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RARE-EARTH ELEMENT BEARING PEGMATITES IN THE WOLVERINE METAMORPHIC COMPLEX: A NEW EXPLORATION TARGET (93N/9E, 93O/12W, 5W)

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KEYWORDS: Economic geology, Mount Bisson, rare-earth elements, pegmatites, Wolverine Complex, petrology, exploration targets.

INTRODUCTION

Both alkaline and subalkaline rare-earth element (REE) bearing pegmatites occur within the Wolverine Metamorphic Complex of the Omineca crystalline belt west of Williston Lake (Figure 2-9-1). Detailed geological mapping (1:5000) of the Mount Bisson area between the Manson River and Munroe Creek has delineated a number of small REE-bearing intrusions (Figure 2-9-2) that are the topic of this study. The major REE-bearing phases are allanite and monazite. Indeed, in some of the REE-bearing pegmatites allanite occurs as a rock-forming phase: REE concentrations in such pegmatites range as high as 17 per cent rare-earth oxides.

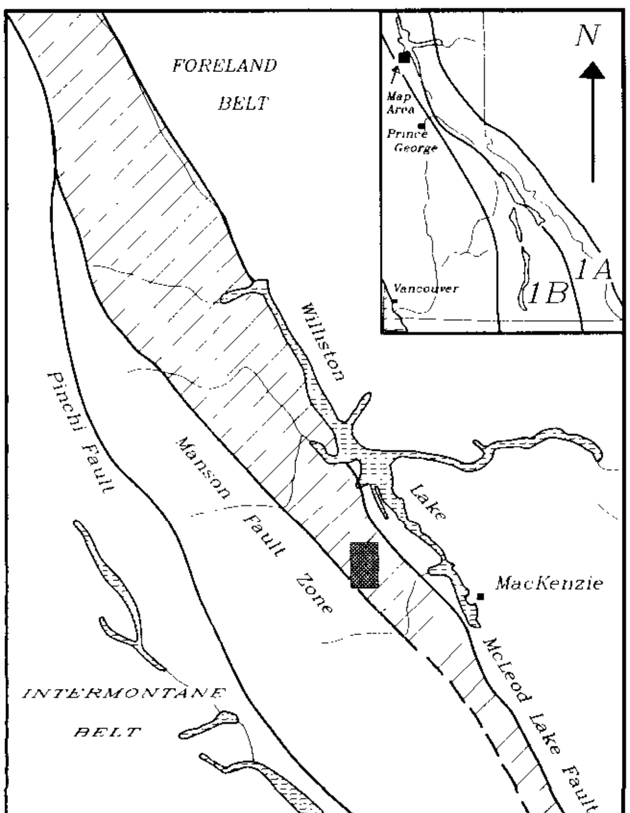

Figure 2-9-1. Location of Mount Bisson field area relative to tectonic framework of the Canadian Cordillera (modified from Ferri and Melville, 1988). Mount Bisson lies within the Omineca crystalline belt (lined pattern). Inset figure locates Mount Bisson area relative to belts of alkaline ultrabasic rocks types (1A and 1B) defined by Pell (1987).

The REE pegmatites, especially the alkaline pegmatites, represent a new exploration target within the Wolverine Complex. Rare-earth mineralization was discovered on Mount Bisson in 1986 and 1987 and Chevron Minerals Ltd. conducted a limited exploration program for rare-earth elements in 1988 (Halleran, 1988). Subsequently, the Mount Bisson REE-bearing units were investigated in more detail by Halleran and Russell (1990) and Halleran (1991). The objective of this paper is to present petrographic and geochemical data on these pegmatites and to elucidate their origins and economic potential. The regional framework for this research is derived entirely from recent regional mapping by Mansy and Gabrielse (1978), Ferri and Melville (1988, 1989, 1990), Deville and Struik (1990), and Struik and Northcote (1991).

