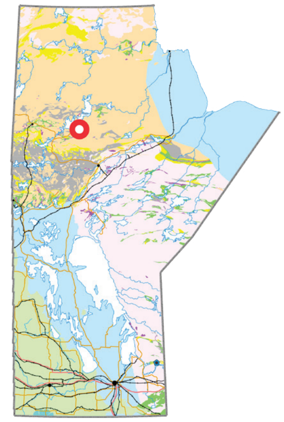
Rare Metals *in* Manitoba

South Bay pegmatite field



UTM: 495806E, 6281996N; NAD 83, UTM Zone 14

Area: Northeast of the town of Leaf Rapids

NTS: 64B11

Access: via Provincial Road 391 from Thompson to Leaf Rapids, then via Provincial Road 493 to O-Pipon-Na-Piwin (South Indian Lake)

Location and Exploration Summary

The main exposures of the South Bay pegmatite field are found in road cuts along Provincial Road 493 about 60 to 70 km northeast of Leaf Rapids and close to the turn off to the old South Bay ferry road. Fairly large exposures of pegmatite and pegmatitic granite can also be found along the shoreline of Southern Indian Lake (Figure 1).

The pegmatites at South Bay were first described by Mumin and Corriveau (2004). Since then, the Tantalum Mining Corporation of Canada Ltd. completed an enzyme leach soil geochemical survey over the area (Assessment File 74323, Manitoba Growth, Enterprise and Trade, Winnipeg), and prospecting and sampling were carried out by Wildwood Geological Services in 2010 (Assessment File 74928, Manitoba Growth, Enterprise and Trade, Winnipeg). The Manitoba Geological Survey (MGS) carried out 10 days of field work in this area to characterize in detail the different pegmatite bodies (Martins and Kremer, 2013).

Geological setting

The pegmatites of the South Bay pegmatite field intrude supracrustal and plutonic rocks of the Southern Indian domain (Figure 1). The Southern Indian domain is dominated by variably migmatitic metasedimentary rocks, with minor metavolcanic and volcaniclastic rocks, and rare inliers of latest Archean granitic gneiss (Corrigan et al., 2007; Kremer, 2008; Kremer et al., 2009), and, for the most part, correlates with the Rottenstone domain in Saskatchewan (Corrigan et al., 2001). Metasedimentary and metavolcanic rocks in the Southern Indian domain have been subdivided into several distinct lithotectonic assemblages (Kremer, 2008, Kremer et al., 2009), all of which have been flooded with voluminous granitic intrusions with ages ranging from 1.86 to 1.80 Ga (Corrigan et al., 2000). The Southern Indian domain is flanked to the south by the Lynn Lake–Leaf Rapids domain, which includes volcanic and associated sedimentary rocks dated at 1.90–1.88 Ga (Baldwin et al., 1987), and has been broadly correlated with the La Ronge domain in Saskatchewan (Maxeiner et al., 2001). In Manitoba, this domain includes two metavolcanic belts with unique stratigraphic successions, geochemistry and structure (Baldwin et al., 1987): the Lynn Lake and Rusty Lake belts. Field relationships suggest that the various volcanosedimentary assemblages were assembled into a tectonic collage prior to emplacement of ca. 1876 Ma calcalkaline plutons (Baldwin et al., 1987). The area is affected by greenschist- to upper-amphibolite–facies metamorphism (Baldwin et al., 1987).

Pegmatite types at South Bay

Martins and Kremer (2013) described and sampled the main pegmatite exposures in order to characterize the pegmatite bodies in terms of their mineralogy, whole-rock geochemistry and rare-metal potential. Based on mineralogy and texture, several different types of pegmatite has been identified at South Bay. The pegmatites intrude diorite composed of quartz, plagioclase, biotite and hornblende, and highly metamorphosed metasedimentary rocks with migmatite injections.

Quartz-feldspar-garnet pegmatite

This is the most common type of pegmatite found in the area and has simple mineralogy with K-feldspar>>plagioclase, quartz, muscovite, garnet and biotite. Internal zonation is not well developed, although there are some examples where a crude inward zonation is observed, from: i) chilled margin

