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GEOLOGY OF THE STRANGE LAKE ALKALIC COMPLEX AND THE ASSOCIATED Zr-Y-Nb-Be-REE MINERALIZATION

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ABSTRACT

The Strange Lake Alkalic Complex is located on the Quebec-Labrador border in northern Labrador. It contains substantial quantities of Zr, Y, Nb, Be and REE, which are concentrated in lenses and veins of fine grained and pegmatitic granite.

Petrographic and mapping studies have identified three major subdivisions of the riebeckite ± aegirine granite, based on the volume percent of exotic minerals (many of which are ore minerals). These subdivisions are: exotic-poor (<5 percent exotic minerals), exotic (5 to 10 percent exotic minerals) and exotic-rich (>10 percent exotic minerals). The spatial relationships between these subdivisions are illustrated in cross-section and plan views of the complex. Age relationships, as indicated by field evidence, indicate that the exotic mineral contents increase with decreasing age.

The comparative chemistry of the subdivisions reflect the exotic mineral contents, as most incompatible elements, including Zr, Be, Y, Nb, and Th, increase in concentration with differentiation; REE concentrations and patterns also follow this trend.

Mineralization at Strange Lake occurs in the most exotic mineral enriched phases, which are late stage and enriched in incompatible elements. Concentrations of many elements are economically interesting.

INTRODUCTION

The Strange Lake Alkalic Complex (SLAC) is a peralkaline granite complex which hosts significant quantities of Zr, Y, Nb, Be and REE mineralization. It is truly 'strange', as it contains unique mineralogical assemblages, including several rare and un-named minerals, and is extremely enriched in many incompatible elements. To date, several other 'Rare Metal Granites' have been reported in the literature, e.g., Thor Lake (Trueman *et al.*, 1985) and the Saudi Arabian occurrences (Drysdall *et al.*, 1984), but none of these other occurrences have the unusual mineralogy and chemical signature of the Strange Lake deposit.

The complex is located on the Quebec-Newfoundland border approximately 250 km northeast of Schefferville, Quebec, and 150 km west of Nain, on the Labrador coast (Figure 1). It underlies an area, southeast of Lac Brisson, of approximately 32 km². The discovery, by the Iron Ore Company of Canada in 1979, resulted from follow-up work on a F in lake water and U in lake sediment anomaly, discovered in a regional survey carried out in 1978 under the Canada-Newfoundland Uranium Reconnaissance Program (Geological Survey of Canada / Newfoundland and Labrador Department of Mines and Energy, 1979). Part of this regional anomaly, about 20 km down-ice from the bedrock source, was due to the extensive glacial dispersal train from the alkalic complex. Boulder tracing within this dispersal train led to the bedrock discovery.

This is a progress report of work being done on the complex and also a summary of publicly available assessment reports by Iron Ore Company of Canada personnel (Hlava and Krishnan, 1980; Venkatswaran 1981). Other work includes a preliminary report on the complex by Currie (1985) and Miller (1985).

