or Anomaly	Description**		Zr	Nb	Y	Ce	Th	Sn	Sample No.	Comments	REF.
1	Malachite	Minor stain in sheared rhyolite	Trace over 1 m^2								Not analyzed	T
2	Radioactive. Up to 6 x background	Patchy. In isolated fractures in peralkaline granite	Fractures over 100 x 20 m area	581	Tr	799	Tr	620	Tr	JT-131		T
3	Radioactive	In peralkaline granite	-	11661	805	n.a.	n.a.	268	93	CH-3B-1		H
4	Pyrite, galena	Disseminated in subvertical 2-m wide sericitized zone in peralkaline granite	2 percent pyrite, trace galena	1190	Tr	139	Tr	Tr	Tr	JT-129	Also 481 g/t Pb and 840 g/t Zn	T
5	Pyrite, galena	In quartz vein cutting, peralkaline granite	Trace								Not analyzed	H
6	Radioactive	In peralkaline granite	-	9518	556-	n.a.	n.a.	259	70	19		H
7	Radioactive, pyrite	Fractures, weak anomalous radioactivity in peralkaline granite	Up to 5 percent pyrite							JT-86	All values at background levels	T
8	Radioactive	In peralkaline granite	-	7576	974	n.a.	n.a.	477	47	18		H
9	Chalcocite, malachite	Veinlets in 1-m wide quartz vein cutting; biotite granite in fault zone	Trace over 0.5 m^2 area							JT-57		T
10	Malachite	In 0.5-m wide quartz vein cutting, peralkaline granite	Trace over 0.5 m^2								Not analyzed	T
11	Radioactive	Fracture surfaces in south-facing scarp in peralkaline granite	10 m^2 area	6800	809	1619	762	364	40	JT-67		T
12	Radioactive, hematite	In aplite veins (to 12 cm, average 3 cm wide) in peralkaline granite. Abundant fine-grained zircon in fractures	1 x 2 m area	20000 19208	2334 1860	n.a. 2968	n.a. 1550	550 725	240 90	11 JT-124	Also 108 g/t Ta and 41 g/t U	H T
13	Radioactive	In peralkaline granite	-	10208	425			187	118	14		H
14	Malachite, chalcocite	In 2-m-wide quartz vein cutting biotite granite	Trace								Not analyzed	H
15	Radioactive	-	-	6328	316			188	37	22		H

H—Hopfengaertner (1982); T—Tuach (in prep.); *—All values in g/t. Tr—trace; n.a.—not analyzed; **—Unavailable or sketchy for some of the Saarberg Interplan occurrences.

Plate 1. *Mineralized peralkaline aplite veins cut medium-grained peralkaline granite at occurrence 12.*

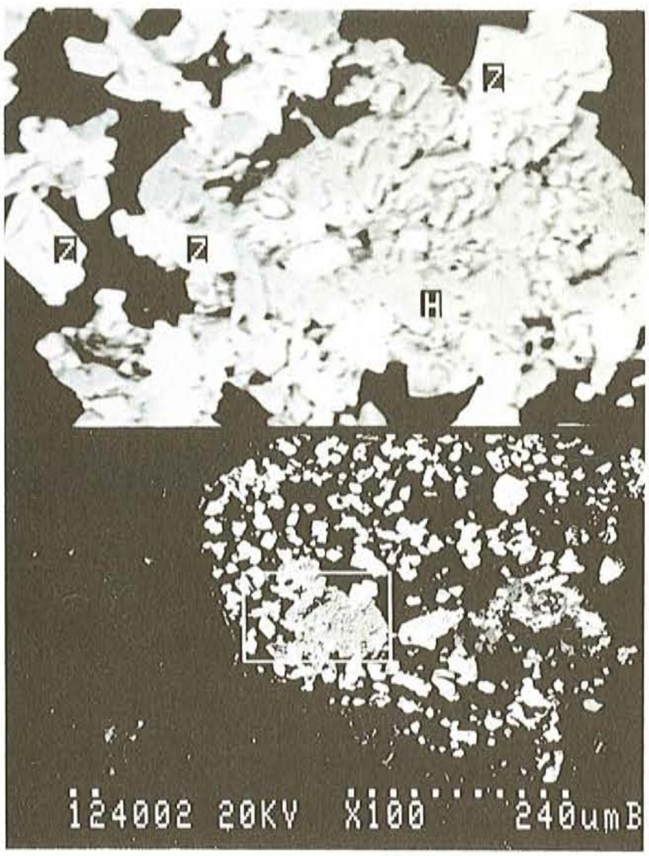

Plate 2. *SEM backscatter photograph of euhedral zircon (Z) intergrown with hematite (H); black is silicate gangue; scale bar refers to lower half of photo; scale of top (area in box) is 5x scale of bottom; sample JT-124.*