Compiled by T. Martins

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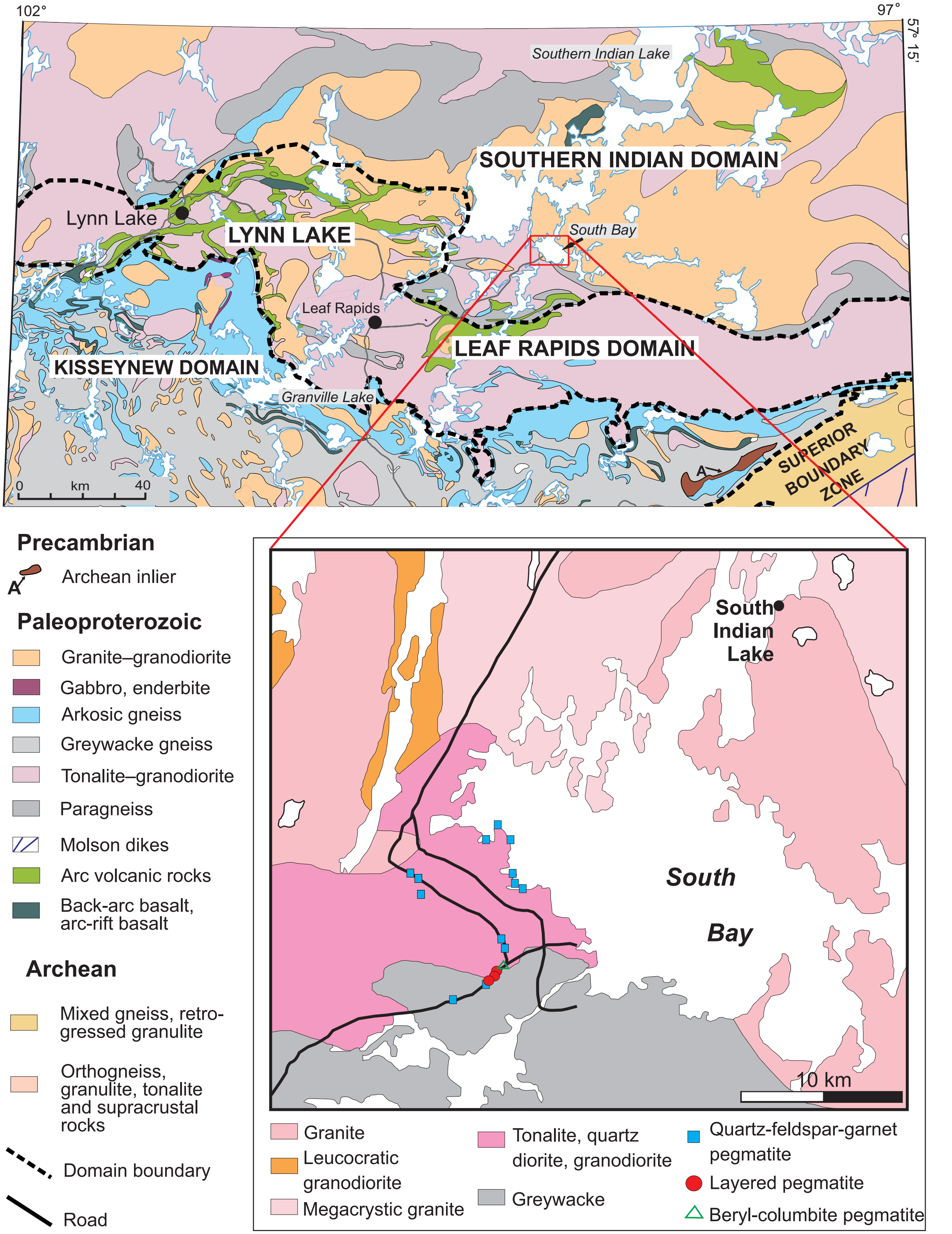

Figure 1: *Regional geology map of the Trans-Hudson orogen in northern Manitoba showing location of South Bay pegmatite field (red square) and inset with location of the studied pegmatites.*

(usually varying from 1 to 2 cm), ii) quartz and comb structure feldspar, iii) aplite and iv) quartz core. The pegmatites are inequigranular to equigranular, usually non magnetic, and display typical granophyric and graphic textures of quartz and feldspar (Figure 2a). Booklets of biotite and muscovite are common, as are K-feldspar crystals arranged in a comb structure (Figure 2b). Aplite is also present and is commonly associated with a higher percentage of muscovite. Petrographic studies indicate that microcline is more common than orthoclase. K-feldspar is locally replaced by sericite, and perthite is common. Muscovite is medium-grained and interstitial to feldspar or is coarser-grained, occurring in larger plates. Garnet occurs throughout and is locally replaced by chlorite. Biotite is mostly interstitial between feldspar and quartz. Chlorite and rare hematite partially or totally replace biotite grains. Rare acicular grains of Nb-Ta oxide minerals (belonging to the columbite group of minerals, CGM) are also observed in thin section.

As described by Martins and Kremer (2013), these bodies have variable thickness from 2 to 12 m and intrude both metasedimentary rock and diorite. For the most part, the contacts are irregular but sharp, but straight contacts are also observed. The orientations of the pegmatite dikes are variable, but most trend 230° and are subvertical. A pronounced mineralogical layering, referred to as 'line rock' (fine-grained, garnet-rich bands alternating with albite- and quartz-rich bands), is also common in the aplitic portions of the pegmatites (Figure 2c).