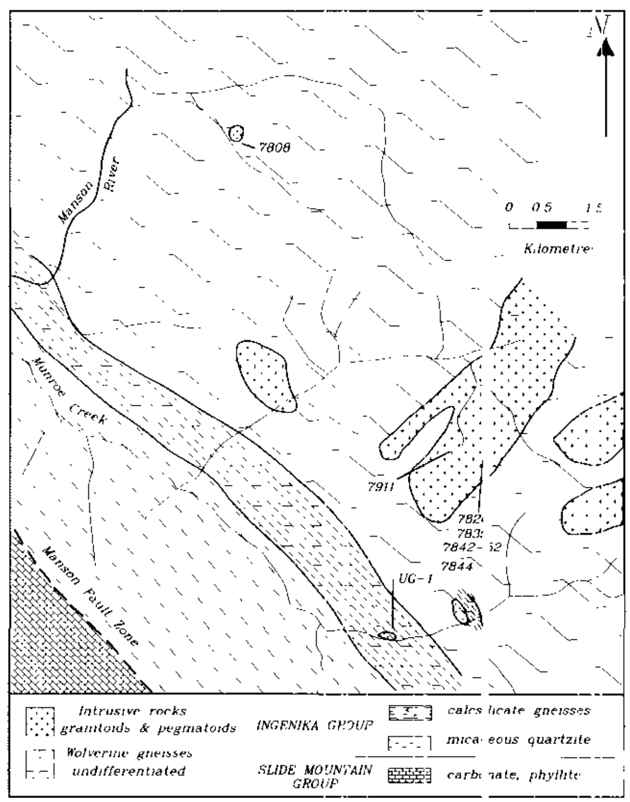

Figure 2-9-2. Geological map of the Mount Bisson area with pegmatite sample locations denoted by sample numbers (*See* Tables 2-9-1 and 2-9-2). Ingenika Group stratigraphy is from Ferri and Melville (1988).

GEOLOGICAL SETTING

The Mount Bisson study area lies mainly within the Omineca crystalline belt and is dominantly underlain by undifferentiated metamorphic rocks of the Wolverine Complex (Figure 2-9-2). Schists and gneisses of the Ingenika Group, including calcsilicate gneisses and micaceous quartzite, parallel Munro Creek to the southwest of Mount Bisson (Ferri and Melville, 1988). Farther to the southwest, the Ingenika Group rocks are in fault contact with phyllites and carbonates of the Slide Mountain Group (Figure 2-9-2). Both Wolverine gneisses and Ingenika rocks are intruded by apparently small granitic and pegmatitic intrusions. Pegmatite commonly occurs as small (<5 m thick) sills and dikes oriented subparallel to the metamorphic layering in the Wolverine gneisses and as larger (1 km diameter) irregular bodies.

Previous workers have argued for at least two separate periods of intrusive activity based on relative age relationships. Intrusive rocks affected by the amphibolite facies metamorphism and deformation which characterize the Wolverine Metamorphic Complex are considered to be at least Cretaceous in age (Tipper *et al.*, 1974; Parrish, 1976, 1979; Ferri and Melville, 1989; Deville and Struik, 1990). Deville and Struik (1990) ascribe the metamorphism and coincident intrusive activity to deep burial of the Wolverine rocks during Cretaceous crustal thickening. Intrusions within the Wolverine gneisses which clearly postdate the peak of metamorphism and deformation are most likely Tertiary (Parrish, 1976, 1979; Ferri and Melville, 1989; Deville and Struik, 1990; Struik and Northcote, 1991) and may be associated with crustal extension and regional uplift of the Wolverine Complex.

Based on mineralogy and chemical composition, both alkaline and subalkaline pegmatites are recognized in the Mount Bisson area and many are enriched in rare-earth elements. We distinguish three types of pegmatites as: alkaline versus subalkaline REE-bearing pegmatites and barren pegmatites. In addition to being chemically distinct, the alkaline and subalkaline REE-bearing pegmatites are not all the same age. Several of the subalkaline pegmatites are deformed or foliated, suggesting a minimum age of Cretaceous. In contrast, the alkaline REE pegmatites crosscut the Wolverine structural fabric and are themselves unfoliated, suggesting they are Tertiary.

Pell's (1987) regional synthesis of alkaline ultrabasic rocks in the Canadian Cordillera established three belts containing all significant carbonatite and related alkaline rock occurrences. The divisions reflect the age relationships, tectonic history and mineralogical and chemical characteristics of these igneous rocks. Mount Bisson lies within Belt 1B, which comprises the Devono-Mississippian syenites and carbonatites at Manson Creek, Blue River and Three Valley Gap. In contrast to these occurrences of alkaline ultrabasic rocks, the Mount Bisson REE pegmatites, based on field observations, are Cretaceous or younger in age, chemically basic to acidic and alkaline to subalkaline. Furthermore, they appear to be unrelated to carbonatite magmatism.

