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Exploration Techniques for Rare-Element Pegmatite in the Bird River Greenstone Belt, Southeastern Manitoba

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ABSTRACT

The exploration for rare-element pegmatite bodies requires a combined geological and geochemical approach. A variety of techniques are available. The exploration efforts of the Tantalum Mining Corporation of Canada in southeastern Manitoba has shown the value of using exploration geochemistry. A combination of rock lithogeo-chemistry and selective leach soil geochemistry has been successfully tested and used to find buried rare-element pegmatites.

INTRODUCTION

The Tantalum Mining Corporation of Canada Limited(Tanco) is a private company wholly owned by Cabot Corporation of Boston, Massachusetts and operated by the Cabot Supermetals division. Tanco has been mining the highly fractionated, rare-element Tanco pegmatite at Bernic Lake, Manitoba since 1969, and produces tantalum, pollucite and spodumene mineral concentrates. Currently, Tanco is North America.s only producer of these products. Reserves at the end of 1992 stood at 1.09 million tonnes grading 0.12% Ta_2O_5, 3.5 million tonnes at 2.71% Li_2O (Giancola, 2002). Pre-production pollucite reserves were 350,000 tons grading 23.3% Cs_2O. (Crouse et al., 1979).

Tanco has actively explored the Bernic Lake area for commercially viable, rare-element pegmatites since the commencement of production. Large areas of ground have been mapped, sampled and prospected over the years. Very few surface pegmatites of sufficient volume and tenor to warrant exploitation have been discovered. Tanco.s search for buried pegmatites in the Bernic Lake area has resulted in the discovery of numerous pegmatites. Several pegmatite bodies are presently proceeding into an advance exploration stage. The following paper will outline the exploration methodology and techniques employed by Tanco.

Geology and Exploration of the Bernic Lake Area

The Bernic Lake area is located in southeastern Manitoba approximately 175 kilometres northeast of Winnipeg (Figure 1). Geologically, the area is situated within the Archean Bird River subprovince of the western Superior Province (Černý et al. 1981, Card and Ciesielski, 1986 and Figure 2) that is underlain by the metavolcanic-metasedimentary Bernic Lake Formation (Trueman, 1980). The Bernic Lake pegmatite group consists of a number of subhorizontal, lithium-cesium-tantalum (LCT)-family pegmatites of which the two largest known members are the Tanco and Dibs pegmatites (Figure 3). Both of these pegmatites are hosted by late-stage, subvolcanic, metagabbro intrusions.

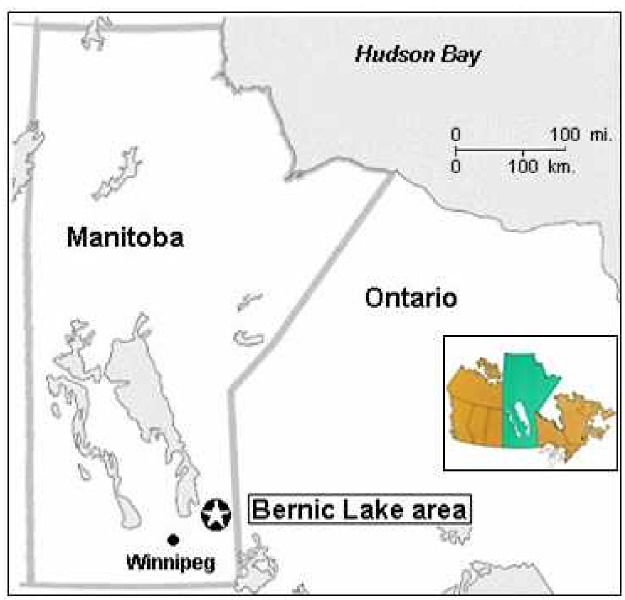

Figure 1: Location of the Bernic Lake area.