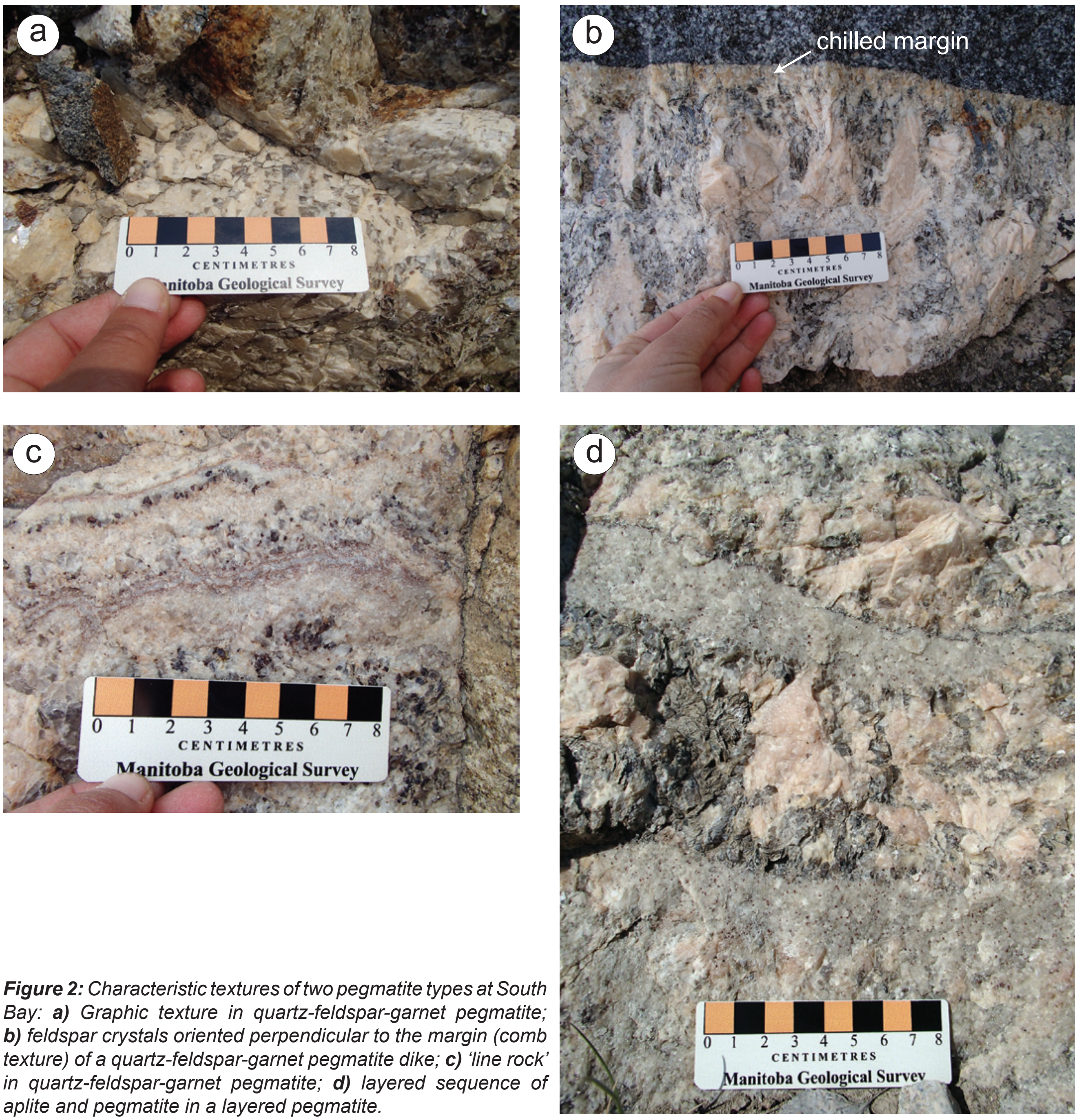

***Figure 2:** Characteristic textures of two pegmatite types at South Bay: **a)** Graphic texture in quartz-feldspar-garnet pegmatite; **b)** feldspar crystals oriented perpendicular to the margin (comb texture) of a quartz-feldspar-garnet pegmatite dike; **c)** 'line rock' in quartz-feldspar-garnet pegmatite; **d)** layered sequence of aplite and pegmatite in a layered pegmatite.*

Layered pegmatite

Layered pegmatite is characterized by alternating layers of aplite and pegmatite. These pegmatites have sharp contacts, strike northeast and have apparent thicknesses of approximately 4.5 m.

The aplite layers are mostly composed of plagioclase>>quartz, K-feldspar, and muscovite. Petrography shows that orthoclase is more common than microcline. Perthite is present but is not common. Muscovite varies from a minor component to up to 40% of the aplite. The pegmatitic layers are characterized by comb texture and abundant garnet (Figure 2d). They are predominantly composed of K-feldspar>plagioclase, quartz, muscovite, garnet, and biotite. Petrographic observations indicate that muscovite and garnet occur both interstitially with quartz and feldspar (strictly in the pegmatitic layers), and as isolated crystals. Perthite is common and microcline is more common than orthoclase. Biotite is scarce and it is usually altered to chlorite. Acicular to rounded grains of Nb-Ta oxide minerals belonging to the columbite group are observed in some pegmatite bodies of this type.

Beryl-columbite pegmatite

The main exposure of this pegmatite type is a near-vertical dike that strikes 210° and is exposed in a roadcut that extends approximately 16.5 m along strike (Martins and Kremer, 2013). The studied beryl-columbite pegmatite is a zoned body. The following zones were identified: i) aplitic, ii) intermediate, iii) beryl-rich, and iv) quartz core. More pegmatites of this type were found along the lakeshore of Southern Indian Lake but are not as well exposed. As with many of the examples observed in this area, it intrudes diorite and the alteration aureole in the country rock is minor or nonexistent. The aplitic zone is usually located close to the margin of the pegmatite, and the beryl zone is characterized by the presence of very large crystals of quartz, albite and beryl (up to 2 cm across).

The aplitic texture present in most of the pegmatite zones (i to iii) is essentially composed of plagioclase>K-feldspar, quartz, beryl, and CGM. Coarser-grained quartz, feldspar and beryl are locally surrounded by the aplitic matrix. The pegmatitic texture is present in zones ii and iii and it is mainly composed by K-feldspar>plagioclase, quartz, beryl, CGM, garnet, and muscovite. Locally, K-feldspar is replaced by sericite, particularly in the rims. Perthite is common, minor myrmekite texture is observed, and microcline is more common than orthoclase.

Geochemistry

The complete dataset of whole-rock major and trace-element compositions for the pegmatites at South Bay is available as a Data Repository Item (Martins, 2014a). The samples are considered representative of the whole rock because the pegmatites are relatively simple in terms of their mineralogy, are not complexly zoned, and bulk samples (~10-15 Kg) were obtained to mitigate the issue of grain size. The studied pegmatite bodies are all granitic. The beryl-columbite pegmatites can be further classified as belonging to the rare-element (REL) class, beryl type, beryl-columbite subtype (classification scheme of Černý and Ercit, 2005).