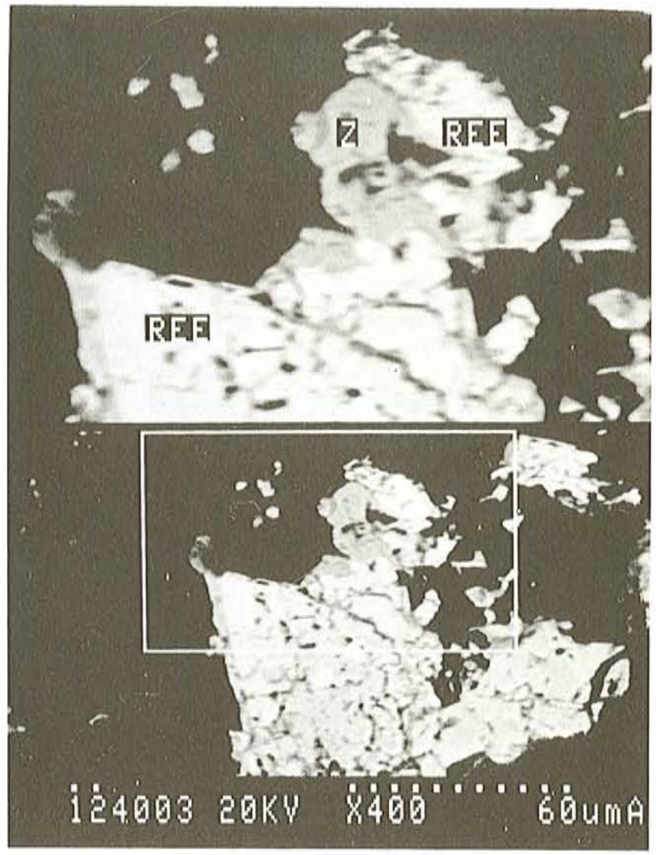

Plate 3. *SEM backscatter photograph of REE mineral intergrown with zircon (Z); spectral scan of REE mineral is shown in Figure 4d; scale of top is 2x scale of bottom; sample JT-124.*

RARE-EARTH ELEMENTS

Six samples of peralkaline granite, including a mineralized sample from occurrence 11 and one from the mineralized peralkaline aplite vein at occurrence 12, were analyzed for rare-earth elements by ICP-MS. The analytical methods are given in Tuach *(in preparation)* and the results are shown in Figure 5. The four unmineralized peralkaline granite samples have relatively flat REE patterns and negative Eu anomalies. However, sample 437 is enriched in both light REE (LREE) and heavy REE (HREE). The two mineralized samples, 067 and 124, are enriched in total REE, but have highly enriched, convex-upwards HREE patterns. All samples except 155 have HREE maxima at Tm. Four samples also have extremely high Ce values that appear to be somewhat independent of HREE concentrations. A Ce-rich mineral has been found in sample 124 (Figure 4d).

DISCUSSION

Significant enrichment of HREE over LREE is a common feature of similar peralkaline granite-hosted mineralization. Taylor *et al.* (1981) and Taylor and Fryer (1983) documented a five to seven-fold HREE enrichment in