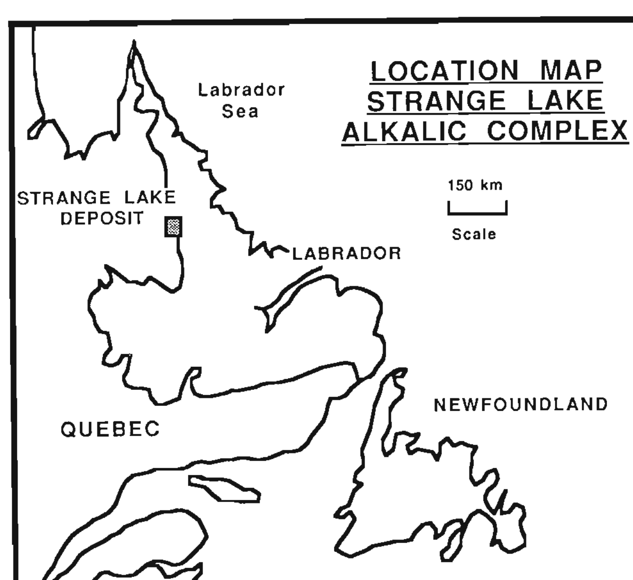

Figure 1: *Location of the Strange Lake deposit.*

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

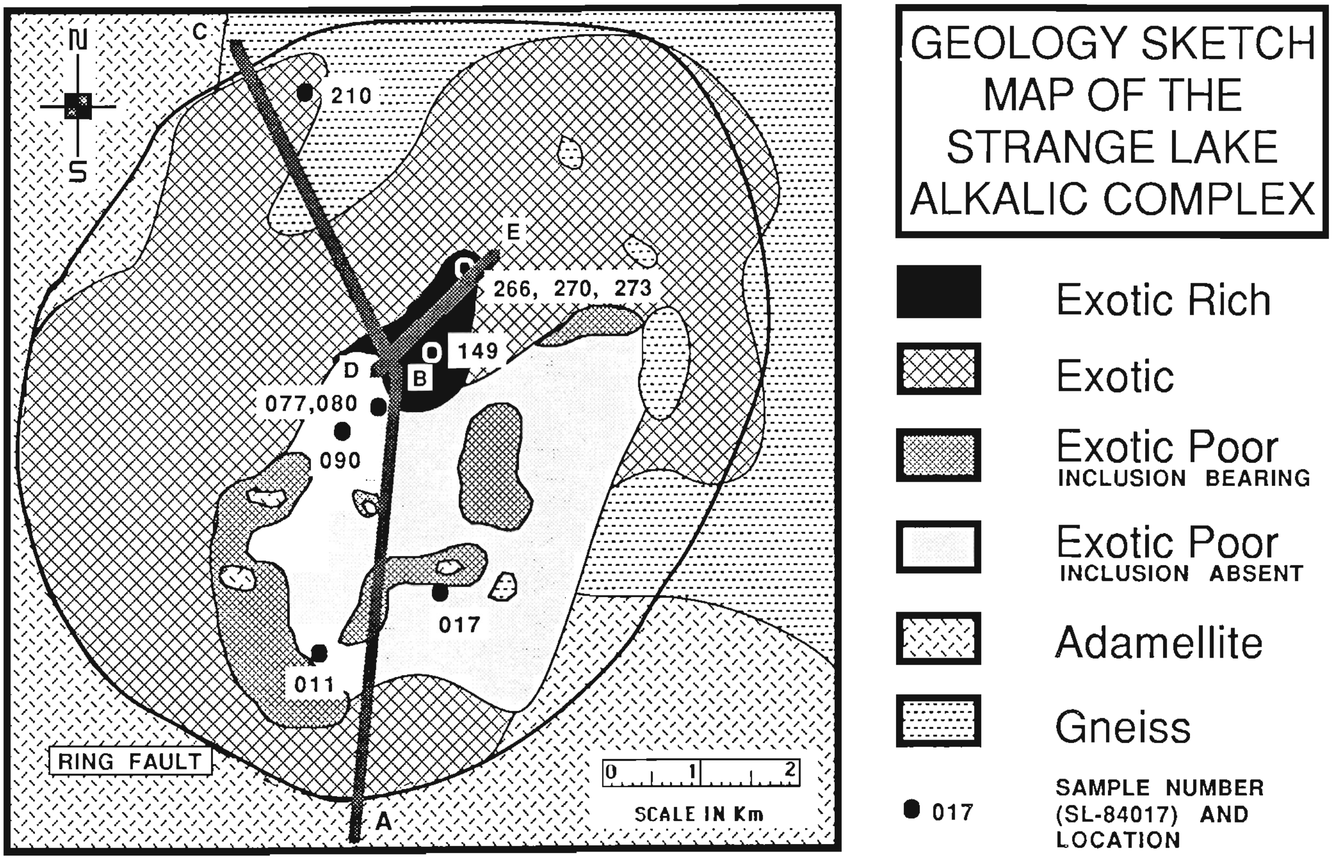

Figure 2: *Generalized geology of the Strange Lake Alkalic Complex with sample locations and cross section lines.*

GEOLOGY

The Strange Lake Alkali Complex occurs within the Churchill Province (Taylor, 1975), but is intrusive into, and much younger than, the surrounding rocks, as indicated by field relationships and a K/Ar date on amphibole (1270 ± 30 Ma; Zajac *et al.*, 1984). Adamellite (quartz monzonite) forms the country rock on the southern and western contacts, and also occurs as small inclusions and roof pendants in the northeastern portion of the complex (Figure 2). A suite of gneisses, including amphibolites, quartzites and quartzo-feldspathic gneisses, occurs in the contact area to the north and east, and also as inclusions and roof pendants in the northeastern portion of the complex.

The occurrence of roof pendants, discrete pegmatites, chilled contacts and discrete inclusions, indicate that the present erosion surface intersects the roof zone of a high level intrusive body. The occurrence of a circular or ring fault (dipping outwards 20 to 35°; Zajac *et al.*,1984) around the complex (indicated by drilling and VLF-EM data) also corroborates these conclusions. This ring fault is often filled by a fluorite ± hematite breccia matrix and veinlets, and occurs within the surrounding host rocks, commonly less than 20 m from the contact.

All of the granite in the complex is peralkaline as indicated by the ubiquitous presence of riebeckite ± aegirine (commonly forms pseudomorphs after riebeckite). The feldspars consist of either albite + K-feldspar, or microperthite. The exotic minerals[1], which generally total >10 percent of the mode, include elpidite ($Na_2ZrSi_6O_{15}\cdot 3H_2O$) and gittinsite ($CaZrSi_2O_7$). Other exotic minerals include: pyrochlore ($[Ca,Na]_2[Nb,Ta]_2O_6F$), armstrongite ($CaZrSi_6O_{15}\cdot 2\frac{1}{2}H_2O$), gadolinite ($Y_2Fe^{+2}Be_2Si_2O_{10}$), fluorite ($CaF_2$), kainosite ($Ca_2[Ce,Y]_2\ Si_4O_{12}[CO_3]\cdot H_2O$), allanite ($[Ce,Ca,Y]_2[Al,Fe^{+3}]_3[SiO_4]_3[OH]$), sphene ($CaTiSiO_4\ [O,OH,F]$), zircon ($ZrSiO_4$) and thorite ($ThSiO_4$). Several 'un-named' minerals also occur.

Granites that occur within the complex can be subdivided into several units based on texture, e.g., grain size, absence or presence of fine grained, more-mafic inclusions, and the percentage of exotic minerals (Figure 3). The three main subdivisions are based on the percentages of exotic minerals observed:

Exotic-poor	(<5%, EP)
Exotic	(5 to 10%, locally up to 15%; Ex)
Exotic-rich	(>10%; ER)

Table 1 lists some estimated modal ranges of representative samples of the main subdivisions. Note that the percentage of exotic minerals is usually dominated by gittinsite and/or elpidite.

[1] Exotic minerals are defined for the Strange Lake Alkali Complex as all unusual, rare and/or previously unknown minerals that are enriched in incompatible elements.