All pegmatite types are peraluminous (Figure 3) with Alumina Saturation Index [ASI=Al_2O_3/(CaO + Na_2O + K_2O)] ranging from 1.46 to 1.76. Selected variation diagrams illustrate the chemical compositions of the different types of pegmatites at South Bay, and do not show significant variation in terms of major elements (Figure 4).

Trace element diagrams indicate that the pegmatites are all very similar in terms of their trace element composition (Figure 5), although the beryl-columbite pegmatites have slightly higher Nb, Ta, Sr and Be. Geochemical ratios used to measure fractionation (e.g., K/Rb, K/Cs, Mg/Li) indicate that the pegmatites at South Bay are fractionated (particularly the beryl-columbite type), but not as highly fractionated as the Tanco pegmatite,

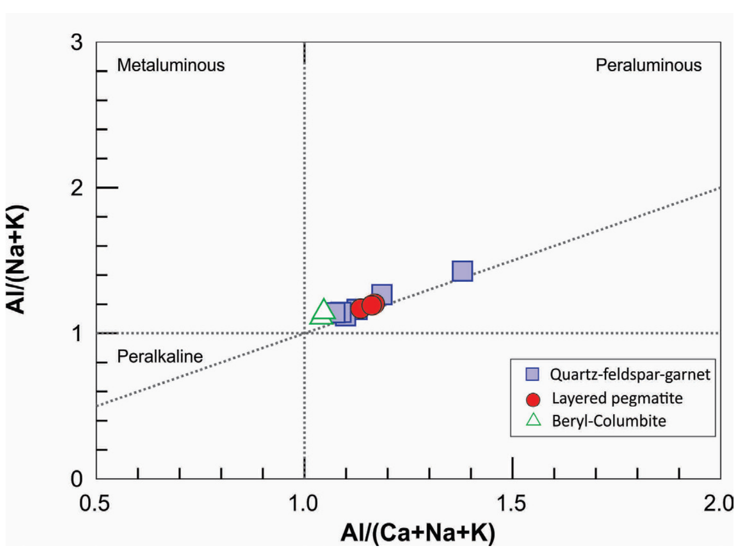

Figure 3: *ASI diagram for the different pegmatite types at South Bay.*

for example. This is also reflected by a number of geochemical indicators (e.g., K/Rb, 83.32–152.96; Mg/Li, 2.74–45.23; Rb/Cs, 65.00–320.00).

Chondrite-normalized REE patterns (Figure 6) for all pegmatite types are similar. The patterns show that the HREE are slightly enriched in comparison to the LREE, with moderate negative Eu anomalies and chondrite-normalized La values of 1.3–9.7 and Yb values of 0.62–12.4, as is commonly observed in granitic pegmatites, which are generally very REE depleted (Černý, 2007). The HREE values for the beryl-columbite type are not represented because they are below detection limit.

Mineral geochemistry: columbite group minerals

Columbite group minerals from beryl-columbite pegmatite at South Bay were examined in detail. Minerals belonging to this group have been shown to be useful indicators of fractionation and chemical evolution both within and among pegmatites in a district (e.g., Černý et al., 1985, 2004; Ercit et al., 1995; Tindle and Breaks,

