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YTTRIUM (Y) AND OTHER RARE METALS (Be, Nb, REE, Ta, Zr) IN LABRADOR

R.R. Miller
Mineral Deposits Section

ABSTRACT

The occurrence of significant rare-metal mineralization in the Strange Lake alkaline complex (Zr–Y–Nb–Be–REE) and in the Letitia Lake area (Nb–Be–Y) and the growing demand for rare metals in the 'high tech' industries has led to increased interest in rare-metal mineralization in Labrador. The study of the geology, petrography and geochemistry of known rare-metal mineralization has resulted in the development of exploration criteria that will aid further exploration in Labrador and other areas.

Mineralization in the Strange Lake deposit, the Flowers River Igneous Suite, the Mann #1, Mann #2, Michelin, Two Tom Lake and SW Ten Mile Lake showings in the Letitia Lake area and the Red Wine Alkaline Intrusive Suite (Shallow Lake area) exclusively occurs in peralkaline rocks. The following varieties of peralkaline rocks host rare-metal mineralization in Labrador: 1) granites, 2) syenites (oversaturated), 3) undersaturated intrusives and 4) trachytic and rhyolitic volcanic rocks. All of these rocks are highly evolved, and are interpreted to have been emplaced into high levels of the crust as either volcanic rocks or subvolcanic stocks.

Several modes of mineralization have been recognized in each of the different host rocks. The highest grade mineralization usually occurs as pegmatite–aplite lenses and veins, whereas lower grade–higher tonnage mineralization commonly occurs as disseminated zones within intrusive rocks or stratiform zones within volcanic rocks. The potential for the highest grades appears to be greatest in high-level intrusions that did not vent magma to the surface. This setting allowed the high concentrations of rare metals to collect in a limited area. In contrast, volcanic feeder stocks and related volcanic rocks provide a large area over which the available rare metals can be diluted rather than concentrated. When high grades of mineralization are discovered in volcanic feeder-stock settings they commonly occur within or on top of the stock.

Application of the criteria developed from the study of known rare-metal mineralization indicates that there are several unevaluated and unexplored areas of good rare-metal potential in Labrador and insular Newfoundland.

INTRODUCTION

The rare-metal elements, including Y, Be, Nb, REE, Ta, Zr, have rapidly become indispensable in the 'high tech' industries, and, as a result, the demand for these elements has been steadily increasing. This increasing demand has encouraged the exploration for economic deposits of rare metals throughout the world. Recent exploration activity in Labrador has revealed the Strange Lake deposit and several other Y-bearing showings; past exploration activity has discovered several Nb–Be showings in the Letitia Lake area. This report discusses the geology, geochemistry and setting of the rare-metal showings and deposits in Labrador to aid explorationists in discovering more of these deposits. A number of exploration targets, based on data presented in this report, will also be identified.

The 'high tech' uses of the rare metals as a group include the use of these elements in the manufacturing of: laser garnets, high temperature–high strength ceramics, superconducting materials, supermagnets, speciality steels, oil products, lamp–television phosphors and nuclear-reactor components. Many of these materials are used in the aerospace, defense, electronics and computer industries (Table 1). Generally speaking, the continuous growth in these industries is fuelling the increasing demand for new sources of the rare metals. Estimates of the increase in demand for these elements, after considering new uses and the introduction of substitute materials, ranges from 3 to 10 percent per year (US Bureau of Mines, 1985a, 1985b and 1987) up to the year 2000.

Table 2 lists the known rare-metal showings in Labrador along with a reference to previous exploration activity (MODS showing number), location, economically interesting elements, host rock, discovery date, property status, and the public source of sample analyses.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

Table 1. Some uses of the rare-metal elements

ELEMENT	MATERIAL PRODUCED	PRODUCTS MANUFACTURED
BERYLLIUM	Be metal	Aircraft components
	BeO ceramics	Electronic components
		Microchips and circuit boards
	Be-Cu alloys	Automobile parts
		Electronics
		Missile components
NIOBIUM	High strength, low alloy steels	Pipe for oil / gas pipelines
		Automobile components
		Drilling pipe
	Nb metal	Electronic components
		Carbide tools
		Superconductors
		Supermagnets
		Jet-Engine components
RARE EARTHS	High strength, low alloy steels	Pipe for oil / gas pipelines
	Ceramic raw material	Colouring agent
		Light-absorbing agent
		High-temperature ceramics
	Phosphors	Televison / Monitor colour tubes
	Permanent magnets	Headphones, speakers, generators, alternators,
		Electric motors
	Garnets	Microwave garnets
		Laser garnets
	Chemicals	Petroleum catalysts
	Electronics	Capacitors
		Cathodes and electrodes
		Thermisters
		Semiconductors
YTTRIUM	Phosphors	Television / Monitor colour tubes
		Fluorescent lamp tubes
	Garnets	Laser crystals
		Microwave crystals
	Stabillized zirconia ceramics	Cutting edges
		Automobile parts
		Tool dies
ZIRCONIUM	Refractories	Zirconium bricks
		Zirconium sand
	Ceramics	Oxygen sensors in furnaces
		Oxygen sensors in gas engines
		Colouring agent
		Electronic components
		Circuit boards
		Cutting edges
		Automobile parts
	Abrasives	Glass polishing compounds

Table 2. Rare-metal showings in Labrador

Name of Showing	MODS #	Location N	Location E	Elements	Host Rock/Setting	Discov. Date	Status	Analysis Ref.
Strange Lake	Zr 001 24A/8	56°18′45″	62°06′45″	Zr-Y-Nb Be-REE	Peralkaline granite pegmatite	1979	Staked I.O.C.	Miller (1986a)
Flowers River	Fsp 006 13N/11	55°35′00″	61°05′00″	Zr-Y-Nb	Peralkaline granite/ Felsic volcanics	1977	Unstaked	Hill (1981, 1982)
Mann #1	Be 001 13L/1	54°14′00″	62°24′00″	Be-Nb	Peralkaline syenite/ Comenditic volcanics	1956	Cuvier	Dujardin (1961)
Michelin	Nb 002 13L/1	54°14′00″	62°27′00″	Be-Nb	Peralkaline syenite/ Comenditic volcanics	1956	Unstaked	Miller (1986b)
Mann #2	Nb 001 13L/1	*54°13′00″	62°27′00″	Be-Nb	Peralkaline syenite/ Comenditic volcanics	1956	Unstaked	Miller (1986b)
Two Tom Lake	REE 001 13L/1	54°13′00″	62°09′00″	Be-Nb-Y	Peralkaline syenite/ Comenditic volcanics	1967	ASARCO	Batterson and Miller (1987)
SW Ten Mile Lake	REE 001 13L/2	54°14′30″	62°31′00″	Y	Peralkaline syenite ?	1985	Unstaked	Miller (1986b)
Red Wine Suite	Zr 001 13L/2	*not located	not located	Y-Zr	Undersaturated per-alkaline complex	1972	Unstaked	Curtis and Currie (1981)

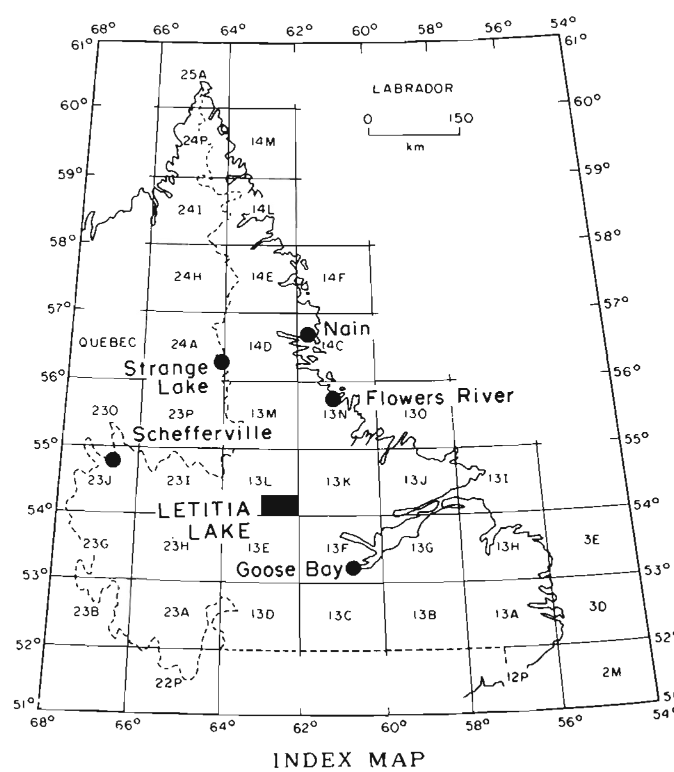
* many small showings in the vicinity MODS—Department of Mines Mineral Inventory File Numbers

The Strange Lake deposit (Figure 1) and the Mann #1 showing (Letitia Lake area, Figure 1) are the only properties for which there is some estimate of tonnage and grade, although the Mann #1 property reserves are not well known. Poorly evaluated showings and occurrences that contain interesting quantities of rare metals include:

- Flowers River occurrence (Flowers River Igneous Suite)
- Mann # 2 showing (Letitia Lake area)
- Michelin # 1 showing (Letitia Lake area)
- Two Tom Lake showing (Letitia Lake area)
- SW Ten Mile Lake occurrence (aegirine gneiss; Letitia Lake)
- Red Wine North occurrence (Shallow Lake area)

The Flowers River, SW Ten Mile Lake and Red Wine North occurrences consist of anomalous values of rare metals, including Y, in a small number of grab samples (< 3 samples). All known rare-metal deposits and showings in Labrador, with the exception of the Strange Lake deposit, have not been properly evaluated.

In this paper, the mineralization and host rocks at each of the properties listed in Table 2 are examined to help develop exploration criteria for rare-metal deposits in Labrador. In most cases, geochemical data for mineralization and host rocks are known, as are the geology, style of mineralization and geological settings. Plans, cross-sections and geochemical tables are used to present this data.