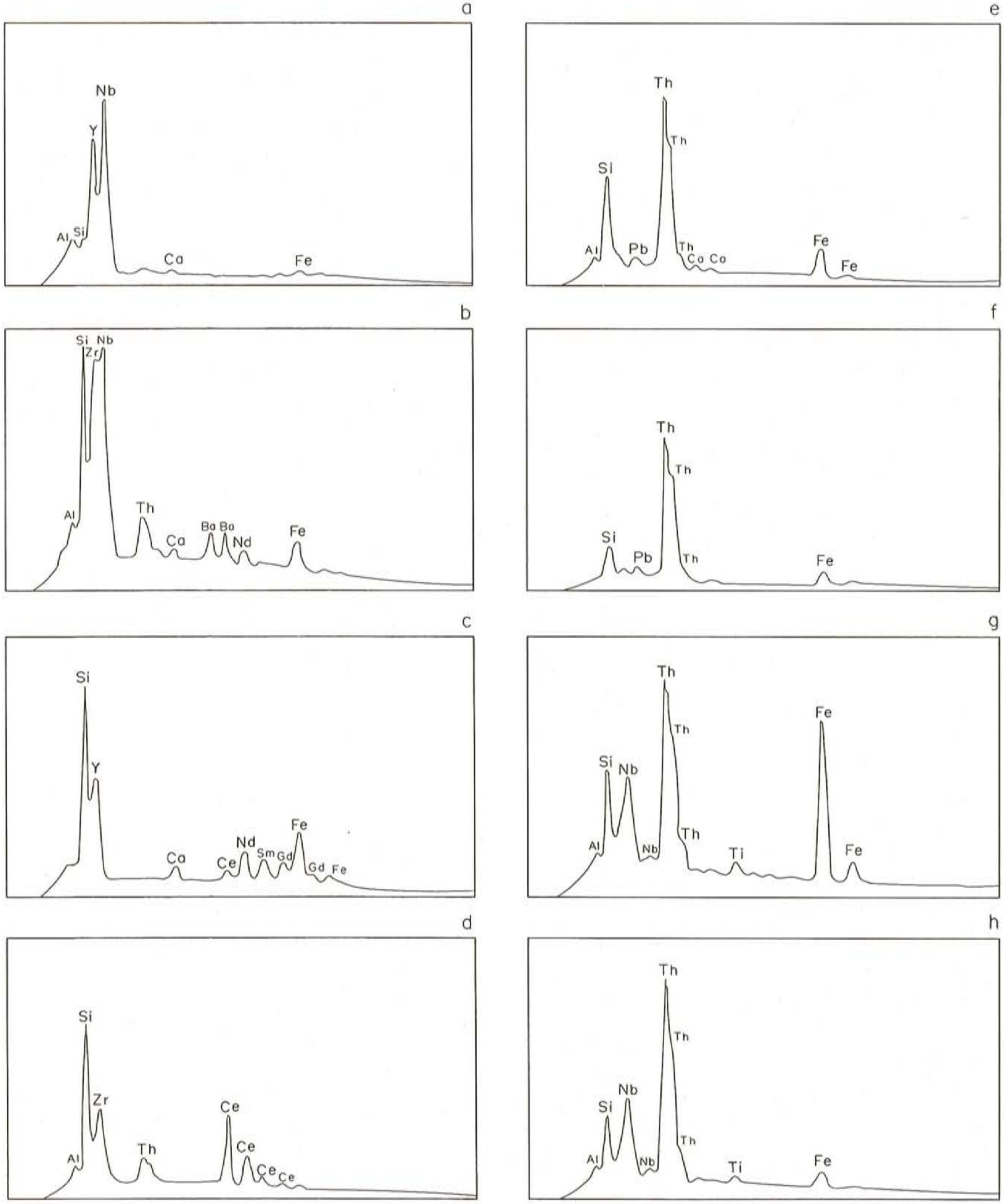

Figure 4. *Scanning electron microscope spectra of minerals from occurrence 11—sample JT-067 and occurrence 12—sample JT-124: a) fergusonite?—sample 124; b,c,d) unidentified minerals—sample 124; e) thorite?—sample 067; f) thorium oxide—sample 067; g,h) unidentified minerals—sample 067.*