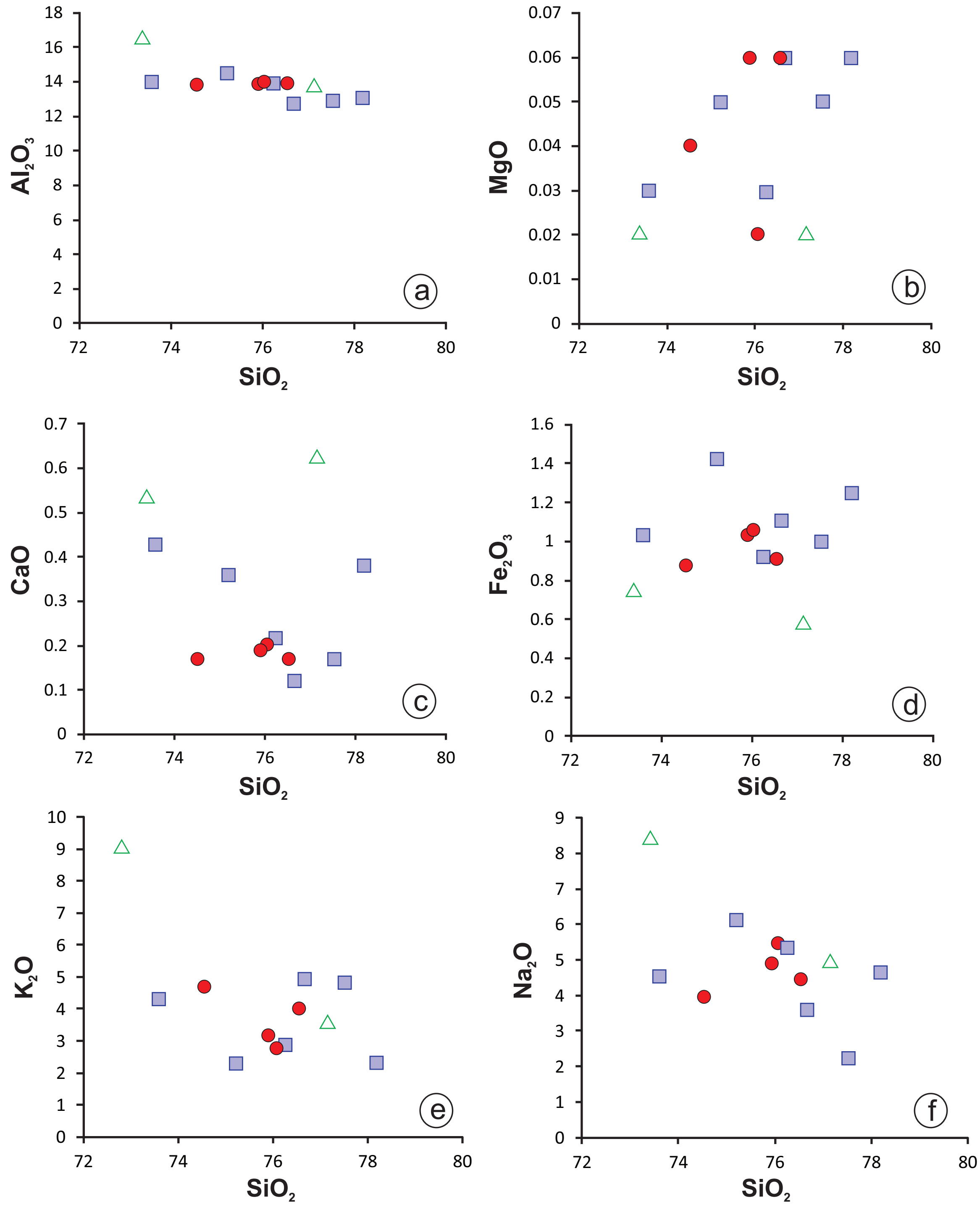

Figure 4: *Major element variations of Al, Mg, Ca, Fe, K and Na oxides (wt.%) with SiO_2 (wt.%) (a-f). The data represent compositions of the various pegmatite types at South Bay. Symbols as in previous figures.*

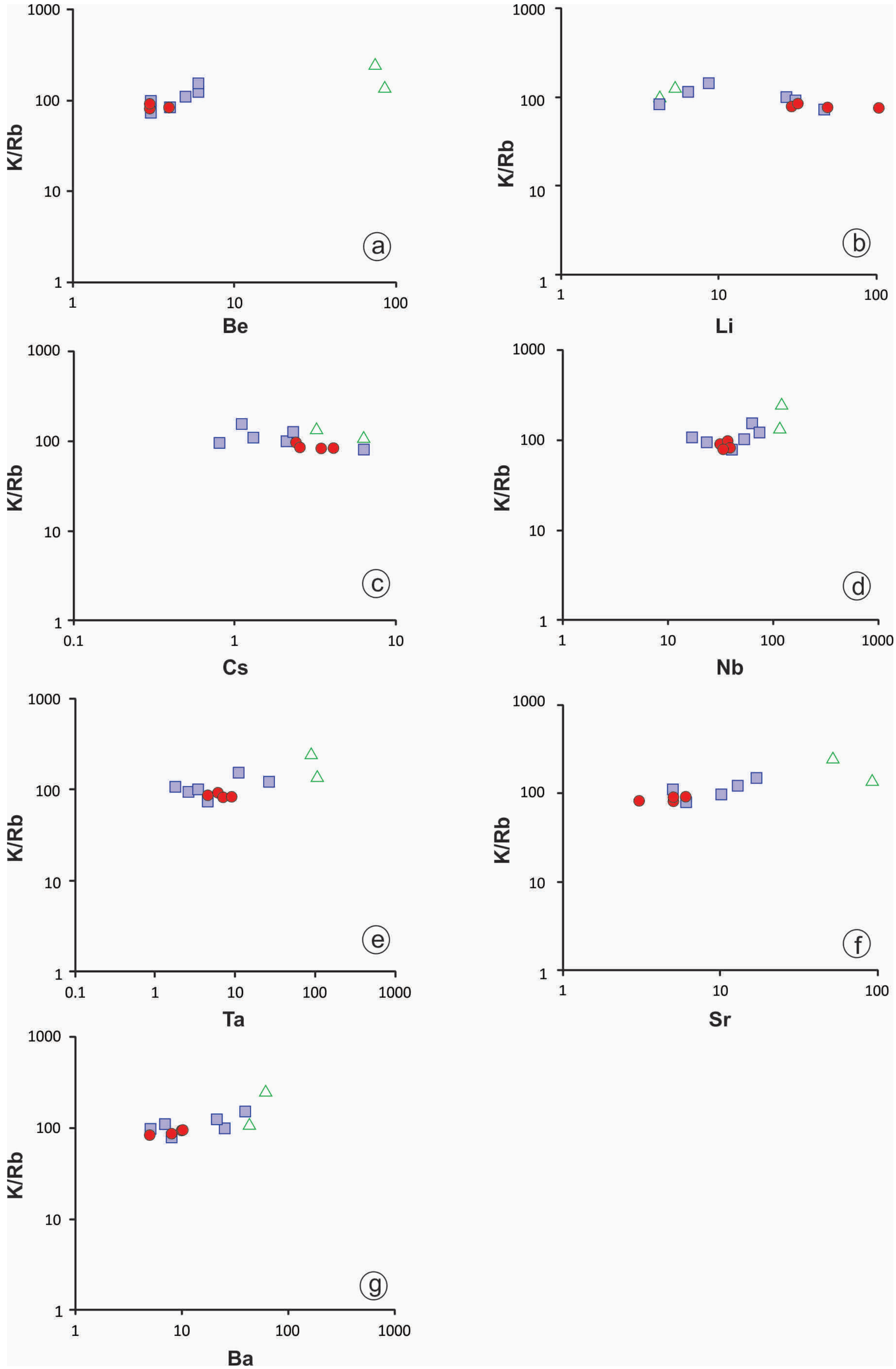

Figure 5: *Trace element contents vs. K/Rb ratio for the different pegmatite types at South Bay. Symbols as in Figure 3.*