INDEX MAP

Figure 1. *Location of the Letitia–Shallow lakes area, Flowers River area and the Strange Lake deposit.*

DEPOSIT–SHOWING–OCCURRENCE DESCRIPTIONS

Strange Lake Deposit

Introduction. The Strange Lake alkaline complex, which hosts the Strange Lake deposit, is located on the Quebec–Labrador boundary approximately 250 km northeast of Schefferville, Quebec, and 150 km west of Nain, on the Labrador coast (Figure 1). It consists of three major phases of aegirine–riebeckite-bearing, peralkaline granite. Extensive drilling within the complex, by the Iron Ore Company (Venkatswaran, 1983) from 1979 to 1983, has outlined one deposit having approximately 50 million tonnes of Zr–Y–Nb–Be–REE mineralization.

Geology. The peralkaline granite phases are characterized by varying amounts of exotic minerals (e.g., elpidite, armstrongite, gittinsite, gadolinite, zircon, astrophyllite, fluorite, titanite), most of which contain important concentrations of rare metals. Each granitic phase has similar textural variants (i.e., pegmatitic, medium grained, porphyritic, fine grained, inclusion-bearing; Miller, 1986a). The three major phases are called exotic-poor, exotic and exotic-rich in order of increasing exotic-mineral and rare-metal contents, and in order of decreasing age. Figure 2 illustrates the distribution of the major phases within the complex in a plan view, whereas Figure 3 illustrates the relationships in a north-south cross-section.

All contacts are sharp and there is little or no obvious metasomatism of host rocks at the contacts. The complex is roughly circular in plan and is encircled by a ring fault (outward dips of 20 to 35°) that occurs at or near the contact of the granite and the host rocks (Miller, 1986a).

Table 3 lists the major- and minor-element contents of representative samples of each of the major, and some of the minor, variants in the Strange Lake complex.

Mineralization. All of the mineralization occurs in exotic-rich granite, the youngest phase of the complex. As illustrated by Figure 3, the mineralization occurs in a small stock or subsidiary intrusion at the contact between the two other major phases in the complex. The exotic-rich stock occurs over an approximately 2 km² area. Representative analyses are listed under 'exotic-rich' phase in Table 3.

High-grade zones within the exotic-rich stock (Figure 4) occur as:

1) pegmatite–aplite lenses that intrude the exotic phase,

2) pegmatite–aplite lenses and zones at or near the upper and lower contacts of the exotic-rich stock,

3) pegmatite veins cutting the medium grained variant, which is the major rock type within the stock, and

4) small veins, mostly pegmatitic, cutting the exotic-poor phases.

The most mineralized and economically interesting mineralized zones are the occurrences of pegmatite or pegmatite–aplite zones, which are characterized by high concentrations of rare metals (Table 3) and high radioactivity. Larger tonnages of medium-grade mineralization occur as disseminated mineralization in the medium grained exotic-rich stock.

Published reserve figures (Venkatswaran, 1983) indicate that this mineralized stock contains reserves of approximately 52,000,000 metric tons grading 2.93% ZrO_2, 0.31% Y_2O_3, 0.38% Nb_2O_5, 0.54% REE and 0.08% BeO; all reserves can be recovered by open pit mining. There is a high grade zone within this reserve (tonnages not published to date), which contains 3.25% ZrO_2, 0.66% Y_2O_3, 0.56% Nb_2O_5, 1.30% REE and 0.12% BeO (Dawe, 1984). The analyses of representative samples of the exotic phase of the granite indicate that ZrO_2 values of 2% and Y_2O_3 values of 0.25% are common (Table 3).

Setting. The Strange Lake complex occurs at the contact of relatively unmetamorphosed quartz monzonite (adamellite) to the south and east, and a metamorphic suite of mainly intrusive rocks to the north and south. An age date of 1189 ± 32 Ma (Rb–Sr wholerock, Duthou *et al.*, 1986) for the peralkaline granite and the lack of metamorphic textures indicate that it is postmetamorphic (post-Elsonian metamorphism–Neohelikian in age). Crosscutting relationships indicate that it is younger than the surrounding host rocks.

Abundant evidence indicates that the complex is a high-level pluton that has intruded into cold crust. The major evidence sited in favour of this conclusion is:

1) the occurrence of abundant discrete inclusions of host rock and peralkaline granite; inclusions exhibit only minor alteration,

2) the abundance of fine- to very fine-grained textural varieties (< 0.5 mm), particularly in the outer and upper portions of the complex,

3) the presence of a ring fault that completely circles the complex; similar to those of the subvolcanic–volcanic complexes in Nigeria (Jacobson *et al.*, 1958),

4) the occurrence of fine grained porphyritic rocks, and

5) the presence of primary microperthitic feldspars.

Most of this evidence suggests rapid cooling of the granite magma in a near surface environment.

There is very little direct evidence to indicate whether or not volcanic rocks were produced from the Strange Lake magma system. Aside from the very fine grained, exotic-poor phase, there are no observed phases which have the grain size or characteristics of volcanic rocks. Veins of the very fine grained phase crosscutting host rocks indicate that at least

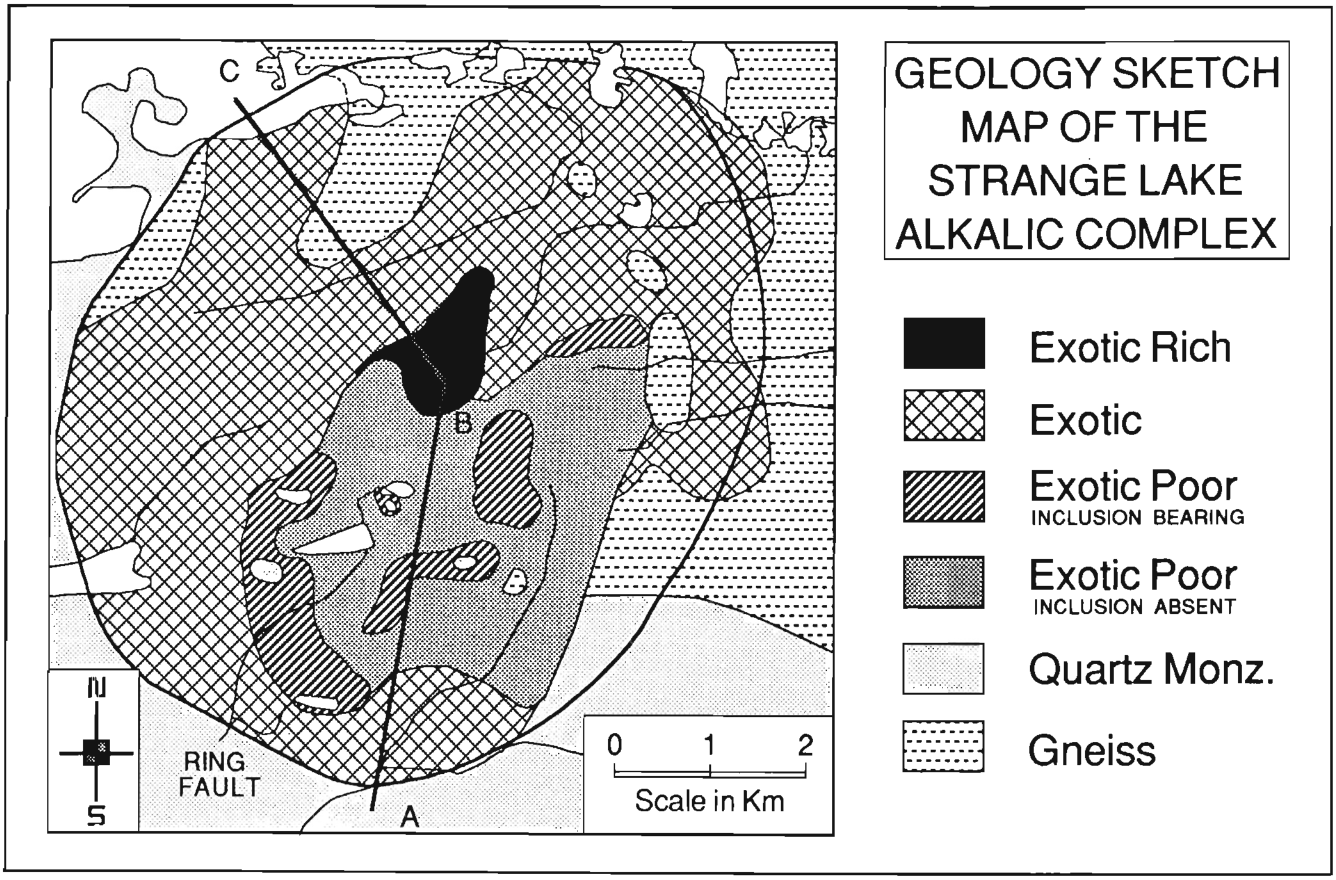


Figure 2. *General geology of the Strange Lake complex.*

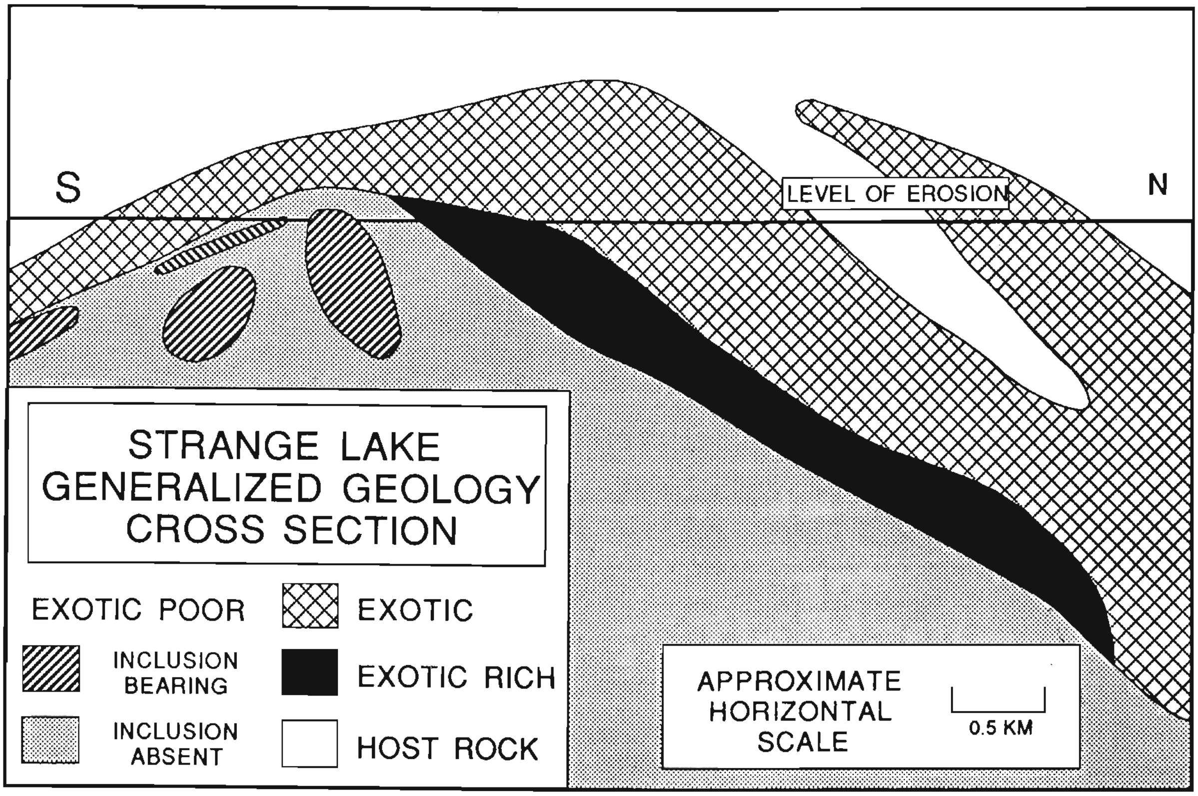


Figure 3. *Interpretive north-south cross-section through the Strange Lake complex; see Figure 2 for the location of the section line A-B-C.*