STRANGE LAKE GRANITE CLASSIFICATION						
%EXOTICS	EXOTIC POOR (< 5%)		EXOTIC (5-10%)		EXOTIC RICH (> 10%)	
TEXTURE	INCLUSION BEARING	INCLUSION ABSENT	INCLUSION ABSENT	INCLUSION BEARING	ANHEDRAL SUBHEDRAL	SUBHEDRAL EUHEDRAL
COARSE GRAINED (>5 mm)		OCCURS AS RARE VEINS				HIGHLY MINERALIZED
MEDIUM GRAINED (2-5 mm)	CONTAINS EXOTIC POOR INCLUSIONS		ALTERED EXOTIC POOR	CONTAINS EXOTIC POOR INCLUSIONS	HIGHLY MINERALIZED	HIGHLY MINERALIZED
FINE GRAINED (< 2 mm)		SOURCE OF INCLUSIONS		RARE	RARE	HIGHLY MINERALIZED

Figure 3: *Classification scheme for the Strange Lake peralkaline granite, based on texture and percent of exotic minerals. The shaded areas represent categories for which examples have not been observed. See the text for more details.*

TABLE 1. Estimated Ranges in the Modes of the Major Units of the Strange Lake Alkalic Complex

	Exotic Poor	Exotic	Exotic Rich
Quartz	15 - 60	30 - 60	25 - 60
Microcline	0 - 15	<5	<10 - 45
Microperthite	0 - 70	20 - 40	<10
Albite	0 - 5	<5 - 25	<10
Amphibole	0 - 10	3 - 15	0 - 8
Aegirine	<5	<5	0 - 10
Pyrochlore	TR	<0.5	<1
Elpidite	0 - TR	0 - 5	0 - 5
Gittinsite*	0 - TR	3 - 10	3 - 20
Zircon	0 - TR	<1	<2
Sphene	TR	0 -<1	<1
Fluorite	<1	<1	<2
Astrophyllite[1]	TR	<2	0 - 5
Opaques	TR	TR	TR
% Exotics	<5	5 - 10	10 - 25

NOTE: Modes are volume % estimates from thin section investigation.

* volume % of pseudomorph of which gittinsite is the most abundant mineral (original mineral was most likely elpidite).

[1] 'astrophyllite' is a sphene + quartz + fluorite pseudomorph after possible astrophyllite.

The exotic-poor (EP) subdivision consists of a suite of rocks ranging from very fine grained (<0.5 mm), through fine grained (0.5 to 2 mm) and medium grained (2 to 5 mm), to pegmatitic (>5 mm). Discrete inclusion-bearing units, surrounding host rock roof pendants, can also be mapped. These units contain 5 to 50 percent rounded to subrounded (0.01 to 2 m in diameter) inclusions of very fine grained, darker colored, EP granite. Crosscutting relationships and the occurrence of inclusions indicate that relative ages within the EP subdivision become younger from the very fine grained unit to the inclusion-bearing unit, and finally to the pegmatitic veins. Elpidite and gittinsite are not common in the EP granite (Table 1).

Rocks classified in the exotic (Ex) subdivision are characterized by the presence of inclusions similar to those described in the EP granite. The two textural varieties that have been mapped are a massive medium grained variety and a finer grained amphibole porphyritic variety. These varieties contain inclusions of very fine grained EP granite (similar to that described in the EP inclusion-bearing unit) and, in the case of the medium grained variety, porphyritic Ex inclusions; thus, the porphyritic variety is the older. The porphyritic variety also has lower exotic mineral contents (5 to 10 percent compared to 10 to 15 percent) and lower ZrO_2 contents (1.25 to 1.8 percent compared to 1.8 to 2.2 percent). Most of the ZrO_2 in the Ex rocks occurs in elpidite, gittinsite and zircon.

The exotic-rich subdivision (ER) can be broken down into rocks containing subhedral to euhedral gittinsite and/or elpidite, and those containing anhedral to subhedral gittin-

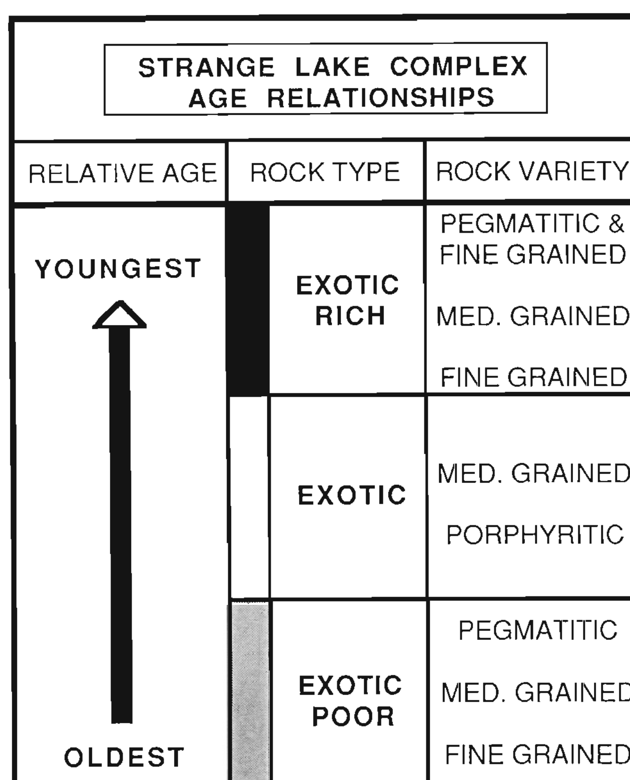

Figure 4: *Illustration of the age relationships between the various subdivisions (ROCK TYPE) and varieties of the Strange Lake peralkaline granite. These relationships are based on field observations.*