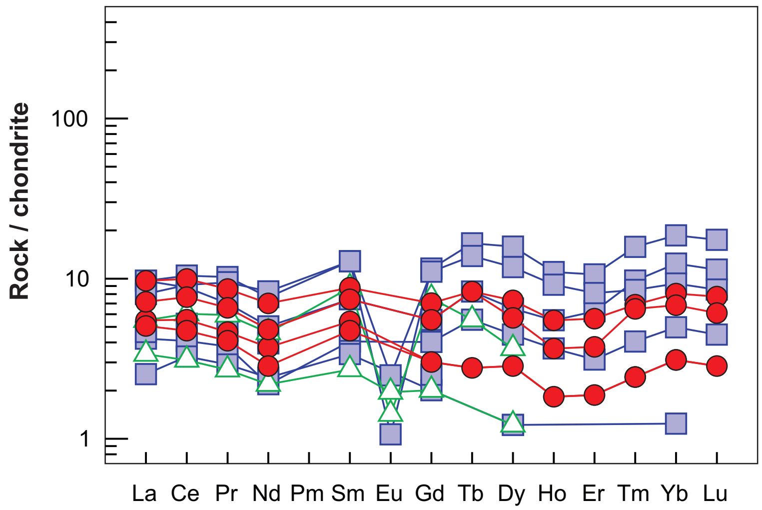

***Figure 6:** Chondrite-normalized REE diagram (average chondrite values after McDonough and Sun, 1995) for the different pegmatite types found at South Bay. Symbols as in previous figures.*

2000; van Lichtervelde et al., 2006; Martins et al., 2011), which can serve as an important guide for exploration.

Minerals of this group are the most common type of Nb-Ta oxides found in granitic pegmatites. The minerals are orthorhombic and include end-member columbite-(Fe) ($FeNb_2O_6$), columbite-(Mn) ($MnNb_2O_6$), and tantalite-(Mn) ($MnTa_2O_6$), respectively corresponding to compositions as follows: Ta/(Ta + Nb) and Mn/(Mn + Fe) < 0.5; Ta/(Ta + Nb) < 0.5 and Mn/(Mn + Fe) > 0.5; and Ta/(Ta + Nb) and Mn/(Mn + Fe) > 0.5. These minerals occur in a solid solution, with the general formula AnBmOx. The A site is usually occupied by Fe or Mn (less commonly Ca, Na, REE, Y, Th, U, Sb, Al and Cs). The B site is usually occupied by Ti, Nb, Ta and Sn. In CGM, the Mn:Fe ratio is reported to increase with fractionation within a pegmatite group or body. Likewise, the Ta:Nb ratio is expected to increase with fractionation.

The studied grains from the beryl-columbite pegmatite at South Bay range in size from 20 µm to 5 mm and are subhedral to euhedral. They are disseminated in the groundmass of both aplitic and pegmatitic layers. In backscattered electron imagery the grains do not exhibit complex zonation (Figure 7). Usually a darker Nb-enriched core is surrounded by a brighter rim of higher Ta composition.

Table 1 shows electron microprobe results. Other elements such as Bi, Sc, As, Sb, Y, U, Zr, F, and REE were sought but they were either below detection limit or not present in the analyzed CGM.

The sum of cations ranges from 3.00 to 3.02 apfu, very close to the ideal value of 3. Overall the CGM exhibit little change in their Fe and Mn content, with FeO ranging from 12.72 to 16.56 wt.% and MnO varying from 3.28 to 4.44 wt.%. Tantalum and Nb content present a wider variation with values of Ta_2O_5 varying from 10.78 to 56.49 wt.% and Nb_2O_5 from 68.95 to 26.84 wt.%.

The analyzed grains are mostly columbite-(Fe) and define a distinguishable trend toward tantalite-(Fe) [(Fe>Mn) $(Ta>Nb)_2O_6$] (Figure 8). This trend (Fe-rich trend) is typical of F-poor pegmatites (as is the case for