Table 3. Major- and minor-element analyses of representative samples from the Strange Lake complex

	EXOTIC POOR					EXOTIC		EXOTIC RICH		
	SL-84017 Inclusion	SL-84273 Inclusion	SL-84090 Fine Grained	SL-84011 Medium Grained	SL-84071 Medium Grained	SL-84266 Porphyritic	SL-84210 Medium Grained	SL-84280 Fine Grained	SL-84270 Pegmatitic	SL-84108 Fine Grained
SiO_2	69.95	69.75	70.45	71.05	72.60	70.30	75.45	71.60	67.20	64.10
TiO_2	0.16	0.28	0.24	0.28	0.25	0.40	0.27	0.29	0.08	0.79
Al_2O_3	12.52	11.89	11.78	11.34	10.21	9.70	8.07	9.23	5.07	4.42
Fe_2O_3	1.50	2.02	3.68	1.72	1.91	2.61	2.40	2.67	2.43	4.78
FeO	2.58	2.45	0.31	3.09	2.72	2.57	1.09	1.89	0.01	1.48
MnO	0.07	0.14	0.06	0.10	0.12	0.17	0.15	0.11	0.15	0.32
MgO	0.04	0.14	0.03	0.02	0.09	0.30	0.09	0.02	1.31	1.65
CaO	0.79	1.21	1.11	0.39	0.22	1.87	1.40	1.39	8.05	5.08
Na_2O	4.93	4.54	6.61	5.49	4.91	4.29	2.78	4.82	0.55	2.88
K_2O	6.26	5.88	3.72	4.54	4.57	4.02	4.24	3.41	4.27	0.59
P_2O_5	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.14
ZrO_2	0.39	0.73	0.68	0.77	0.89	1.86	2.33	2.17	0.61	3.03
Y_2O_3	0.10	0.12	0.07	0.08	0.21	0.27	0.37	0.32	2.02	1.58
Nb_2O_5	0.03	0.05	0.06	0.04	0.13	0.15	0.16	0.15	0.18	2.00
BeO	0.01	0.01	0.01	0.01	0.05	0.04	0.04	0.06	1.45	0.40
H_2O	0.11	0.04	0.50	0.37	0.68	0.47	0.50	0.50	2.23	3.28
CO_2	0.05	0.03	0.13	0.10	0.12	0.04	0.01	0.11	0.10	0.26
F	0.59	0.42	0.65	0.38	0.20	0.63	0.45	0.77	3.32	1.77
F=O	-0.25	-0.18	-0.27	-0.16	-0.08	-0.27	-0.19	-0.32	-1.40	-0.74
Total	99.84	99.53	99.84	99.63	99.82	99.45	99.64	99.23	97.67*	97.81*
U	7.7	16.7	21.9	18.3	29.7	50.2	52.6	65.7	134.0	252.0
Th	32	47	91	101	134	163	227	375	2572	4884
Rb	774	1262	531	524	1074	1310	987	960	758	142
Sr	15	31	48	3	9	72	35	22	266	673
Zn	342	753	365	432	903	803	1005	947	1681	1553

Notes: All oxides and F in Weight %; trace elements quoted as ppm. Major elements, Be, and Zn were analysed by A.A. method (Nfld. Dept. of Mines); F by Specific Ion Electrode Method and CO_2 + H_2O by I.R. Method (Nfld. Dept. of Mines); Th, Rb, Sr, Y, Zr, Nb by XRF method (Memorial University XRF Lab.); U by neutron activation (Nuclear Activation Services Ltd.).

* Samples contain 2-3% REE.

some of this exotic-poor phase has a pluton chill margin, rather than a volcanic, setting. Indirect evidence, such as the extreme concentration of rare metals and other incompatible elements in the late stages of the complex, suggest that there was no tapping of the magma chamber to bring incompatible-element-laden volatiles to the surface. Fluorite vein breccias within the ring fault are the only example of extensive host rock-veining brecciation, yet they are extremely deficient in rare metals, suggesting a closed system for rare metals within the granite magma chamber. It appears that the apparent lack of volcanism in this case contributed to the concentration of rare metals in the exotic-rich (i.e., late) phase.

There are no obvious structural controls on the location of the Strange Lake complex. Although peralkaline granites are often associated with rift zones and crustal upwelling there is no obvious evidence of faulting near the Strange Lake complex (B. Ryan, personal communication, 1986).

Flowers River Igneous Suite

Introduction. The Flowers River Igneous Suite (Hill, 1982) occupies an area of approximately 1700 km^2 in the Flowers River area on the coast of northern Labrador, 250 km north of Goose Bay (Figure 1). It consists of a peralkaline, amphibole–pyroxene granite batholith, several satellite, peralkaline granite plutons and an overlying sequence of peralkaline, rhyolitic pyroclastic rocks and flows. There has been no recorded rare-metal exploration activity in this vicinity although reports on the geochemistry of the volcanics of the complex (Hill, 1982) indicate Y values up to 500 ppm and Zr up to 4000 ppm. The analysis of a granite dyke in the complex yielded the following encouraging values: 1020 ppm Nb, 2233 ppm Y and 20,594 ppm Zr (Hill, 1982).

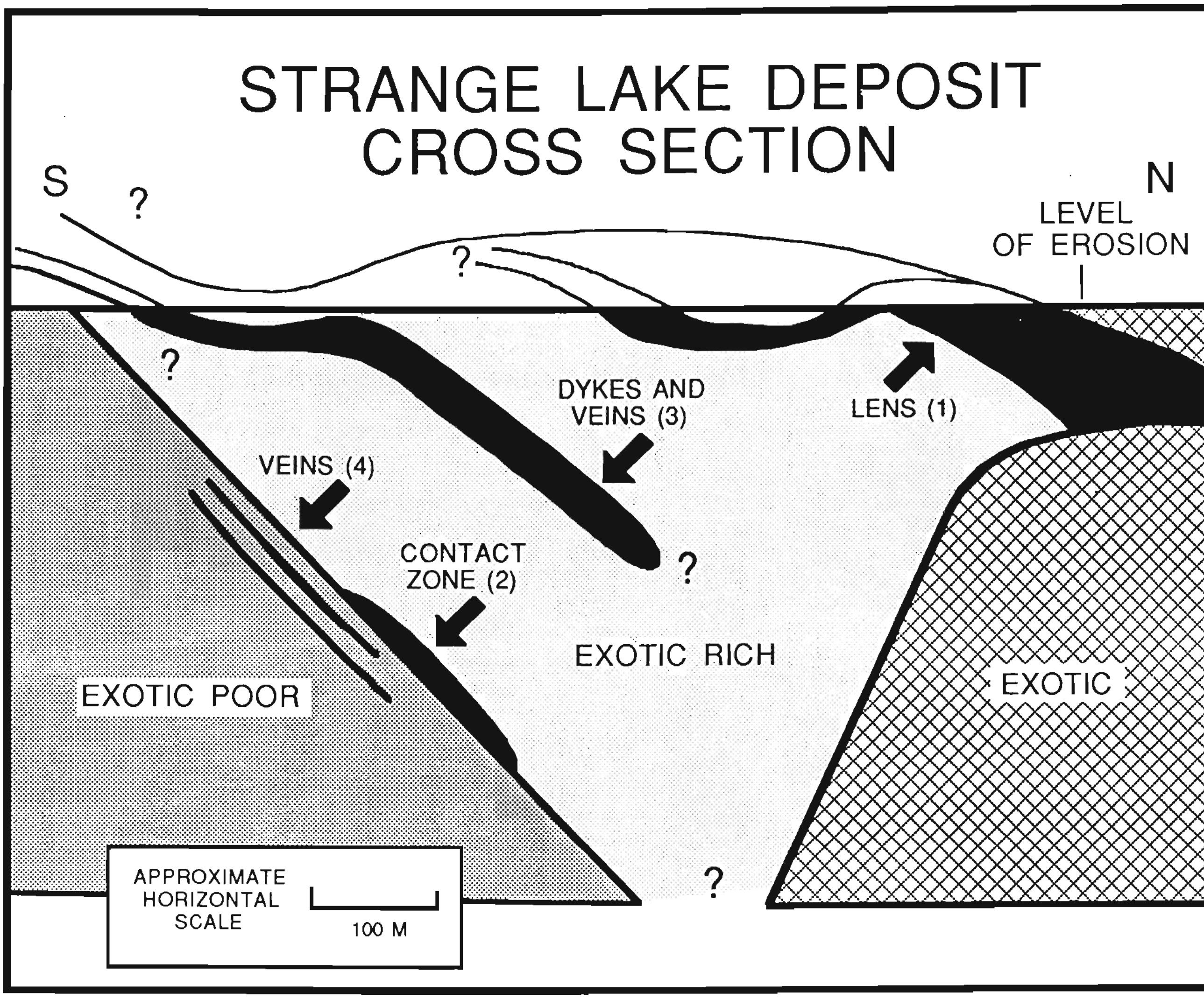


Figure 4. *Interpretive north-south cross-section through the main rare-metal zone in the Strange Lake complex; the various types of mineralization, as indicated by the numbers in brackets, are described in the text.*

Geology. Hill (1982) reported four main textural varieties of felsic volcanic rocks within the Flowers River suite: massive porphyry, felsite, tuffaceous pyroclastics and breccia; most consist mainly of quartz and feldspar with no primary mafic minerals. All contain aphanitic or fine grained matrices. The felsite, tuffs and porphyries grade into each other through the variation in quartz–feldspar phenocryst content and the presence or absence of flow banding. These rocks represent flows, pyroclastics and subvolcanic feeder dykes.