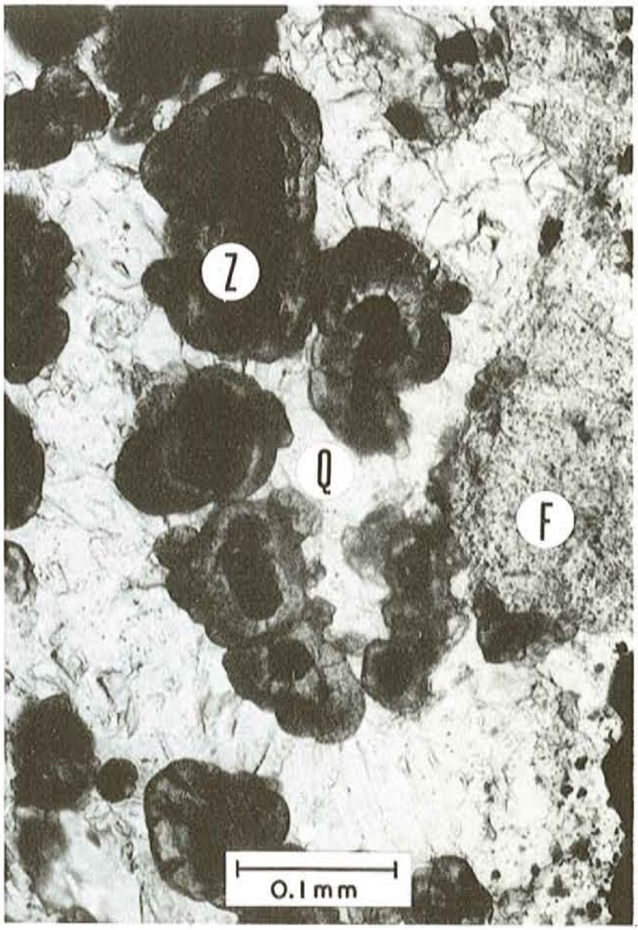

Plate 4. *Photomicrograph of hydrothermal, botryoidal, zoned zircon (Z) from occurrence 11; also visible are K-feldspar (F) and quartz (Q); sample JT-067, plane light.*

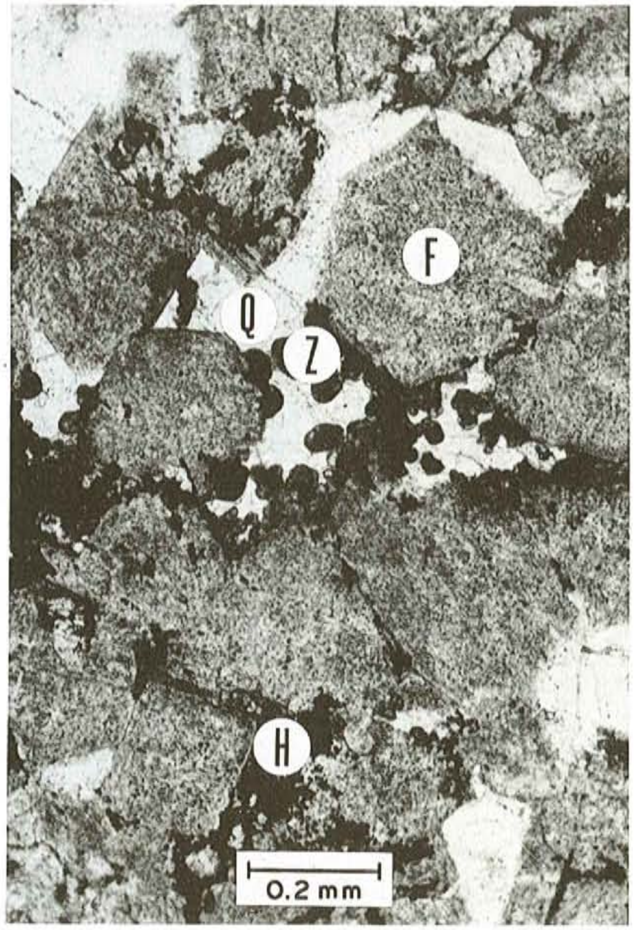

Plate 5. *Photomicrograph of botryoidal zircon (Z) surrounding K-feldspar crystals (F); also visible are quartz (Q) and fine-grained hematite (H); sample JT-067, plane light.*

peralkaline rocks of the Topsails Igneous Complex. These rocks contain albite, riebeckite, zircon, fluorite and Fe-Mn carbonate. Miller (1986) reported that the more mineralized 'exotic-rich' peralkaline granite from the Strange Lake Zr-Y-Nb-Be-REE deposit, has a high total REE content and is strongly enriched in HREE.