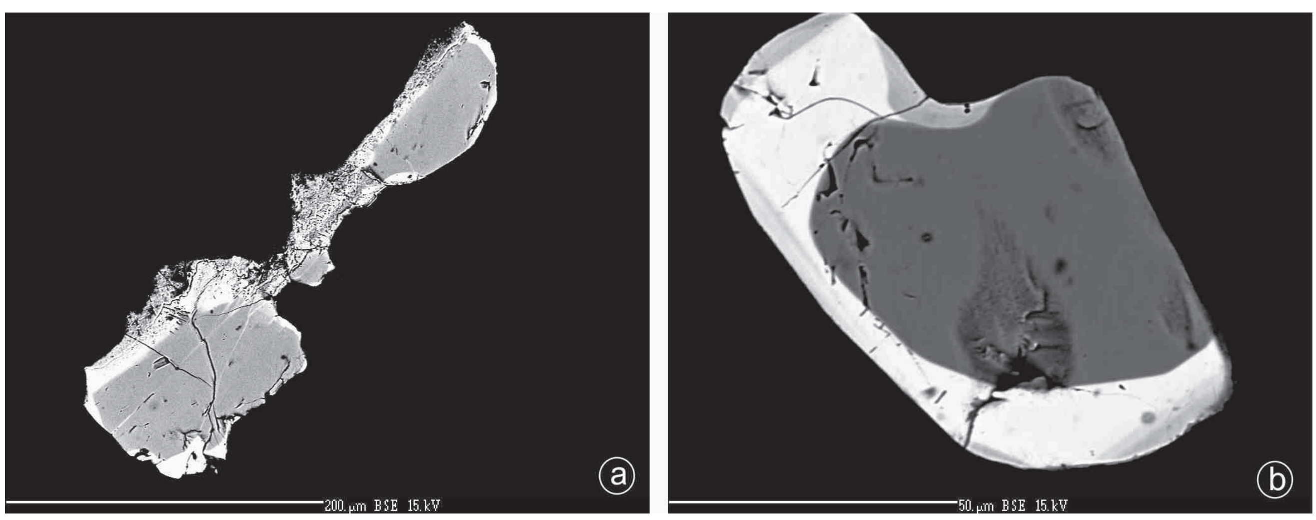

***Figure 7:** Back-scattered electron images of CGM grains from the studied beryl-columbite pegmatite: **a)** elongated grain with weak compositional zonation; **b)** CGM grain with distinct compositional zones.*

Table 1: Compositions of columbite-(Fe) and tantalite-(Fe) from beryl-columbite pegmatite at South Bay.

	Grain 1		Grain 2		Grain 3		Grain 4	Grain 6		Grain 7			Grain 8				Grain 9	
	1	2	1	2	1	2	1	1	2	1	2	3	1	2	3	4	1	2
Ta_2O_5 wt.%	11.50	29.78	14.59	34.28	14.70	12.32	32.12	11.35	48.71	10.78	56.49	36.64	13.31	19.88	31.55	35.98	15.43	30.24
Nb_2O_5	69.35	51.51	65.41	46.68	65.81	67.47	49.49	68.43	32.99	68.95	26.84	41.00	67.88	61.53	48.84	45.31	64.78	50.76
SnO_2	0.03	0.02	0.09	0.06	0.03	0.02	0.04	0.04	0.01	0.01	0.07	0.01	0.01	0.01	0.02	0.03	0.02	0.03
TiO_2	0.38	0.74	0.36	0.70	0.44	0.27	0.74	0.34	0.86	0.38	1.09	0.88	0.26	0.33	0.76	0.49	0.54	0.65
WO_3	0.21	0.58	0.36	0.03	0.26	0.20	0.25	0.01	0.12	0.01	0.00	1.13	0.43	0.38	0.04	0.02	0.14	0.16
MgO	0.46	0.43	0.49	0.50	0.47	0.03	0.43	0.40	0.43	0.42	0.42	0.46	0.33	0.47	0.41	0.22	0.48	0.49
CaO	0.01	0.01	0.02	0.02	0.02	0.13	0.02	0.01	0.00	0.00	0.01	0.04	0.00	0.01	0.01	0.02	0.02	0.09
MnO	4.23	3.76	4.16	3.66	4.22	3.89	3.48	4.14	3.49	4.26	3.28	3.63	4.44	4.15	3.85	3.90	4.42	3.95
FeO	15.64	14.63	15.37	13.91	15.41	16.56	14.66	15.84	12.93	15.68	12.72	13.80	15.58	15.13	14.33	14.40	15.09	13.98
Total	101.81	101.46	100.85	99.84	101.36	100.89	101.23	100.56	99.54	100.49	100.92	97.59	102.24	101.89	99.81	100.37	100.92	100.35
Ta *apfu*	0.180	0.505	0.234	0.603	0.234	0.196	0.552	0.180	0.922	0.170	1.091	0.672	0.209	0.322	0.549	0.637	0.247	0.519
Nb	1.803	1.453	1.741	1.366	1.742	1.784	1.413	1.802	1.038	1.812	0.862	1.249	1.774	1.657	1.414	1.334	1.727	1.449
Sn	0.001	0.000	0.002	0.002	0.001	0.000	0.001	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.001	0.001	0.000	0.001
Ti	0.016	0.035	0.016	0.034	0.019	0.012	0.035	0.015	0.045	0.017	0.058	0.045	0.011	0.015	0.037	0.024	0.024	0.031
W	0.003	0.009	0.005	0.001	0.004	0.003	0.004	0.000	0.002	0.000	0.000	0.020	0.006	0.006	0.001	0.000	0.002	0.003
ΣB	2.003	2.003	1.999	2.006	2.000	1.996	2.005	1.998	2.007	2.000	2.012	1.986	2.001	2.000	2.001	1.996	2.001	2.003
Mg	0.039	0.040	0.043	0.048	0.041	0.003	0.040	0.035	0.045	0.036	0.044	0.046	0.028	0.042	0.039	0.021	0.042	0.046
Ca	0.001	0.001	0.001	0.001	0.001	0.008	0.001	0.001	0.000	0.000	0.001	0.003	0.000	0.001	0.001	0.001	0.001	0.006
Mn	0.206	0.199	0.207	0.201	0.209	0.193	0.186	0.204	0.206	0.210	0.197	0.207	0.217	0.209	0.209	0.215	0.221	0.211
Fe	0.752	0.764	0.757	0.753	0.755	0.810	0.774	0.772	0.753	0.762	0.755	0.778	0.753	0.754	0.767	0.784	0.744	0.738
ΣA	0.998	1.003	1.009	1.003	1.006	1.014	1.003	1.011	1.003	1.009	0.998	1.034	0.999	1.005	1.016	1.022	1.008	1.002
Ta/(Ta+Nb)	0.091	0.258	0.118	0.306	0.118	0.099	0.281	0.091	0.470	0.086	0.559	0.350	0.106	0.163	0.280	0.323	0.125	0.264
Mn/(Mn+Fe)	0.215	0.207	0.215	0.210	0.217	0.192	0.194	0.209	0.215	0.216	0.207	0.210	0.224	0.217	0.214	0.215	0.229	0.222

Cation formula based on six atoms of oxygens per formula unit (apfu).