The peralkaline granites are characterized by riebeckite–arfvedsonite, aegirine, quartz and perthite. Accessory minerals include aenigmatite, astrophyllite, opaques, fluorite, zircon, allanite and apatite. Textures range from fine- to coarse-grained and are typically massive and equigranular; related aplitic and pegmatitic peralkaline granite dykes are also present.

Figure 5 is a plan view of the geology of the Flowers River suite. The volcanic suite occurs as a centrally located unit within the the main peralkaline granite batholith. Topographic considerations indicate that the volcanics are structurally higher than the granite. Hill (1982) reported outcrops in which granitic roof rocks pass gradationally upward into compositionally similar volcanic rocks. Crosscutting relationships indicate that the granite is younger than the volcanics. Flow-banding measurements suggest that the volcanics occupy a depression in the roof of the granite batholith.

Table 4 lists the major- and minor-element analyses of representative samples of the various units in the Flowers River suite as well as average values of the peralkaline granites and felsic volcanics as calculated by Hill (1982).

Mineralization. The only economically significant rare-metal mineralization reported from the Flowers River area is the partial analysis of a peralkaline granite dyke, containing 10 percent fluorite, reported by Hill (1981, 1982; reprinted in Table 4). The extent, location and mineralogy of this dyke

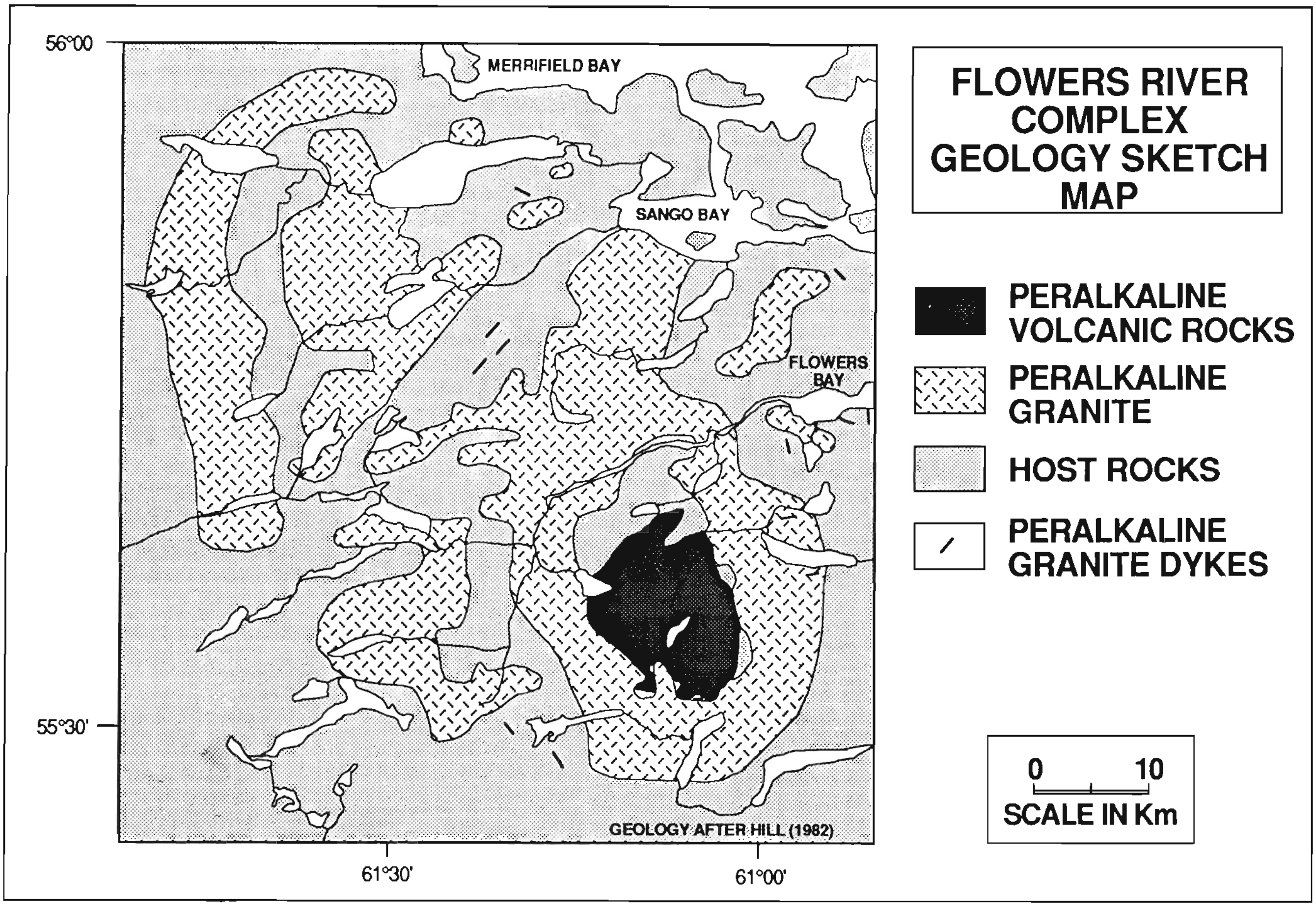


Figure 5. *General geology of the Flowers River Igneous Suite (after Hill, 1982).*

Table 4. Major- and minor-element analyses of representative samples from the Flowers River Igneous Suite

	JH-77-066 Porphyry	JH-77-071A Porphyry	JH-77-361 Felsite	JH-77-330 Tuff	JH-77-040 Granite	JH-77-153 Granite	JH-77-298A Granite	JH-77-592D Granite	JH-77-076 Dyke	JH-77-423B Dyke
SiO_2	77.54	73.15	76.68	73.02	74.30	74.60	73.60	75.90	73.13	–
TiO_2	0.33	0.38	0.28	0.45	0.36	0.36	0.48	0.25	0.23	–
Al_2O_3	11.88	11.14	9.39	10.11	12.05	11.65	11.60	10.70	10.30	–
Fe_2O_3	0.88	1.64	0.75	7.27	–	–	–	–	2.32	–
FeO	2.24	7.58	4.98	1.69	2.79	3.19	4.22	3.25	2.44	–
MnO	0.03	0.05	0.04	0.05	0.04	0.04	0.05	0.04	0.09	–
MgO	0.08	0.11	0.03	0.00	0.05	0.03	0.11	0.02	0.20	–
CaO	0.11	0.19	0.11	0.23	0.53	0.53	0.67	0.27	0.63	–
Na_2O	0.02	0.65	0.02	0.27	4.13	4.07	4.15	4.12	4.63	–
K_2O	5.00	1.72	2.62	5.46	5.12	5.01	4.85	4.78	4.51	–
P_2O_5	0.00	–	0.00	–	–	–	–	–	–	–
H_2O	1.66	3.17	2.43	1.13	0.44	0.58	0.12	0.47	0.72	–
CO_2										
F	0.12	–	–	0.38	0.16	0.16	0.02	0.16	–	–
F=O	-0.05	–	–	-0.16	-0.07	-0.07	-0.01	-0.07	–	–
Total	99.84	99.78	97.33	99.90	99.90	100.15	99.86	99.89	99.20	–
Zr	1090	1967	7072	4717	691	614	835	1138	1764	20594
Y	100	231	547	489	116	122	103	147	315	2233
Nb	43	91	264	151	91	61	47	140	163	1020
Be	–	–	–	–	–	–	–	–	–	–
U	–	–	–	–	3.0	2.0	2.0	–	–	–
Th	–	–	–	–	26	20	12	–	–	–

Notes: All oxides and F in Weight %; trace elements quoted as ppm.
H_2O is Loss on Ignition.
Analyses from Hill (1982).

was not reported. The occurrence of such high values of Y, Zr, and Nb in a grab sample certainly suggests a rare-metal potential for the suite. Further examination of the rare-metal contents of the representative analyses of rocks from the suite indicates that the volcanics generally contain the highest values of Y and Zr, whereas the granites and dyke rocks contain lower values.

Setting. The Flowers River suite intrudes the southeast corner of the Paleohelikian Nain Plutonic Suite and also intrudes Aphebian gneisses. Age relationships indicate that the peralkaline rocks are not genetically related to these spatially related rocks. An age date reported by Hill (1982) gives a Neohelikian age of 1270 $\pm$ 14 Ma for the Flowers River peralkaline granite.

The spatial relationships of the peralkaline volcanic rocks and peralkaline granite indicate that the suite consists of a subvolcanic batholith that crosscuts coeval, cogenetic subaerial volcanics. The chemical and mineralogical relationships are not as clear cut because the volcanic rocks contain much lower concentrations of sodium and do not contain peralkaline mafic minerals. Yet, the work of Hill and Thomas (1983) clearly indicates that the Flowers River volcanic rocks are peralkaline in nature and are thus related to the granites. The chemical differences have been attributed to postmagmatic processes (Hill and Thomas, 1983).

Letitia–Shallow Lakes Area

Introduction. The Letitia–Shallow lakes area is located in the Central Mineral Belt of Labrador 160 km northwest of Goose Bay (Figure 1). Nb–Be showings have been known in this area for more than 30 years. The largest of these, the Mann #1 showing, contains an estimated 2 million short tons of 0.35–0.40 percent BeO and 0.24 percent Nb_2O_5 in one mineralized zone (Dujardin, 1961). Recent work by Miller (1986b) and Batterson and Miller (1987) has also revealed the potential for Y mineralization in the area as well.