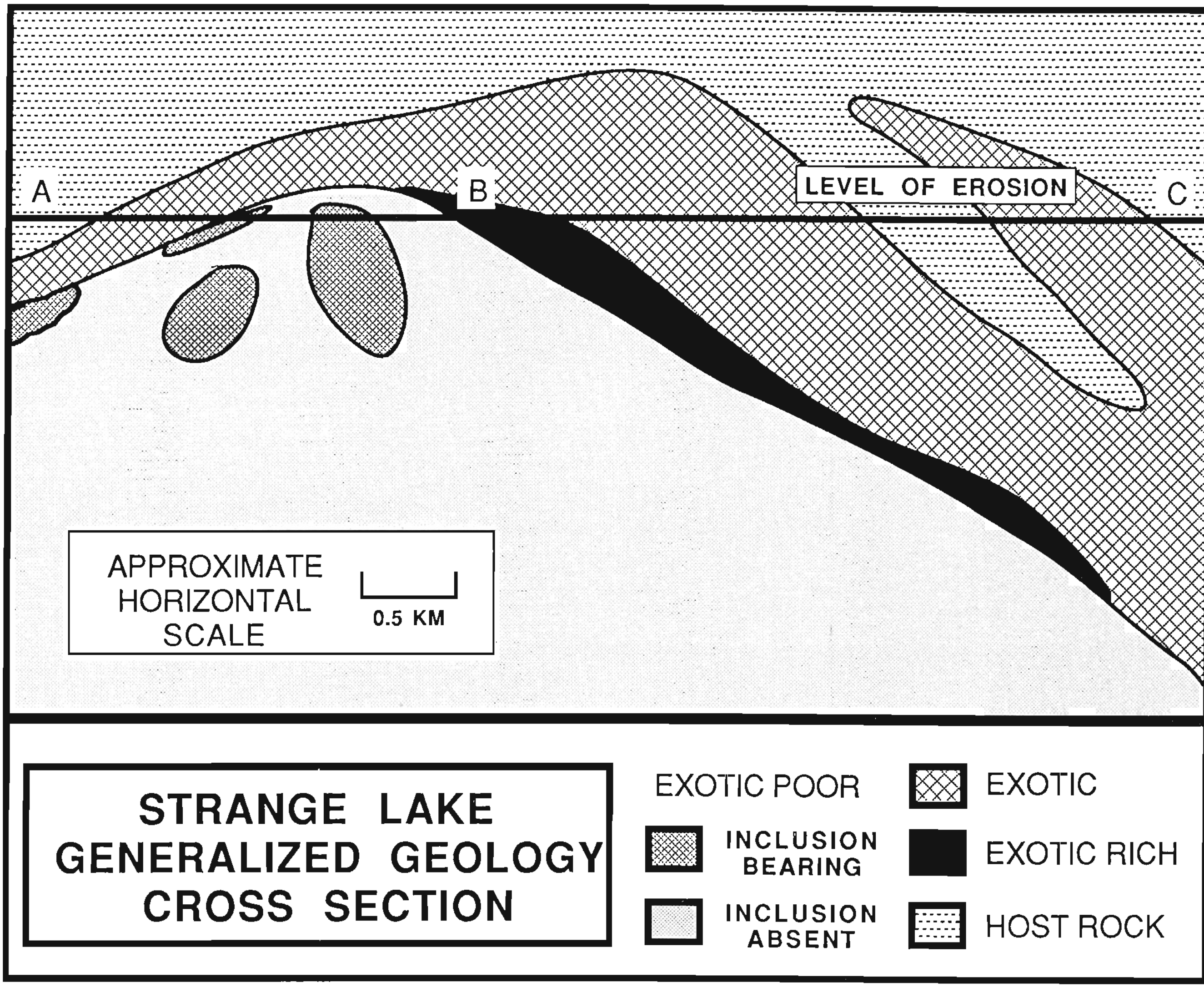

Figure 5: *Generalized geological cross section of the Strange Lake Alkalic Complex (Section ABC on Figure 2).*

site and/or elpidite. Each of the two subgroups can be further subdivided into fine grained (<2 mm), medium grained (2 to 4 mm) and riebeckite porphyritic varieties, with the subhedral to euhedral group also having a pegmatitic (>4 mm) variety. The anhedral to subhedral group is the more abundant and appears to be the older, based on the occurrence of crosscutting dikes and veins of the subhedral to euhedral group within the main intrusion of the anhedral to subhedral group. The younger group also contains higher concentrations of Zr as well as Y, REE, U, Th, Nb, and F.

Crosscutting relationships between the major subdivisions indicate that the EP unit is the oldest and the ER unit is the youngest. This indicates increasing exotic mineral contents with decreasing age, a trend that is also observed within each subdivision. Figure 4 illustrates the age relationships between the various granite types (subdivisions) and textural varieties.

Mapping of the complex (Figure 1), including outcrop and drill core data, indicates the following relationships between the subdivisions:

1) The EP granite occupies approximately 12 km in the south-central portion of the complex.

2) The Ex granite, dominated by the medium grained variety, occupies 22 km^2 of the complex and almost completely surrounds the EP granite, with the exception of the southwestern corner of the complex.

3) Most of the ER granite, dominated by the medium grained anhedral to subhedral group, occurs in the north-central portion of the complex at the contact between the EP and Ex units, where it occupies approximately 1 km^2.

4) Small ER veins and dikes (<0.5 m thick) intrude the Ex unit, the EP unit and roof pendants throughout the complex.

5) An extensive zone of ER veins and dikes, cutting EX granite, occurs in the northwestern part of the complex.

Some of these relationships are illustrated in Figure 5.

GEOCHEMISTRY

Preliminary results are now available from major, minor and REE analysis of some of the representative samples collected from the Strange Lake Alkalic Complex. Some of these analyses are listed in Tables 2 and 3. Figure 6 illustrates the relationship between the various types of exotic granite and the variation of SiO_2 and Al_2O_3. Note that there is little systematic variation in SiO_2 contents between the varieties, while Al_2O_3 is lowest for the ER (youngest) and highest for the EP (oldest) rocks. Al_2O_3 was thus chosen as a variation index; the Al_2O_3 axis has been reversed to reflect decreasing age (increasing differentiation ?) toward the right.