DESCRIPTION OF PEGMATITES

Mineralogically the REE pegmatites are diverse (Table 2-9-1). Chemical discrimination of the alkaline and subalkaline pegmatites (Macdonald and Katsura, 1964) is shown in Figure 2-9-3. The alkaline and subalkaline chemistry is expressed modally by the presence of nepheline or quartz, respectively. The alkaline pegmatites are also characterized by abundant sodic pyroxene (*e.g.*, aegirine-augite) and accessory sphene. Mineralogical distinction can also be based on whether the dominant REE-bearing phase is allanite or monazite (Table 2-9-1).

REE ALKALINE PEGMATITES

The REE alkaline pegmatite group comprises numerous allanite-bearing dikes which outcrop at two localities in the Mount Bisson map area (Samples 7826 and 7911: Figure 2-9-2). These pegmatite bodies commonly occur as dikes 1 to 4 metres wide with minimum strike lengths of over 30 metres. In several places they crosscut the structural fabric of the Wolverine gneisses.

The REE alkaline pegmatites comprise perthitic potassium feldspar, plagioclase, green to brown pleochroic allanite (<35 volume %), titanite (<5 volume %), apatite, with minor aegirine-augite and trace zircon and opaques. One sample contains fresh nepheline. The allanite occurs as subhedral to euhedral grains 0.3 to 20 millimetres in size and is typically associated with titanite and apatite. The modal abundance of allanite varies substantially and the mineral commonly occurs in clusters and along the edges of the dikes.

TABLE 2-9-1
VISUALLY ESTIMATED MODAL MINERAL ABUNDANCES (VOLUME PER CENT) FOR MOUNT BISSON PEGMATITES

Sample No.	Q	Pl	Ksp	Px	Hbl	Al	Ttn	Ap	Bi	Zr	Other
7826	-	33	33	11	-	15	5	2	tr	tr	Nepheline
7911	tr	40	30	16	-	10	tr	2	tr	tr	Opaques
7842-52	28	33	31	2	-	3	2	1	-	tr	Thorite
UG - 1	40	25	35	-	-	tr	tr	tr	tr	tr	Monazite
7835	2	75	2	-	20	tr	tr	tr	-	-	Epidote
7844	50	25	25	-	-	-	-	-	tr	tr	Monazite
7808	3	87	-	10	-	tr	tr	-	tr	-	Epidote

Q - quartz, Pl - plagioclase, Ksp - K-feldspar, Px - pyroxene, Hbl - hornblende, Al - allanite, Ttn - titanite, Ap - apatite, Bi - biotite, Zr - zircon.

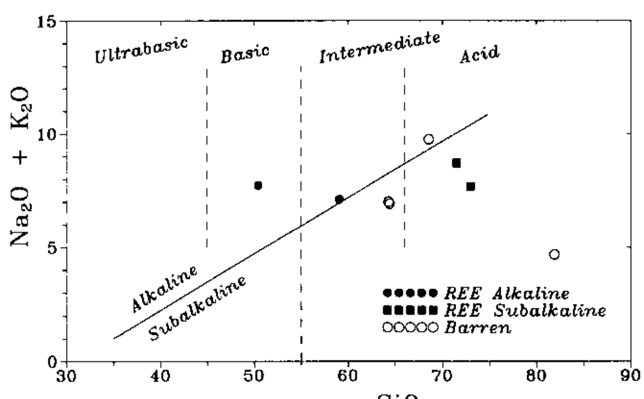

Figure 2-9-3. Chemical compositions of pegmatites plotted as Na_2O+K_2O vs SiO_2 with superimposed silica-content classification.

The allanite pegmatites have little to no fabric, suggesting that they intruded the Wolverine metamorphic rocks after the peak metamorphic-deformational event and are presumed to represent Tertiary magmatism (Deville and Struik, 1990).

REE Subalkaline Pegmatites

Monazite is the most abundant rare earth bearing mineral in the REE-enriched subalkaline pegmatites. A single exposure of quartz allanite pegmatite occurs at Mount Bisson (Sample 7842-52: Figure 2-9-2). It is 0.5 metre wide, tens of metres long, and has an internal fabric paralleling the metamorphic foliation of the Wolverine gneisses.

Although the quartz allanite pegmatite is chemically subalkaline (Figure 2-9-3), mineralogically it comprises heterogeneous clusters of mafic minerals including: allanite (5 volume %), titanite, euhedral apatite, pink pleochroic zircon and thorite. These intergrowths occur with uncommon aegirine-augite in a groundmass of potassium feldspar, quartz and minor plagioclase. The allanite occurrence is erratic and commonly limited to compositionally distinct bands. Anhedral polycrystalline quartz grains are elongate parallel to the mafic bands.