The rare-metal showings in this area are associated with peralkaline syenites of the Red Wine Alkaline Intrusive Suite (Thomas, 1980) and volcanic rocks of the Letitia Lake Group (Figures 6 and 7). In most cases, aegirine–riebeckite syenite dykes or plutons ($\pm$ quartz) are associated with the mineralization, which is hosted within the syenite or nearby trachytic volcanic rocks. In one case, anomalous rare-metal values are found within undersaturated syenites and nepheline syenites of the the Red Wine suite. The volumetrically important quartz–feldspar porphyries and rhyolitic flows of the Letitia Lake Group appear to be devoid of significant mineralization.

As mentioned earlier and in Table 2, several showings of interest will be discussed; Red Wine North occurrence, SW Ten Mile Lake occurrence, Two Tom Lake showing, Michelin # 1 showing, Mann # 1 and Mann # 2 showings.

Geology. The general geology of the Letitia and Shallow lakes area is outlined on Figure 6 and 7, and the stratigraphy of the area is outlined in Figure 8. The peralkaline rocks of interest are part of the Letitia Lake Group volcanics and volcanogenic sediments, and part of the Red Wine suite. The Letitia Lake Group is underlain by the North Pole Brook Intrusive Suite, to the south and east, and is unconformably overlain by the subaerial sedimentary and volcanic rocks of the Seal Lake Group to the north and west. The Red Wine suite intrudes the Letitia Lake Group or, locally, it intrudes the North Pole Brook Intrusive Suite near the lower contact of the Letitia Lake Group.

The Letitia Lake Group has been subdivided into three stratigraphic units:

1) a lower unit of quartz - feldspar porphyries (oldest),

2) a middle unit of rhyolitic flows and pyroclastic rocks, and

3) an upper unit consisting of trachytic–comenditic volcanics in its lower portions and volcanogenic sediments in its upper portions.

The chemistry of the first two units has been reported by Thomas (1980); representative analyses from his report and the present study are presented in Table 5. Analyses for some volcanics from the upper unit are listed in Table 6.

The quartz and quartz–feldspar porphyries of the lower unit are massive rocks which may be flows or subvolcanic feeder dykes. As in the volcanic rocks of the Flowers River Igneous Suite, many rocks in this unit contain few or no peralkaline mafic minerals.

Middle unit volcanic rocks east of the Mann #1 showing also have few or no peralkaline minerals; their mineralogy is dominated by quartz and feldspar. Outcrops to the west of the Mann #1 showing, however, commonly contain abundant peralkaline minerals. This dichotomy suggests that there may be some problems with the present assignment of rocks to the middle unit.

There are three main varieties of volcanic rocks in the upper unit:

1) massive to amygdular, fine grained ($<$ 0.2 mm) aegirine-bearing,

2) banded, tuffaceous(?) aegirine–riebeckite bearing ($<$ 0.5 mm), and

3) feldspar-porphyritic aegirine–riebeckite bearing ($<$ 0.5 mm).

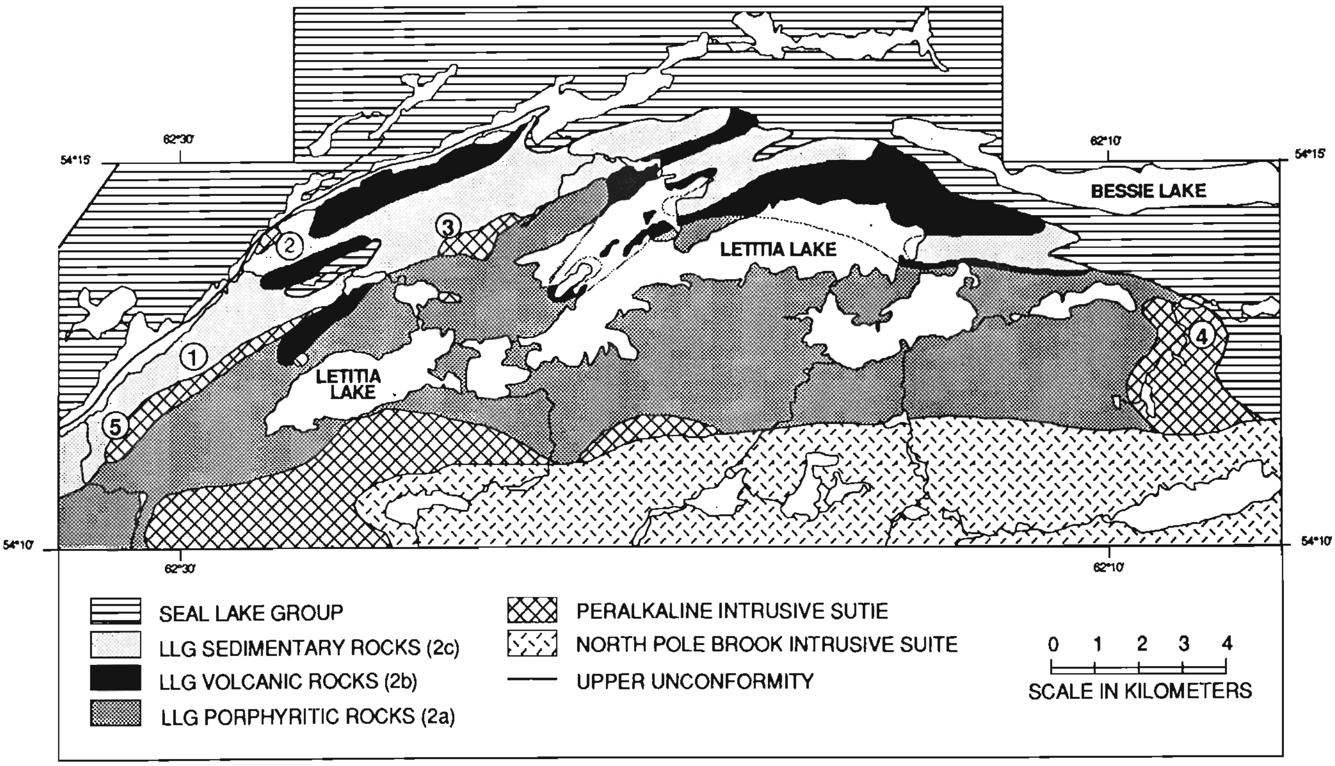


Figure 6. *Generalized geology of the Letitia Lake area. The numbered localities are the main rare-metal showings in this area: 1–Mann #2; 2–Michelin; 3–Mann #1; 4–Two Tom Lake; 5–SW Ten Mile Lake. LLG–Letitia Lake Group. Modified from Thomas (1981)*

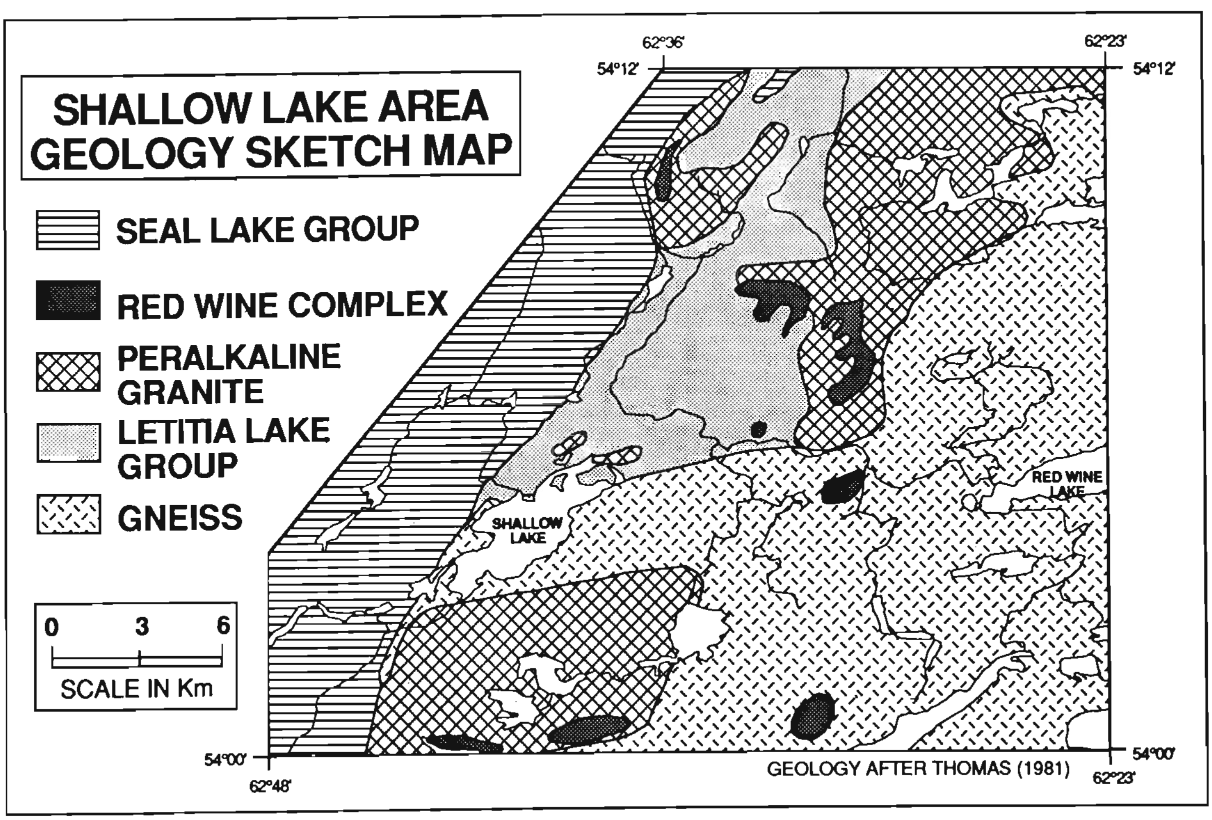


Figure 7. *General geology of the Shallow Lake area. Modified from Thomas (1981). This area is 1 km southwest of the area depicted in Figure 6.*