Al_2O_3 variation diagrams for some of the elements are displayed in Figure 7. Some of the interesting points illustrated in these diagrams are:

1) MgO and CaO increase with increasing differentiation.

2) K_2O contents are relatively constant.

3) Na_2O increases with differentiation, although the peralkalinity trend remains fairly constant (Figure 8).

4) Be, ZrO_2 and Y_2O_3 increase with increasing differentiation.

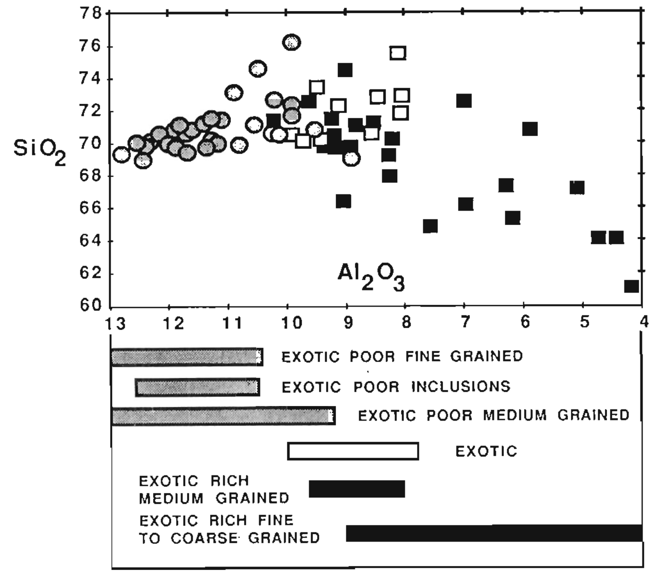

Figure 6: *Illustration of the variation of weight percent SiO_2 and Al_2O_3 with rock variety. Note that Al_2O_3 contents vary systematically with exotic mineral contents, while SiO_2 appears to vary relatively little. The Al_2O_3 axis is reversed to illustrate decreasing relative age towards the right.*

Table 2. 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-84080 Fine Grained	SL-84270 Pegmatitic	SL-84149 Fine Grained
SiO_2	69.95	69.75	70.45	71.05	72.60	70.30	75.45	71.60	67.20	65.35
TiO_2	0.16	0.28	0.24	0.28	0.25	0.40	0.27	0.29	0.08	0.49
Al_2O_3	12.52	11.89	11.78	11.34	10.21	9.70	8.07	9.23	5.07	6.18
Fe_2O_3	1.50	2.02	3.68	1.72	1.91	2.61	2.40	2.67	2.43	3.26
FeO	2.58	2.45	0.31	3.09	2.72	2.57	1.09	1.89	0.01	0.13
MnO	0.07	0.14	0.06	0.10	0.12	0.17	0.15	0.11	0.15	0.18
MgO	0.04	0.14	0.03	0.02	0.09	0.30	0.09	0.02	1.31	1.42
CaO	0.79	1.21	1.11	0.39	0.22	1.87	1.40	1.39	8.05	5.36
Na_2O	4.93	4.54	6.61	5.49	4.91	4.29	2.78	4.82	0.55	1.10
K_2O	6.26	5.88	3.72	4.54	4.57	4.02	4.24	3.41	4.27	5.62
P_2O_5	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.17
ZrO_2	0.31	0.54	0.49	0.58	0.69	1.73	2.29	2.07	0.69	2.38
Y_2O_3	0.10	0.12	0.07	0.08	0.21	0.27	0.37	0.32	2.02	3.33
Nb_2O_5	0.03	0.05	0.06	0.04	0.13	0.15	0.16	0.15	0.18	0.88
BeO	0.01	0.01	0.01	0.01	0.05	0.04	0.04	0.06	1.45	0.61
H_2O	0.11	0.04	0.50	0.37	0.68	0.47	0.50	0.50	2.23	2.10
CO_2	0.05	0.03	0.13	0.10	0.12	0.04	0.01	0.11	0.10	0.19
F	0.59	0.42	0.65	0.38	0.20	0.63	0.45	0.77	3.32	1.60
F=O	-0.25	-0.18	-0.27	-0.16	-0.08	-0.27	-0.19	-0.32	-1.4	-0.67
Total	99.76	99.34	99.65	99.44	99.62	99.32	99.60	99.13	97.75*	99.68
U	7.7	16.7	21.9	18.3	29.7	50.2	52.6	65.7	134.0	212.0
Th	32	47	91	101	134	163	227	375	2572	2350
Rb	774	1262	531	524	1074	1310	987	960	758	1771
Sr	15	31	48	3	9	72	35	22	266	445
Zn	342	753	365	432	903	803	1005	947	1681	1389

NOTE: Major elements, Be, and Zn were analyzed by A.A. method; F by Specific Ion Electrode Method and CO_2 + H_2O by I.R. Method (Newfoundland Department of Mines and Energy); Th, Rb, Sr, Y, Zr, Nb by X.R.F. method (Memorial University X.R.F. Lab); U by neutron activation (Nuclear Activation Services Ltd.). All oxides and F in weight %; trace elements quoted as ppm.

* This sample contains 2.55 % REE.