The Cross Hills Plutonic Suite has many geological, geochemical and metallogenic similarities to five posttectonic alkali to peralkaline granites from Saudi Arabia, which are of similar late Precambrian age. These granites are typically enriched in Nb, Ta, Sn, REE, Y, Th, U and Zr and in some cases contain economically important concentrations of some of these elements (Drysdall *et al.*, 1984; Jackson *et al.*, 1985). In particular, the Ghurayyah and Jabal Tawlah deposits show extreme enrichment in HREE and the Jabal Sa'id deposits are enriched in HREE and sporadically enriched in LREE (Figure 6) (Harris and Mariner, 1980; Drysdall *et al.*, 1984).

It has been suggested that under alkaline and oxidizing conditions HREE are partitioned into F^-- or CO_3^{2-}-bearing fluids (Kosterin, 1959; Flynn and Burnham, 1978; Kerrich and Fryer, 1979; Taylor *et al.*, 1981). Harris and Mariner (1980) demonstrated that fluorine is enriched in the Ghurayyah Granite and shows a positive correlation with HREE contents. They further suggested that HREE were maintained as fluoride complexes until the final stages of crystallization of the granite.

The peralkaline granite phase of the Cross Hills Plutonic Suite is actually depleted in fluorine compared to the biotite granite (Table 1). Although CO_2 contents of the granite are generally low (Table 1), the presence of an irregular 2- by 5-m vein of hematite-stained calcite within the peralkaline granite (centre of Figure 2), indicates that carbonate-rich fluids were formed during the hydrothermal evolution of the Cross Hills Plutonic Suite (Tuach, *in preparation)*. This suggests that CO_3^{2-} may have been more important in the concentration of elements in the Cross Hills Plutonic Suite as suggested by Taylor *et al.* (1981) for the Topsails complex.

The distribution of units, intrusive relationships, arrangement of textures and compositional variation within the Cross Hills Plutonic Suite, suggest a zoned magma

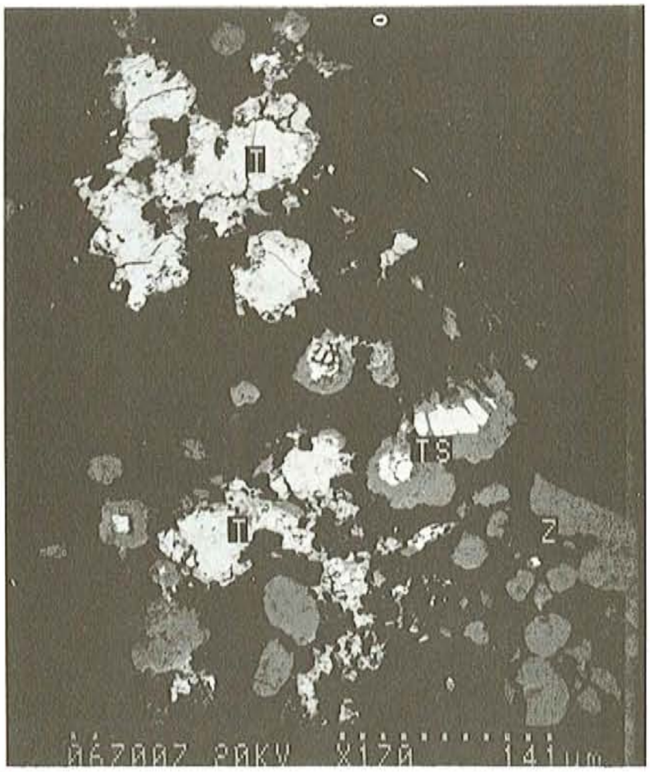

Plate 6. *SEM backscatter photograph showing botryoidal zircon (Z) thorite (TS) and thorium oxide (T); sample JT-067.*

chamber model (Figure 3), in which a dominantly liquid peralkaline magma was underlain by a similarly liquid (biotite) granite magma during the evolution of the pluton. Pressure-quenching resulted in a 'chill zone', which transected the compositional boundary between the two magmas (Figure 3). Crystallization of the peralkaline magma resulted in fluid-overpressure and transportation of Zr, Y, Nb, REE etc., to new depositional sites in the granite (Tuach, *in preparation*).

The inconsistent enrichment of Ce presumably is controlled by its oxidation state. Ronov *et al.* (1967) noted that tetravalent cerium has chemical properties that are more similar to those of the HREE than the other LREE. Its fractionation from the other LREE in some samples indicates that conditions were locally favourable to the maintenance of Ce in the +4 state. This is supported by the ubiquitous presence of hematite and its abundance in tuffisite, which indicates that oxidizing conditions prevailed during the final stages of granite formation.