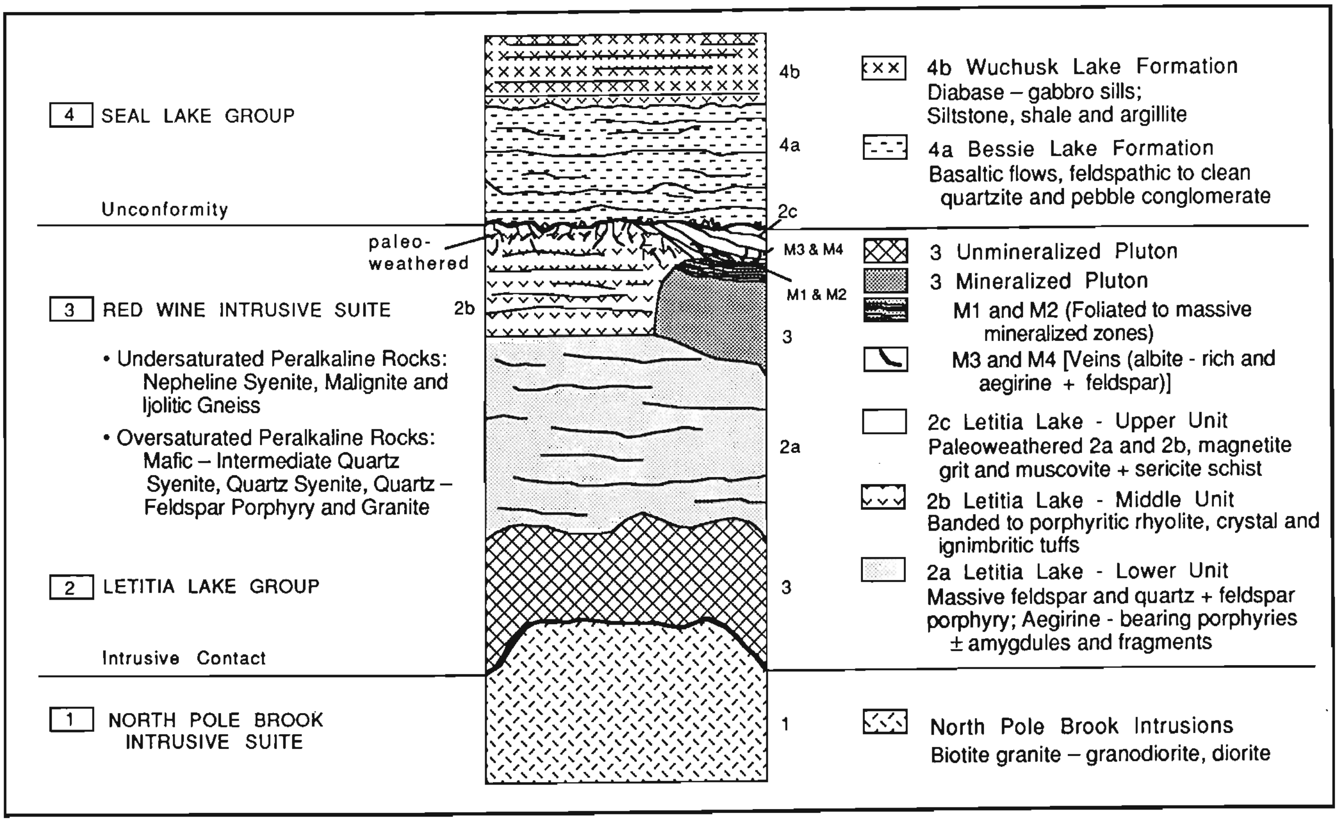


Figure 8. *General stratigraphy of the Letitia Lake area.*

Table 5. Major- and minor-element analyses of representative samples from the Letitia Lake Group volcanic rocks

	LL–84014 Aegirine -rich	LL–86021 Feldspar Porphyry	LL–84082 Feldspar Porphyry	LL–85018 Feldspar Porphyry	LL–85072 Very Fine Grained Flow	LL–85063 Feldspar Porphyry	LL–86013 Quartz-Feldspar Porphyry	LL–86014 Quartz-Feldspar Porphyry	T78-03 Crystal Tuff	T78-21 Ash Flow Tuff
SiO_2	57.95	64.45	65.15	60.65	68.15	69.55	74.65	76.40	74.40	78.90
TiO_2	1.38	0.83	0.74	0.75	0.28	0.64	0.27	0.29	0.35	0.25
Al_2O_3	10.98	13.86	10.00	11.75	12.79	11.64	10.87	10.11	9.70	9.40
Fe_2O_3	5.09	3.12	9.43	9.47	4.79	2.38	2.10	1.18	1.20	1.13
FeO	4.84	2.65	0.07	1.43	0.10	3.24	0.75	1.70	3.03	1.44
MnO	0.55	0.12	0.20	0.28	0.45	0.10	0.06	0.04	0.15	0.04
MgO	2.35	0.86	0.13	0.21	0.03	0.32	0.10	0.06	0.19	0.10
CaO	4.84	2.24	1.29	2.15	0.32	0.72	0.51	0.11	2.35	0.06
Na_2O	7.77	5.06	6.42	8.14	8.84	4.67	4.22	2.49	0.02	0.04
K_2O	2.53	5.05	4.55	4.46	1.95	4.92	4.95	5.38	5.05	7.14
P_2O_5	0.52	0.23	0.11	0.54	0.23	0.12	0.05	0.03	0.00	0.01
H_2O	0.73	0.46	0.08	0.39	0.60	0.23	0.10*	0.47*	3.31*	1.18*
CO_2	0.00	0.30	0.00	0.09	0.12	0.07	0.03	0.08	–	–
F	0.19	0.09	0.04	0.03	0.06	0.16	0.02	0.04	–	–
F=O	-0.08	-0.04	-0.02	-0.01	-0.03	-0.07	-0.01	-0.02	–	–
Total	99.64	99.28	98.21	100.33	99.11	98.29	98.94	98.57	99.75	99.69
Zr	260	432	1890	1853	205	1087	838	868	1161	1042
Y	160	63	158	200	110	133	93	95	142	109
Nb	837	22	142	204	1487	44	40	42	73	66
Be	133	5	14	16	1210	10	8	3	10	4
U	6.0	3	5	6	4	3	7.0	9.0	–	–
Th	46	2	23	26	144	11	3	13	–	–

Notes: All oxides and F in Weight %; trace elements quoted as ppm.
* H_2O is Loss on Ignition.

Table 6. Major- and minor-element analyses of representative samples of Letitia Lake Area intrusive rocks

	LL–85028 Two Tom Syenite	LL–85031 Two Tom Syenite	LL–84075 Mann Fine Grained Syenite	LL–85023 Mann Medium Grained Syenite	LL–84131 Quartz Porphyritic Syenite	LL–85067 Letitia Lake Syenite	LL–86015 Letitia Lake Granite	LL–86019 Letitia Lake Granite	LL–86002 Shallow Lake Granite	LL–86010 Shallow Lake Granite
SiO_2	60.40	60.45	61.15	63.05	63.10	61.50	75.70	72.55	78.70	74.80
TiO_2	0.78	0.81	0.80	0.50	0.82	0.76	0.30	0.45	0.21	0.24
Al_2O_3	11.41	12.65	13.29	14.19	12.01	13.27	10.61	10.21	9.73	10.73
Fe_2O_3	8.05	6.87	6.53	2.84	4.38	8.25	1.88	2.41	1.21	1.68
FeO	3.09	2.85	1.15	4.27	5.66	0.93	1.11	3.50	1.40	2.18
MnO	0.25	0.23	0.30	0.20	0.25	0.15	0.06	0.10	0.05	0.07
MgO	0.14	0.23	0.43	0.18	0.25	0.07	0.04	0.06	0.02	0.02
CaO	1.89	1.89	1.82	1.75	1.69	1.03	0.26	0.24	0.25	0.26
Na_2O	7.61	7.63	6.80	6.53	6.49	7.72	4.19	4.88	4.01	4.02
K_2O	4.40	4.80	6.82	5.16	4.40	5.20	4.75	4.83	3.82	4.62
P_2O_5	0.18	0.20	0.09	0.09	0.13	0.06	0.02	0.02	00.0	0.02
H_2O	0.38	0.31	0.29	0.64	0.46	0.35	0.17	0.24	0.13	0.27
CO_2	0.79	0.11	0.05	0.58	0.22	0.11	0.08	0.13	0.05	0.05
F	0.05	0.06	0.08	0.03	0.09	0.01	0.02	0.13	0.01	0.10
F=O	-0.02	-0.03	-0.03	-0.01	-0.04	–	-0.01	-0.05	–	-0.04
Total	99.42	99.09	99.57	100.00	99.91	99.41	99.18	99.70	99.59	99.02
Zr	3615	1704	2044	1311	1897	1706	1334	831	725	2336
Y	187	116	274	91	250	172	152	52	141	279
Nb	117	73	387	52	102	70	69	44	72	101
Be	19	13	44	10	15	14	10	7	10	21
U	9.0	3	7	5	6	5	7	1	5	12
Th	41	14	75	14	31	18	28	5	28	45

Notes: All oxides and F in Weight %; trace elements quoted as ppm.
See Table 3 for the analytical techniques.

The mafic trachytic units are either medium- to dark-green or black in appearance, whereas the more felsic varieties are light brown. Volcanogenic sediments and weathered equivalents of the lower two units occur in the upper unit to the east of the Mann #1 showing; the present study suggests that peralkaline volcanics dominate in the upper unit north and west of the Mann # 1 showing.

The syenites that are closely related to or hosting the mineralization of the Mann type are fine- to medium-grained, massive, equigranular aegirine–riebeckite ± quartz syenites. These syenites also contain perthitic feldspar and accessory astrophyllite, fluorite, aenigmatite, titanite, apatite and magnetite. Peralkaline granites in the area have similar mineralogy except that quartz and astrophyllite are more abundant and riebeckite and aegirine are less abundant; no known mineralized zones are associated with peralkaline granites in this region. Undersaturated nepheline–eudialyte–aegirine–riebeckite-bearing syenites and related rocks host the Y mineralization in the Shallow Lake area. Representative analyses of the peralkaline intrusive rocks in the Letitia–Shallow lakes area are listed in Table 6.

Mineralization. The Nb–Be mineralization in the Letitia Lake area occurs both within peralkaline volcanic rocks overlying peralkaline syenites and as veins cutting the volcanics or syenite. Miller (1987) described the geology of the individual Nb–Be mineralized zones. The Y mineralization was only recently recognized (Miller, 1986b; Batterson and Miller, 1987), and thus little is known about this mineralization.