STRANGE LAKE COMPLEX GEOCHEMICAL TRENDS

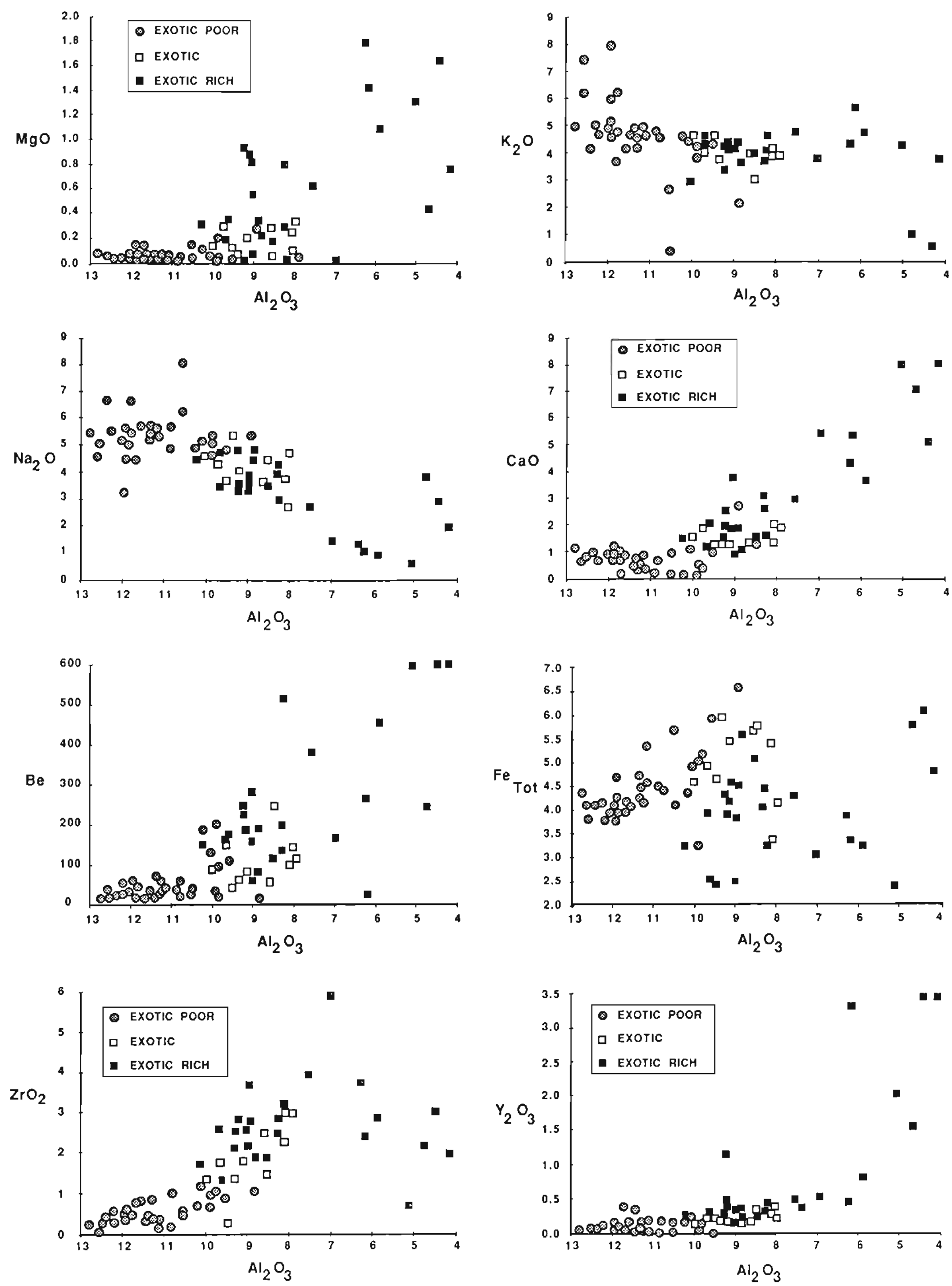

Figure 7: *Chemical variation diagrams for some of the more interesting elements at Strange Lake (71 samples). The symbols are the same for all of the chemical variation diagrams (Figure 6 also). All axes are labelled in weight percent except Be (ppm).* Fe_{tot}=total Fe as FeO

Table 3. REE 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-84080 Fine Grained	SL-84270 Pegmatitic	SL-84149 Fine Grained
La	499.7	558.3	530.2	677.6	2073.9	2266.8	1266.7	660.7	1409.5	2929.1
Ce	1161.3	1270.7	1229	1407.9	4786.5	5260.5	2904.7	1626.1	3352.6	7000.3
Pr	116.9	118.2	126.5	128.3	406.5	531.7	271.9	164.3	562.4	655.7
Nd	583.8	548.4	546.5	562.8	1755	2233.6	1186.6	701.8	2622	2635.2
Sm	144.6	136.3	125	117	432.6	510.4	263.9	202.4	1370.5	1313.5
Eu [1]	2.5	3.1	5.7	0.4	15	3	3.9	6.9	75.9	59.8
Gd	131.3	121.6	108.2	100.5	394.6	435.4	255.8	228.9	1837.9	2244.9
Tb [1]	11.7	26.8	17.7	24.3	53.8	60.6	65.7	45.2	377.6	598.4
Dy	109.8	155.7	93.5	131.5	340.9	407.4	377	354.2	2545	4549.1
Er	48.2	61.8	47.9	67.3	135	164.6	227.5	226.7	1026.6	2343.5
Yb [1]	22.7	35.7	32.2	42.2	72.1	74.9	163.2	166.6	454.2	1191.3
Total REE	2832.5	3036.6	2862.4	3259.8	10465.9	11948.9	6986.9	4383.8	15634.2	25520.8
Ce/Yb	51.16	35.59	38.17	33.36	66.39	70.23	17.80	9.76	7.38	5.88
Eu/Eu*	0.0181	0.0240	0.0489	0.0037	0.0363	0.0063	0.0150	0.0320	0.0473	0.0336

NOTE: All analyses are given in ppm.
1 Analyses for these elements usually have poor counting statistics (values > ± 10% at 90% probability) and thus poor precision. Ho and Lu have extremely poor counting statistics and a Tm tracer was used for the analysis, thus these elements have not been listed. Analyses by the REE Lab at Memorial University of Newfoundland (B. Fryer supervising); thin film X.R.F. method.