Sample UG-1 (Figure 2-9-2) is a representative monazite-bearing pegmatite taken from a body intruding calcsilicate gneisses of the Ingenika Group (Ferri and Melville, 1988). The pegmatite occurs as a strongly deformed to mylonitized dike, 1 to 2 metres wide. It comprises recrystallized potassium feldspar, quartz and oriented albite grains with more weakly oriented monazite. The monazite distribution is erratic with concentrations of up to 2 volume per cent occurring over tens of centimetres. The average monazite concentration of the rock type is less than 0.5 volume per cent. Biotite, chlorite, titanite, allanite and zircon occur as trace phases. The coexistence of monazite and allanite is of petrologic interest as these minerals rarely occur together (Parrish, 1990). Biotite occurs as irregularly shaped crystals intergrown with allanite and appears to be partly replaced by allanite. A similar textural relationship has been described between biotite and allanite in rocks of the Boulder Creek batholith and is ascribed to allanite replacement of biotite (Hickling *et al.*, 1970).

Field and petrographic observations show that at least the monazite pegmatites are affected by the last significant regional metamorphic-deformational event. This suggests that they are older than the alkaline intrusive rocks and may be Cretaceous or older in age.

Barren Pegmatites

Pegmatites devoid of significant REE concentrations also outcrop at Mount Bisson and make a useful petrologic contrast to the REE-bearing pegmatites. They include both alkaline and subalkaline rock types (Figure 2-9-3). Mineralogically this group ranges from quartz feldspar and hornblende pegmatites which are chemically subalkaline, to quartz syenite pegmatites which are alkaline (Table 2-9-1). The contact relationships between them are not known because mutually crosscutting relationships have not been observed, although the rock types commonly outcrop together. Large xenoliths of Wolverine amphibolite are commonly incorporated within the pegmatite bodies.

Major constituents of the hornblende pegmatites are plagioclase, hornblende, potassium feldspar and quartz, with euhedral titanite, apatite, allanite and epidote occurring as trace phases. The quartz feldspar pegmatite contains 5 to 10-millimetre polycrystalline quartz grains, perthitic potassium feldspar, plagioclase and minor magnetite, biotite and chlorite. Trace phases include zircon, euhedral zoned monazite and opaques. The biotite is replaced by chlorite and exhibits slight kink banding. Coarse-grained quartz syenite pegmatite comprises plagioclase, hedenbergite, perthitic potassium feldspar, elongate quartz crystals and late fracture-filling epidote. Late stage recrystallization of quartz and plagioclase also occurs along fractures.

GEOCHEMISTRY

Table 2-9-2 lists the major, trace and rare-earth element compositions of the Mount Bisson pegmatites. The pegmatite suite includes basic to acid rock types based on SiO_2 content (Figure 2-9-3). The majority of pegmatites are metaluminous (Table 2-9-3) and the normative mineralogy parallels the chemical classification used in Figure 2-9-3. The subalkaline REE pegmatites are silica oversaturated and characterized by normative quartz. The alkaline pegmatites are silica undersaturated to saturated depending on the presence or absence of normative nepheline (Table 2-9-3). The barren pegmatites are intermediate to acidic (Figure 2-9-3) and compositionally separate the alkaline (basic to intermediate) and subalkaline (acid) REE pegmatites. Normatively, they are oversaturated with respect to silica. Two pegmatites (UG-1 and 7844) are chemically peraluminous (normative corundum), although neither rock type contains any of the characteristic peraluminous phases.

The REE pegmatites have a wider range in barium content, compared to the barren pegmatites, from 350 to 5300 ppm, and a smaller range in strontium, from 450 to 1000 ppm (Table 2-9-2). The barren pegmatites have barium concentrations of 360 to 800 ppm and strontium concentrations of 100 to 750 ppm. There are also significant differences in trace element contents between the alkaline and subalkaline pegmatites. Alkaline REE pegmatites have 357 to 1841 ppm barium, whereas the subalkaline pegmatitic rocks have substantially higher barium concentrations of 3000 to 5290 ppm. Zirconium and rubidium are below the lower detection limits in the alkaline REE pegmatites but vary from 238 to 517 ppm zirconium and 62 to 83 ppm rubidium, respectively, in the subalkaline REE pegmatites.