As discussed in Miller (1987), the Nb-Be mineralization occurs in 5 different modes:

1) banded feldspar–riebeckite volcanics (M1): occurs at the Mann #1, Two Tom and one of the Mann #2 showings; these volcanics have been assigned to the lower portions of the upper unit of the Letitia Lake Group and are trachytic in composition.

2) massive aegirine–feldspar volcanics (M2): occurs at the Mann #1, Mann #2, and Michelin showings; these volcanics belong to the upper unit and are also trachytic.

3) aegirine–feldspar veins (M3): occurs at the Mann #1, Michelin, Mann #2 and Two Tom Lake showings; these veins appear to be closely related, both mineralogically and spatially, to volcanics of mode M2 and the fine grained syenites.

Table 7. Major- and minor-element analyses of rare metal mineralization from the Letitia Lake–Shallow Lakes area

	LL–84014 Mann M1	LL–84010 Mann M2	LL–84078 Mann M3	LL–84053 Mann M4	LL–85055 Michelin M5	LL–84120 Mann #2 M2	LL–85038 Two Tom M1	85-4521 Two Tom Y	LL–85084 SW Ten Mile	72115 Red Wine Suite
SiO_2	56.55	58.20	55.30	58.85	58.35	61.95	60.00	47.95	53.60	63.60
TiO_2	0.46	1.18	0.88	0.39	0.64	0.62	0.37	0.58	0.25	0.23
Al_2O_3	8.88	10.94	8.26	12.45	12.80	12.41	12.74	3.16	9.59	17.00
Fe_2O_3	4.34	6.01	14.26	1.84	9.61	9.09	5.39	11.95	10.96	1.40
FeO	8.76	3.70	1.04	5.50	1.05	0.79	3.22	1.62	6.63	0.80
MnO	1.36	0.95	0.60	1.10	0.31	0.27	0.65	3.12	0.95	0.04
MgO	0.06	1.64	0.19	0.02	0.06	0.26	0.07	0.83	0.23	0.30
CaO	1.28	3.79	1.16	1.27	1.56	0.95	0.92	7.55	1.37	0.10
Na_2O	8.64	7.02	9.70	9.20	9.69	9.43	8.83	7.69	11.13	4.90
K_2O	1.50	3.89	2.43	0.81	3.79	2.53	8.03	2.22	1.63	11.10
P_2O_5	1.00	0.19	0.25	0.65	0.07	0.10	0.17	1.53	0.03	0.02
H_2O	1.10	0.78	0.29	0.41	–	–	–	2.22*	–	0.30*
CO_2	0.03	0.01	0.07	0.00	–	–	–	–	–	–
F	0.10	0.19	0.06	0.05	0.05	0.01	0.05	–	0.07	0.02
F=O	-0.04	-0.08	-0.03	-0.03	-0.03	–	-0.03	–	-0.03	-0.01
Total	94.02	98.41	94.46	92.51	97.95	98.41	100.41	90.42	96.41	99.80
Zr	44	236	101	41	1805	1008	37	372	891	>19000
Y	156	314	622	332	217	190	384	2347	1898	1300
Nb	9856	1712	818	2908	1086	83	1744	1599	134	310
Be	1750	380	2020	2560	122	141	830	60	34	–
U	15	14	26	24	5	6	11	187	46	–
Th	1979	216	847	1753	63	254	344	5054	66	–

Notes: All oxides and F in Weight %; trace elements quoted as ppm.
* H_2O is Loss on Ignition.
Red Wine suite analysis from Curtis and Currie (1981).

4) albite-rich felsic veins (M4): occurs at the Mann #1 and rarely at the Michelin and Two Tom Lake showings.

5) disseminated (M5): occurs at the Michelin showing.

The grades of each of these modes of mineralization vary greatly (Table 7) but the vein modes (M3 and M4) generally contain the highest grades, whereas the volcanic-hosted mineralization generally contains the largest volumes.

The SW Ten Mile Lake, Two Tom Lake and Red Wine North Y showings have not been extensively studied or sampled. Analyses of one or more grab samples from each showing are listed in Table 7. A description of each of these showings is as follows:

Two Tom Lake: Y mineralization occurs within peralkaline syenites and volcanics but appears to be sporadic in nature; it occurs with Nb–Be mineralization in M2 volcanics but not in all outcrops.

SW Ten Mile Lake: high Y values have been obtained from a fine grained aegirine-rich unit (up to 80 percent aegirine), which may be a recrystallized volcanic rock or a subvolcanic dyke; this sample contains the highest Y value obtained in the Letitia Lake area.

Red Wine Alkaline Intrusive Suite: sporadic analyses with anomalously high Y values have been reported (Curtis and Currie, 1981) from various undersaturated units of this complex; unfortunately no locations have been published for these samples.

Figure 9 illustrates the relationships between the Letitia Lake Group, the peralkaline syenites, the various modes of Nb–Be mineralization and the volcanic-hosted Y mineralization. Most Nb–Be showings in the Letitia Lake area are associated with peralkaline syenite, although significant mineralization has not been discovered near all of the mapped syenites; peralkaline granites do not appear to host mineralization, although they are enriched in many of the rare metals.

Setting. The subaerial volcanic rocks and related intrusives of the Letitia Lake Group and Red Wine Alkaline Intrusive Suite have been interpreted as a rift-related sequence (Hill and Thomas, 1983). A U–Pb (zircon) date for a quartz–feldspar porphyry gave 1327 ± 14 Ma (Thomas, 1981) and a Rb–Sr wholerock isochron date of 1327 ± 75 Ma was obtained for the undersaturated Red Wine suite (Blaxland and Curtis, 1977). These dates indicate that the Red Wine suite and the Letitia Lake Group are Neohelikian in age.

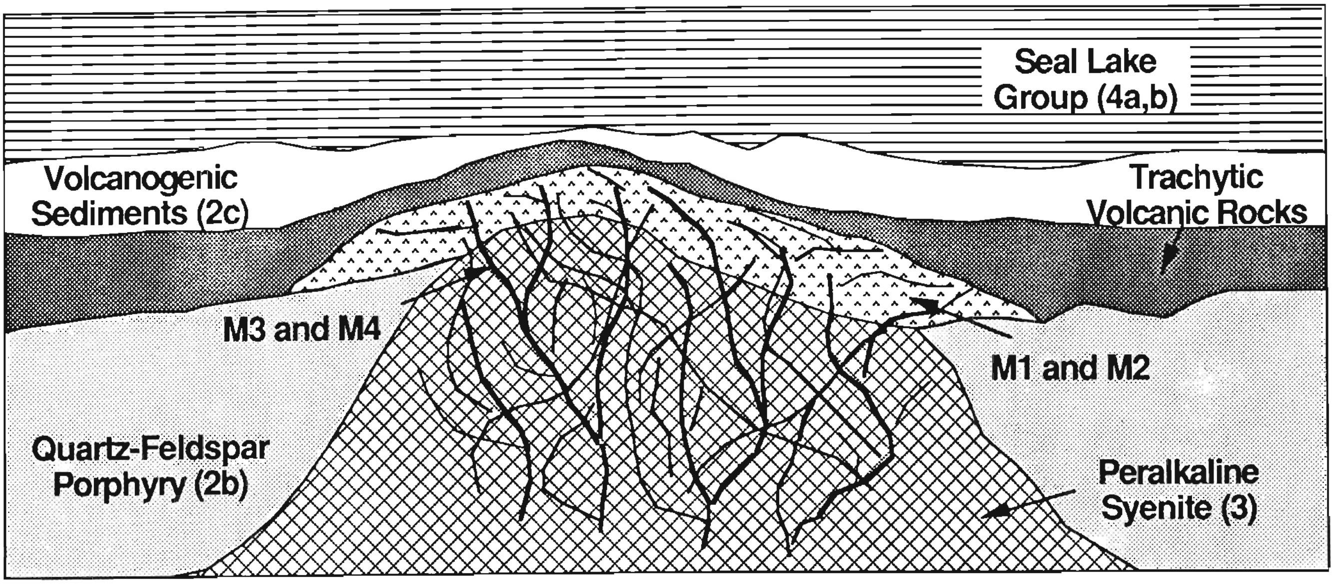


Figure 9. *Sketch illustrating the setting and types of rare-metal mineralization in the Letitia Lake area. See Figure 8 for an explanation of the numbers in brackets and see the text for a description of the mineralization types designated M1, M2, etc.*

Many of the volcanic rocks and porphyries in the lower and middle units of the Letitia Lake Group are not peralkaline with regard to major-element chemistry and mineralogy, but the trace-element comparisons of Hill and Thomas (1983) readily illustrate the peralkaline nature of all of these rocks. Subsequent analyses and thin section examination of quartz–feldspar porphyries indicate that some rocks also have peralkaline major-element chemistry and mineralogy. This adds support to the conclusion of Hill and Thomas (1983) that sodium leaching may have been responsible for the lack of peralkaline minerals and the low Na_2O contents of some of the Letitia Lake Group volcanics. The recognition of high Na_2O and aegirine–riebeckite-rich volcanics in the middle and upper units further confirms the peralkaline nature of the volcanics.

The location of most of the Nb–Be–Y showings within or near peralkaline syenite stocks and related peralkaline, trachytic to comenditic volcanic rocks indicates that this mineralization is high-level magmatic in origin and setting. Figure 9 illustrates the volcanic–subvolcanic setting. These spatial–chemical relationships indicate that the syenites represent the volcanic centres that produced the trachytic volcanics. It also appears likely that the quartz–feldspar porphyries and related comenditic–pantelleritic volcanic rocks were produced from volcanic centres located over or near the peralkaline granite stocks.

CONCLUSIONS

Mineralization Modes and Settings

The descriptions of known rare-metal deposits and showings in Labrador indicate that there are four major rock types with which rare-metal deposits in Labrador are associated:

1) peralkaline granites

2) peralkaline syenites (saturated)

3) undersaturated peralkaline intrusives

4) peralkaline trachytic and rhyolitic volcanics

All of these rock types occur at high levels within the crust as either volcanic feeder stocks, unvented plutons or volcanics.