5) Fe_{tot} increases with increasing differentiation within the EP group but decreases for the overall suite.
6) In most cases, the trends are continuous from EP to ER granites, i.e., increase with exotic mineral contents.
7) ZrO_2 best differentiates between the three subdivisions; EP: 0.15 to 1.25 percent ZrO_2; Ex: 1.25 to 2.2 percent ZrO_2; ER: 2.2 to 4.0 percent ZrO_2.

The significance of each of these observations is not fully understood, as these studies are ongoing, but it appears that the fractional crystallization of a Na+Al rich mineral could account for the decrease of Na_2O and Al_2O_3, and the increase in incompatible elements, e.g., Be and Zr.

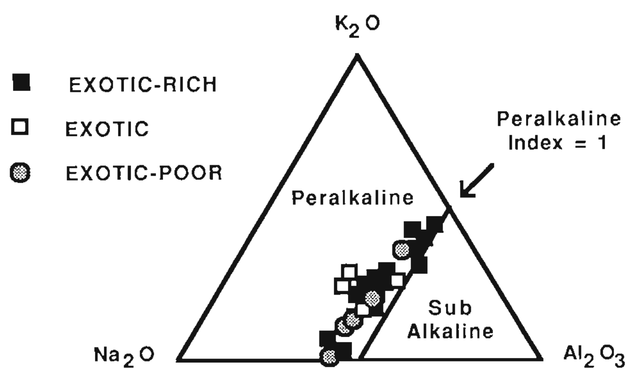

Figure 8: *This ternary diagram illustrates the relationship between molecular proportions of the elements used to calculate the peralkaline index (K_2O + Na_2O/Al_2O_3); all samples that lie to the left of the line, where the peralkaline index equals 1, are peralkaline.*

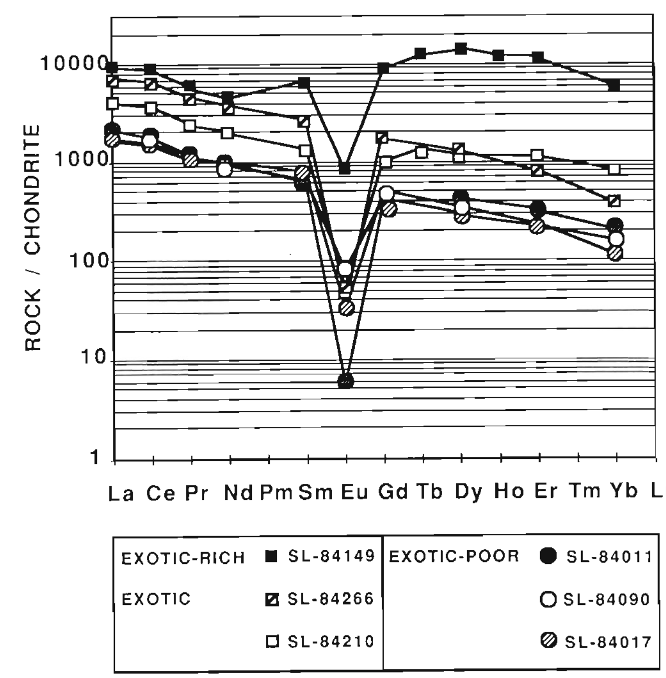

Figure 9: *Chondrite normalized diagram for representative samples from the Strange Lake peralkaline granite. Note that the more exotic-rich samples have higher total rare earth contents and are heavy rare earth enriched relative to the more exotic-poor samples.*

The REE patterns of all of the peralkaline granites exhibit negative Eu anomalies (Eu/Eu* <0.05) and high individual REE values (Table 3) ranging from 100 to 10,000