Figure 2-9-4 illustrates the rare-earth element chondrite-normalized (REE_{cn}) abundance patterns (after Wakita *et al.*, 1971; Boynton, 1984) for representative samples of Mount Bisson pegmatites. As summarized in Table 2-9-3, the REE pegmatites have high total REE concentrations ranging from 2783 to greater than 35 000 ppm, whereas the barren pegmatites have lower values (128 to 607 ppm). The three groups of pegmatites differentiated on the basis of mineralogy, structural fabric and major element chemistry are also distinct in terms of REE_{cn} patterns (Figure 2-9-4): strongly

TABLE 2-9-2
MAJOR ELEMENT OXIDES, TRACE ELEMENT AND RARE-EARTH ELEMENT COMPOSITIONS OF MOUNT BISSON PEGMATITES

	REE Alkaline Pegmatites		REE Subalkaline Pegmatites		Barren Pegmatites		
Sample No.	7826	7911	7842-52	UG-1	7835	7844	7808
SiO_2	50.44	59.08	71.50	72.98	64.34	81.90	68.56
TiO_2	2.96	1.25	1.17	0.12	0.19	0.15	0.03
Al_2O_3	19.92	17.42	12.43	15.28	17.91	7.93	15.50
FeO	4.78	3.78	1.43	0.82	3.07	2.21	1.68
Fe_2O_3	2.45	1.44	0.84	0.18	0.47	1.60	0.60
MnO	0.18	0.17	0.09	0.02	0.08	0.05	0.14
MgO	1.29	1.39	0.51	0.38	1.41	0.16	0.77
CaO	10.22	7.76	2.46	2.17	5.31	0.37	2.53
Na_2O	2.97	5.61	2.86	3.88	5.73	2.48	5.65
K_2O	4.75	1.51	5.86	3.80	1.28	2.20	4.09
P_2O_5	0.67	0.42	0.14	0.17	0.13	0.03	0.03
Total	100.61	99.38	99.30	99.81	99.91	99.10	99.58
LOI	0.56	0.28	0.34	0.38	0.62	0.20	0.35
Trace Element Concentrations (ppm)							
Nb	358	241	554	bd	13	30	9
Zr	bd	bd	245	517	24	736	86
Y	342	157	138	16	21	14	16
Sr	444	474	1031	455	717	100	388
Rb	bd	bd	63	83	20	42	85
Ba	1841	357	5291	3010	416	493	797
Sc	26.1	28.7	7.6	1.3	24.9	0.3	19.9
Th	3050	1090	1910	305	33	58	5
U	91	25	93	6	1.6	10	3.5
Rare Earth Element Concentrations (ppm)							
La	>9000	>9000	1240	751	169	82	19
Ce	>20000	16400	2440	1370	290	150	38
Pr	1400	750	240	140	<50	<50	<50
Nd	4190	2630	430	450	77	35	13
Sm	>200	>200	77	61	11	5	2
Eu	77.8	30.0	18.0	2.7	1.6	0.8	0.6
Tb	24	12	6	2	<1	2	1.5
Dy	117	51	33	5	5	3	2.0
Ho	12	7.4	3.7	<1	<1	<1	<1
Yb	13	8.4	1.7	<0.5	1.4	1.8	1.5
Lu	2	1.3	0.15	<0.10	0.18	0.31	0.26
(La/Lu)n	>450	>667	930	751	93	26.4	7.3
(La/Sm)n	>26	>26	9.2	7.1	8.8	9.6	5.7
(Tb/Yb)n	8.6	6.3	17.6	18.7	3.3	2.6	3.1
Eu/Sm	-	-	0.23	0.05	0.15	0.16	0.32

Major and trace elements were determined by XRF and rare-earth elements by neutron activation. FeO was measured by volumetric analysis. Ce, La and Sm have upper detection limits of >20000 ppm, >9000 ppm and >200 ppm respectively; bd denotes below lower detection limit

REE-enriched alkaline pegmatites, less REE-enriched subalkaline pegmatites and barren pegmatites which lack substantial REE concentrations.

The REE_{cn} patterns for the barren pegmatites are lower and flatter than the corresponding patterns for the REE-bearing pegmatites, indicating that the latter have undergone greater degrees of fractionation. The subalkaline REE pegmatites have lower overall REE concentrations than do the alkaline REE pegmatites (Figure 2-9-4).