Unvented plutons (e.g., Strange Lake) appear to have a high potential for large tonnages of rare-metal mineralization if processes within the magma chamber are able to concentrate the rare metals at or near the top of the chamber. In this setting, the mineralization would occur as pegmatite–aplite dykes, or, as late-stage medium grained intrusions at or near the top of the stock, or above the main portion of the stock in cupolas or subsidiary intrusions. Venting of part of the magma chamber to the surface would result in a wider distribution of rare metals and a reduced likelihood of their being concentrated in economic deposits.

Volcanic feeder stocks, such as those in the Letitia Lake area and the Flowers River suite, also have anomalous rare-metal contents in their higher levels. In the Letitia Lake example, the mineralization occurs in fine- to medium-grained veins, whereas at Flowers River it occurs in pegmatitic–aplitic dykes. Exploration targets in this setting would include large veins and dykes or areas with a high concentration of veins and dykes. There may also be small Strange Lake-like mineralized cupolas or subsidiary intrusions in volcanic feeder stocks, although these would be less frequent and tonnages smaller than in the unvented pluton setting.

The best exploration targets in peralkaline volcanics (e.g., the Letitia Lake area and the Flowers River suite) would be in rocks that formed from rare-metal-enriched magma that had collected at the top of the magma chamber. Presumably, as at Letitia Lake, flows or possibly thick pyroclastic units located near the vent would be the best targets for large tonnages of stratiform, rare-metal mineralization. Volcanic-hosted deposits could also provide large tonnages of lower grade material.

Rare-Metal Exploration Targets in Labrador

This compilation of data on known rare-metal deposits in Labrador reveals several poorly evaluated or unevaluated rare-metal exploration targets in Labrador. A glance at the status column in Table 2 indicates that several showings are not currently staked and that some of these showings have not been explored at all. Showings or areas that should be of particular interest to exploration companies are listed below.

Letitia Lake Area

- The Mann #2 and Michelin Nb–Be showings, which have not been adequately evaluated by surface sampling or drilling.

- The SW Ten Mile Lake showing and the immediate vicinity, which have not been previously explored for Y. The high value obtained in a grab sample from this showing indicates that there is good potential for significant Y mineralization.

- If the interpretation of Miller (1987) is accepted as a plausible model for the location of Nb–Be deposits, then several other zones within the Letitia Lake area, from which no known mineralization has been reported, are also favourable targets.

- The large peralkaline syenite–granite complex southwest of Letitia Lake may also be a good target for pegmatite–aplite or subsidiary intrusion rare-metal mineralization similar to Strange Lake.

Shallow Lake area

- The Shallow Lake peralkaline granite, which has anomalous rare-metal contents, has not been explored for rare-metal-enriched, pegmatite–aplite or subsidiary intrusion mineralization.

- The high values obtained in grab samples from undersaturated rocks of the Red Wine Alkaline Intrusive Suite and the recent discoveries, in North America, of Y in eudialyte-bearing undersaturated rocks similar to the Red Wine intrusive rocks, should make these Y occurrences very good exploration targets.

Flowers River suite

- This suite presents a large area favourable for rare-metal mineralization. Following the interpretation of Hill (1981, 1982), the roof zone of the peralkaline granite batholith would be a very favourable target for cupola or subsidiary intrusion mineralization. Analyses of some peralkaline granite outcrops, interpreted to be distant from the roof zone, indicate that nonroof zone granites are not favourable for rare metal and, in particular, Y mineralization.

- Further exploration for pegmatite–aplite dykes similar to the one sampled by Hill (1982) may also be rewarding. These are located throughout the suite but the most interesting ones probably intrude the roof zone of the granite or the overlying volcanic rocks.

- The high values for Y and some of the other rare metals in the peralkaline volcanics indicate that these rocks may also contain economically interesting showings of stratiform rare-metal mineralization. Since these volcanic rocks overly the peralkaline granite it is assumed that they are near the vent.

Other regions of peralkaline intrusive–extrusive activity

The work of Hill and Thomas (1983), in demonstrating that the Na_2O-poor volcanics of the Letitia Lake Group and the Flowers River Igneous Suite are peralkaline in nature, and the subsequent discovery of Na_2O-rich peralkaline volcanic rocks in the Letitia Lake Group indicates that the current geological mapping of Labrador need not necessarily be correct with respect to the occurrence of peralkaline volcanic rocks. Thus, other occurrences of felsic volcanic rocks should be carefully studied to determine if they are peralkaline and favourable for rare-metal exploration.

A brief review of the geochemistry and petrography of the rhyolitic flows, pyroclastics and quartz–feldspar porphyries of the Upper Aillik Group in the Central Mineral Belt of Labrador suggests that some of these rocks are peralkaline and may be good rare-metal targets. Some of the evidence for this interpretation is:

1) Analyses by Ghandi (1978) and Gower *et al.* (1982) showing many analyses of these rocks with Y in the 50 to 100 ppm range and Zr in the 400 to 1500 ppm range; many of these rocks host U mineralization.

2) Many reports indicate that aegirine and riebeckite occur in these rocks (Ghandi, 1978; Gower *et al.*, 1982; King, 1963; Minatidis, 1975; Watson-White, 1974 and Morse, 1961).

3) Analyses for Zr by Minatidis (1975) from the Michelin, Rainbow, Emben and McLean uranium

showings and deposits indicate that values up to 2200 ppm Zr are not uncommon in these areas.

4) Barua (1969) reported a crystal tuff (analysis # 31) with 65.90 percent SiO_2, 18 ppm Be, 140 ppm Y and 275 ppm Zr.

The felsic (peralkaline ?) volcanics of the Upper Aillik Group have only been extensively prospected for U, Mo and base metals whereas the rare-metal elements have received no attention.

Insular Newfoundland

Even though this report is based on data from deposits and showings in Labrador, there are a large number of similar geological settings in insular Newfoundland that have a high potential for rare-metal deposits. The models and exploration criteria outlined in this report can also be applied to insular Newfoundland (e.g., St. Lawrence peralkaline granite, Topsails intrusive suite, Louil Hills intrusive suite, King's Point complex).

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REFERENCES

Barua, M.C.
1969: Geology of uranium–molybdenum-bearing rocks of the Aillik–Makkovic Bay area, Labrador. Unpublished M.Sc. thesis, Queen's University, Kingston, Ontario, 76 pages.

Batterson, M. and Miller, R.
1987: A new Y–Nb–Be showing in the western part of the Central Mineral Belt, Labrador. Newfoundland Department of Mines, Mineral Development Division, Open File 13L/1 (66), 5 pages.

Blaxland, A.B. and Curtis, L.W.
1977: Chronology of the Red Wine alkaline province, central Labrador. Canadian Journal of Earth Sciences, Volume 14, pages 1940-1946.

Curtis, L.W. and Currie, K.L.
1981: Geology and petrology of the Red Wine alkaline complex, central Labrador. Geological Survey of Canada, Bulletin 294, 64 pages.

Dawe, R.
1984: Mineral-based opportunities in Newfoundland and Labrador. A presentation to Japanese business representatives in Tokyo, Japan. Newfoundland Department of Mines, unpublished document.

Dujardin, R.A.
1961: Ten Mile Lake drilling report. Unpublished report for Rio Tinto Exploration Limited. [13L/1 (12)]

Duthou, J.L., Pillet, D. and Chenevoy, M.
1986: Rb–Sr geochronology of the Lac Brisson peralkaline granite (Labrador, N.E. Canada). Abstract, International Geochemica Cosmochemica Congress, Cambridge, England.

Ghandi, S.S.
1978: Geological setting and genetic aspects of uranium occurrences in the Kaipokok Bay–Big River area, Labrador. Economic Geology, Volume 73, pages 1492-1522.

Gower, C.F., Flanagan, M.J., Kerr, A. and Bailey, D.G.
1982: Geology of the Kaipokok–Big River area, Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-7, 77 pages.

Hill, J.D.
1981: Geology of the Flowers River area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-6, 40 pages.

1982: Geology of the Flowers River–Notokwanon River area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-6, 140 pages.

Hill, J.D. and Thomas, A.
1983: Correlation of two Helikian peralkaline granite–volcanic centres in central Labrador. Canadian Journal of Earth Sciences, Volume 20, pages 753-763.

Jacobson, R.R.E., MacLeod, W.N. and Black, R.
1958: Ring-complexes in the younger granite province of northern Nigeria. Memoirs of the Geological Society of London, Volume 1, 71 pages.

King, A.F.
1963: Geology of Cape Makkovik peninsula, Aillik, Labrador. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 114 pages.

Miller, R.R.
1986a: Geology of the Strange Lake Alkalic Complex and the associated Zr–Y–Nb–Be–REE mineralization. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 11-19.

1986b: Preliminary data from rock samples of the Letitia Lake area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File 13L/63, 8 pages.

1987: The relationship between Mann-type Nb–Be mineralization and felsic peralkaline intrusives, Letitia Lake Project, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 83-91.

Minatidis, D.S.
1975: A comparative study of trace element geochemistry and mineralogy of some uranium deposits of Labrador, and evaluation of some uranium exploration techniques in glacial terrain. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 216 pages.

Morse, S.A.
1961: Petrographic notes on Aillik molybdenum showings, Labrador (N.T.S. 13O/3). British Newfoundland Exploration Ltd. Unpublished document G-61003, 4 pages. [13O/3 (47)].

Thomas, A.
1980: A summary of geology and data collected during 1978 in the Red Wine Lake-Letitia Lake area, central Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File 13L (56), 44 pages.

1981: Geology along the southwestern margin of the Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-4, 40 pages.

U.S. Bureau of Mines
1985a: Mineral Commodity Summaries.

1985b: Mineral Facts and Problems, 1985 Edition. U.S. Bureau of Mines, Bulletin 675.

1987: Mineral Commodity Summaries.

Venkatswaren, G.P.
1983: A report on the geological, geophysical and geochemical assessment work, Strange Lake area, Newfoundland-Labrador, N.T.S. Sheet 24A/8. Unpublished report, Iron Ore Company of Canada. [24A/8 (6)]

Watson-White, M.V.
1974: A petrological study of acid volcanic rocks in part of the Aillik Series, Labrador. Unpublished M.Sc. thesis, McGill University, Montreal, Quebec, 92 pages.

Note: Mineral Development Division file numbers are included in square brackets.