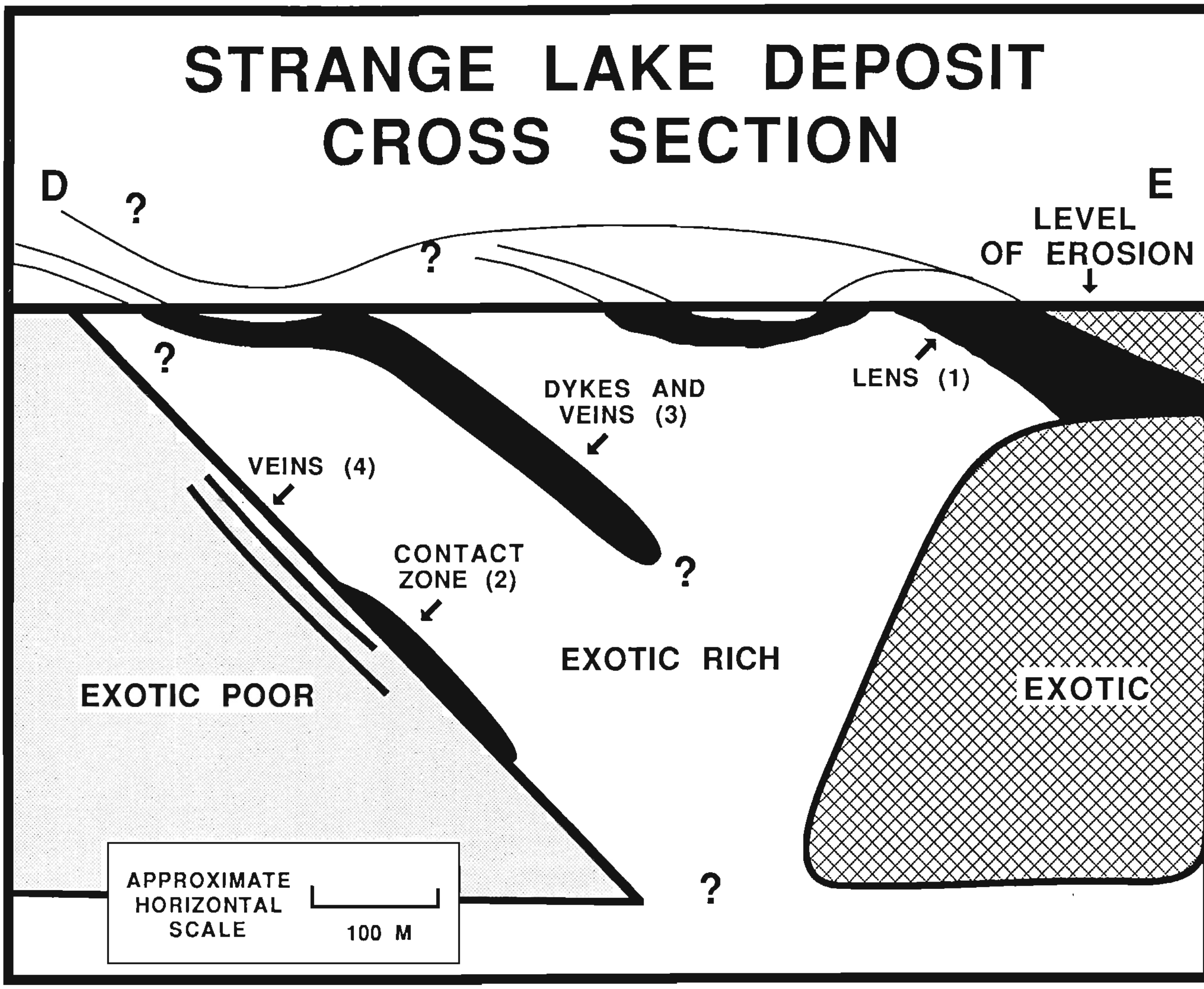

Figure 10: *Generalized cross section of the main exotic-rich intrusion (Section DE on Figure 2), illustrating the location of the highly mineralized zones. The four kinds of mineralization, mentioned in the text, have been illustrated on this cross section.*

C.N. (chondrite normalized; Figure 9). As indicated above, the REE values (incompatible elements) become higher as the percentage of exotic minerals increases, i.e., from EP to ER granites. The proportions of HREE (represented by Yb) to LREE (represented by Ce) also follow this trend as indicated by the value Ce/Yb, which decreases from approximately 50 in EP granites to 6 in the highly mineralized ER granites, i.e., HREE increase relative to LREE.

MINERALIZATION

All of the mineralized zones in the complex occur within, and are classified as, ER granite (Figure 10). In fact, this granite has such elevated abundances of Zr-Y-Nb-Be-REE that the entire unit could be considered as potentially economic. The medium to high grade zones occur in the lenses and dikes of the subhedral to euhedral varieties of ER; the most enriched unit is an approximately 10 m thick, fine grained, and pegmatitic ER lens. In most cases, the pegmatitic units carry the highest values of Y, Nb, Be and REE, whereas Zr is quite variable throughout the ER granites. These highly mineralized zones of ER granite occur as (Figure 10):

1) lenses which extend from the main ER intrusion into the surrounding Ex granite

2) pegmatitic (subhedral to anhedral) and fine grained ER zones on some of the upper and lower contacts of the main ER intrusion

3) either subhedral to euhedral pegmatitic and fine grained veins or pegmatitic veins cutting the main ER intrusion

4) small veins and dikes mostly pegmatitic, cutting the EP unit in the footwall of the ER intrusion.

CONCLUSIONS

At this stage of the study of the Strange Lake Alkalic Complex, it is difficult to present a petrogenetic model, although enough data are available to deduce some aspects of a model. For instance, we know that the alkalic granite crystallized in a high level environment. The high concentrations of volatile elements, such as F, Na and K, suggest that the magma chamber did not have a conduit to the surface. The exotic and exotic-rich granite must have been derived from exotic-poor granite magma at a lower crustal level by a complicated process, which probably involved enrichment through fractional crystallization, thermo-gravitational diffusion and the formation of a fluorine-rich, relatively water-poor, vapour phase. The origin of the magma responsible for the exotic-poor granite is a part of the model which requires more data before a reasonable hypothesis can be proposed.

Ongoing and future work will focus on producing:

1) a model of the evolution of the complex and the associated mineral deposits

2) an exploration case history/exploration strategy for 'Strange Lake type' granites and their associated mineral deposits

ACKNOWLEDGEMENTS

This report is based on field work carried out in the summer of 1984. Dave Molloy aptly carried out the duties of field assistant and Wayne Tuttle and Ken O'Quin supplied the logistical support from Goose Bay. The campsite, helicopter and field equipment were shared with Martin Batterson and Jerry Ricketts of the Quaternary Geology Section; this arrangement resulted in a lightened workload for all concerned. All charts and diagrams in this report were designed and constructed by the author using an Apple Macintosh microcomputer, laser printed by MRI Printing Services and photographically prepared for reproduction by Ken Byrne and assistants. The author gained substantial experience on, and understanding of, the Strange Lake Alkalic Complex while carrying out the drilling and exploration programs on the complex for the Iron Ore Company of Canada. The manuscript was improved by the comments of A. Kerr, J. Tuach and P. Dean.

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