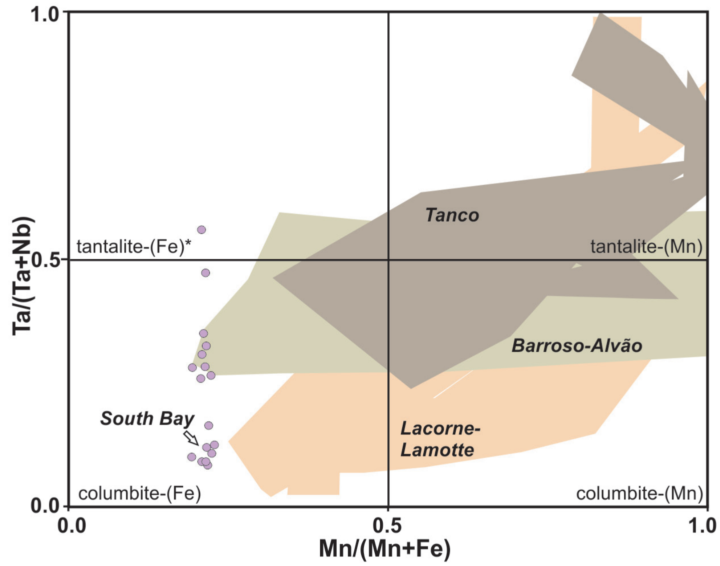

***Figure 8:** Compositions of CGM from beryl-columbite pegmatite at South Bay (purple circles) plotted in the columbite quadrilateral. Coloured fields represent CGM data from the Tanco pegmatite (from Černý, 2005), Barroso-Alvão pegmatite field (from Martins el al., 2011), and the Lacorne and Lamotte pegmatites (from Mulja et al., 1996).*

the South Bay pegmatites, with F values below detection limit, Martins, 2014a, b), whereas enrichment in Mn is typical of F-rich environments (Černý, 1992).

Petrographic observations, specifically the presence of discrete grains that are mostly euhedral and subhedral with terminations, suggest that crystallization of the CGM was synchronous with the primary silicate phases. Hence, the composition of columbite-tantalite, similar to any other magmatic mineral, was controlled by the abundances of Nb, Ta, Fe, and Mn in the evolving magma, the relative solubilities of the end-members, the nature of the coexisting minerals on the liquidus, and the corresponding mineral-liquid partition coefficients for the above elements. In the case of the studied grains, the constant ratio of Fe and Mn with increasing Ta over Nb (Figure 8) could be explained by fractional crystallization of the pegmatitic melt coupled with coeval crystallization of garnet and CGM. Garnet occurs in the groundmass or surrounds larger grains of albite or quartz (Martins and Kremer, 2013) and would incorporate Fe and Mn into its structure during crystallization. As mentioned above this type of behaviour is observed in F-poor systems (e.g., Černý, 1992; Novák et al., 2003).

This type of information helps to establish the degree of fractionation of an individual pegmatite body, and within a group of pegmatites (where comparisons between different pegmatites that contain CGM are possible). For the studied case, it is possible to conclude that the pegmatite is fractionated as demonstrated by the increase in Ta values (Figure 8). This is a common trend observed in other fractionated pegmatites (e.g., Novák et al., 2003; Martins et al., 2011). As observed in other Li-Cs-Ta (LCT) pegmatites (e.g., Tanco, Černý, 2005; Separation Lake, Tindle and Breaks, 2000) the more fractionated pegmatite bodies are, the higher the probability of associated rare element mineralization. Thus, establishing the degree of fractionation of a pegmatite body provides important information to properly design an exploration program in a given pegmatite field.

Mineralization and exploration potential

Martins and Kremer (2013) suggest that the more evolved pegmatites in the area (i.e., those with the highest economic potential) belong to the LCT petrogenetic family, rare element class, beryl-columbite subtype, as indicated above, but also suggest that there could be potential for other pegmatites with LCT mineralization in the area. Similar conclusions were reached by Mumin and Corriveau (2004; Assessment File 74323), based on localized enrichments of Be, Nb, Ta and Cs. Taking into account the ideal regional zoning of pegmatite bodies as a concentric aureole around a central parental pluton (Trueman and Černý, 1982; Černý, 1989), least-fractionated pegmatites should be proximal to the parental pluton whereas the most fractionated pegmatites should be distal. With increasing distance from the parental pluton, the following spatial distribution has been defined (Trueman and Černý, 1982; Černý, 1989): 1) barren; 2) beryl subtype; 3) beryl-columbite subtype; 4) beryl-columbite-phosphate subtype; 5) spodumene or petalite±amblygonite subtypes; 6) lepidolite subtype; 7) albite-spodumene type; 8) albite type. According to the same authors, magmas enriched in H_2O, F, B, P, Li, Rb, Cs and Be may travel further from the parental granite because of their lower viscosity. In the case of South Bay, only barren and beryl-columbite–subtype pegmatites have been identified. As the source for these pegmatites is currently unknown, it is impossible to speculate further on the potential distribution of other, more fractionated, pegmatites of the South Bay field.

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