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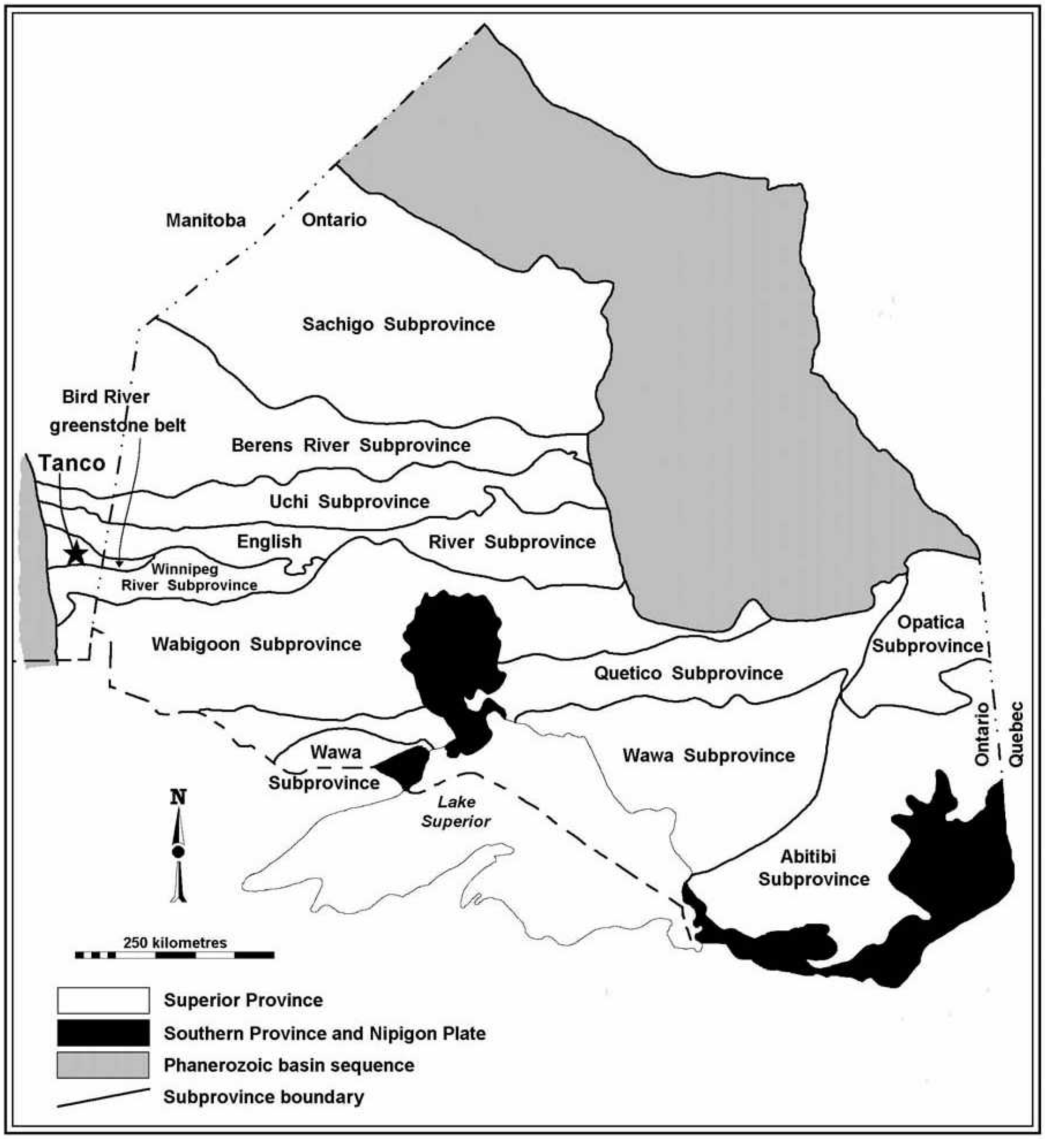

Figure 2: Location of the Bird River Greenstone Belt within the Superior Province (modified from Card and Ciesielski, 1986).

The nature of granitic pegmatites limits the number of applicable exploration tools that can be utilized. To date, no definitive tool has been identified. Initial exploration methodology involved geological mapping, prospecting and sampling of exposed pegmatites followed by drill testing selected targets. In the mid- 1970.s, lithogeochemistry became Tanco.s main exploration tool (Trueman, 1978). In the late 1990's, soil geochemical exploration techniques were assessed (Galeschuk and Vanstone, 2004). The selective extraction Enzyme Leach^{SM} was utilized in orientation surveys over the east end of the Tanco pegmatite and over the Dibs pegmatite, a buried, zoned LCT-family-complex-type, petalite-subtype discovered by Tanco in 1997. As a result of the Tanco and Dibs pegmatites orientation surveys the Enzyme Leach^{SM} technique has gradually replaced lithogeochemistry as Tanco.s main exploration tool. Today, the main exploration tools employed by Tanco include geological mapping and selective extraction soil geochemistry, in conjunction with increasing focus on the identification of structural environments conducive to pegmatite emplacement. Recent work by Tanco in lithogeochemistry has revived interest in this tool and it is felt that a combination of soil and rock geochemistry with augmentation from geological mapping and prospecting is the best exploration strategy.