CONCLUSIONS

The peralkaline granite phase of the Cross Hills Plutonic Suite is host to numerous small Zr-Nb-Y-REE mineral occurrences. The mineralogy of the occurrences and the distribution of mineralization in aplite dykes, tuffisite and fractures, indicate a magmatic-hydrothermal origin. The peralkaline granite provided a source for the mineralizing elements, which include Zr, Nb, Y, Sn, Th, Ce and heavy REE. Concentration and mobilization of these elements was

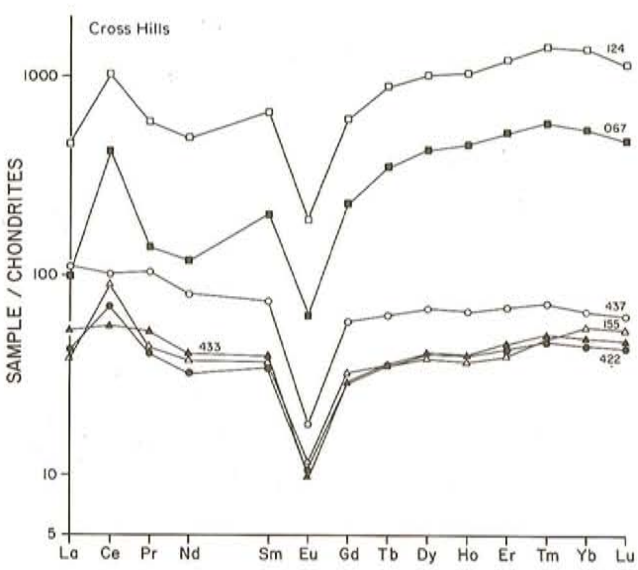

Figure 5. *Rare-earth element profiles of 4 peralkaline granite and 2 mineralized peralkaline granite samples; data are normalized to the chondrite values of Evensen et al. (1978).*

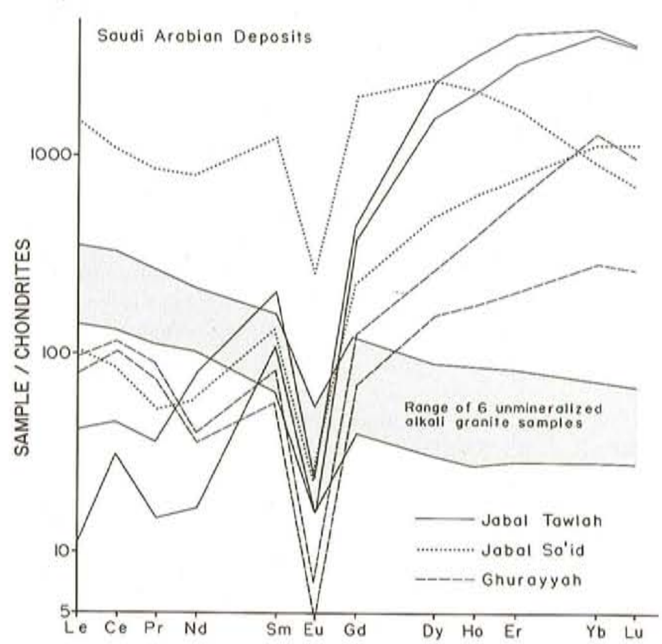

Figure 6. *Rare-earth element profiles of mineralized peralkaline granite samples from three Saudi Arabian deposits—Ghurayyah, Jabal Tawlah and Jaba Sa'id; also shown is the range for 6 unmineralized Saudi Arabian peralkaline granite samples; data from Drysdall et al. (1984).*

aided by the prevalence of oxidizing, alkaline and possibly carbonate-rich fluids.

The similarities between the geology, age and mineralization of the Cross Hills Plutonic Suite and that of the major deposits in Saudi Arabia suggest some potential for major Zr-Y-Nb-REE mineralization in the Cross Hills Plutonic Suite. The presence of similar granites in the Avalon Zone in Newfoundland and the remainder of the Appalachian Orogen points to other potential areas for such mineralization.

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