Table 2-9-2 also lists several calculated parameters based on the measured REE concentrations which can chemically discriminate igneous rocks and elucidate their origins. These indexes (*e.g.*, Haskin, 1984) monitor: overall rare-earth element fractionation $(La/Lu)_{cn}$; light rare-earth element (LREE) fractionation $(La/Sm)_{cn}$; heavy rare-earth element (HREE) fractionation $(Tb/Yb)_{cn}$; and the europium anomaly (Eu/Sm). For example, compared to the REE-bearing pegmatites, the barren pegmatites have much lower ratios of La/Lu and Tb/Yb, indicating that they have undergone significantly less LREE and HREE fractionation. The alkaline and subalkaline REE pegmatites have significantly different La/Lu, La/Sm and Tb/Yb indices. The REE data suggest that although the subalkaline pegmatites are less enriched and represent greater degrees of overall REE fractionation they have undergone less LREE fractionation and more HREE fractionation.

DISCUSSION

The alkaline REE pegmatites are virtually undeformed and are mineralogically and chemically distinct from the subalkaline REE pegmatites. They probably derive from Tertiary magmatism. REE concentrations are greater than 5 per cent and the dominant REE-bearing mineral is allanite. Based on their chemical and mineralogical composition, these pegmatites are inferred to derive from mantle melts (Heinrich, 1966; Currie, 1976; Bell, 1989). There are a variety of other alkaline intrusive rocks in the Mount Bisson study area which crosscut Wolverine structures and appear to have a similar age (Halleran, 1991). They are probably genetically related to the alkaline REE pegmatites and may represent part of a larger alkaline magmatic event. The pegmatites are quite numerous, have sizes consistent with other economic ore bodies and occur close together, presenting a reasonable exploration target.

The subalkaline REE pegmatites are deformed, suggesting a Cretaceous age. Rare-earth element concentrations are predominantly less than 2 per cent and the dominant rare-earth mineral is monazite. The subalkaline pegmatites may derive from melts produced through partial fusion of the upper crust. This is suggested by the normative character of the pegmatite (peraluminous and silica oversaturated) and by the abundance of monazite (*e.g.*, White and Chappell, 1977). Monazite-bearing granitic pegmatites have been shown elsewhere to result from regional metamorphism in granulite facies migmatitic terrains (Shearer *et al.*, 1987). The large negative europium anomaly (Table 2-9-2) is attributable to plagioclase fractionation (*e.g.*, McKay, 1989). The REE-bearing subalkaline pegmatites have lower total REE concentrations than the alkaline pegmatites, are only sporadically enriched in rare-earth elements and occur as small isolated bodies one or more kilometres apart. These characteristics result in the older (Cretaceous?) REE pegmatites exposed at Mount Bisson being of little economic importance.

TABLE 2-9-3
CHEMICAL CHARACTERISTICS OF MOUNT BISSON PEGMATITES

Sample No.	Pegmatite Type	Silica Normative Character	Alumina Normative Character	ΣREE(ppm)
7826	Allanite	Ne	Metaluminous	>35036
7911	Allanite	Ne-Q	Metaluminous	>29090
7842-52	Granite	Q	Metaluminous	4498
UG - 1	Quartz monzonite	Q	Peraluminous	2783
7835	Hornblende	Q	Metaluminous	607
7844	Quartz Feldspar	Q	Peraluminous	329
7808	Quartz Hedenbergite	Q	Metaluminous	128

Q - quartz, Ne - nepheline.

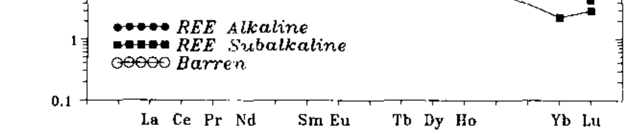

Figure 2-9-4. Chondrite-normalized REE abundance patterns for Mount Bisson pegmatites.

CONCLUSION

The spatial relationship of the pegmatites, their diverse mineralogy, and varying concentration of rare-earth minerals suggest the presence of more than one period of intrusion. The REE-bearing pegmatites which intrude Wolverine metamorphic rocks at Mount Bisson are divided into: Cretaceous or older monazite and allanite-bearing subalkaline pegmatites resulting from crustal anatexis during regional metamorphism and post-Cretaceous allanite-bearing alkaline pegmatites derived from mantle sources. The latter group, and other related alkaline rocks within the study area, may be associated with a larger unexposed alkaline body. The REE alkaline pegmatites represent economic REE targets for the following reasons: they are rich in rare earths, they have potentially economic width and lengths, and the dikes commonly occur together over hundreds of metres.

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