Challenges to Rare-element Pegmatite Exploration

Exploring buried rare-element pegmatites, that is, pegmatites either hidden by overburden or situated at depth, presents a challenge to the geologist. Rareelement pegmatites are best described as geophysical non-responders (Trueman and Černý, 1982) in that they are non-magnetic, contain insufficient metallic

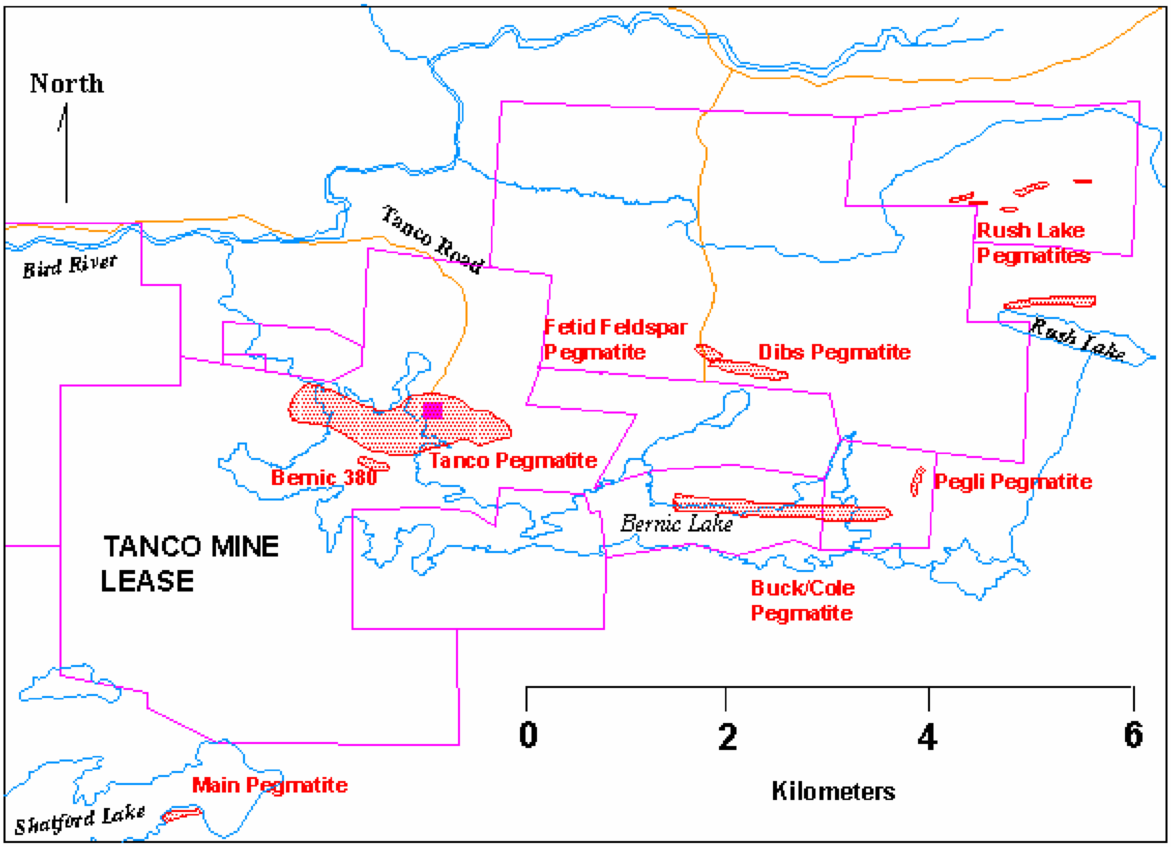

Figure 3: Major pegmatites in the Bernic Lake area.

minerals to be conductive and may not have a sufficient density/mass to allow for differentiation from the host rock utilizing gravity methods. Previous airborne radiometric surveys were unsuccessful in detecting the Tanco and the other pegmatite showings. Mantling of outcrop by exotic glacial sediment hampered traditional geochemical prospecting and exploration based on total extraction soil geochemistry.

Geology and classifications of Pegmatites

Rare element pegmatites are examined and exploited around the world in numerous countries and geological ages. Some of the countries include Canada, Brazil, Mozambique, Namibia, India and Australia. The pegmatites associated with Archean age granite terrains tend to be the most economic. The literature on the subject of pegmatites is vast from an academic point of view and the reader is directed to some of the classic papers from Beus, Jahns, Foord, Černý, Trueman, and London.
The general geological characteristic: of rare element pegmatitesinclude:

- Dyke-like geometries
- Propagation in horizontal and vertical directions
- Association with deep-seated structures and fractures
- Granitic mineralogy of feldspar, quartz, mica and tourmaline
- Fractionation away from the intrusive source (pegmatite granite, granite, etc) and the most distant pegmatites from the source contain economic concentrations of the less common minerals such as tantalum and cesium
- Geochemical alteration of the surrounding host rock, especially with lithophile elements from metasomatic fluids
- Mineralogical alteration by the addition of apatite, tourmaline, carbonate and micas (biotite)
- Varied economic deposits of lithium minerals (petalite, spodumene, etc.), tantalum, pollucite (cesium mineral), beryllium, quartz, feldspar and mica. As well as other minerals as markets demand, including gemstones.
- Shape, size, attitude and degree of fractionation of rare element pegmatites may vary according to depth of emplacement (Brisbin, 1986), host rock competency and existing metamorphic grade.

Černý and Ercit (2005) have devised a classificationscheme for granitic pegmatites that has become an industry standard. The first classification (Table 1) is a five-class system with rare-element pegmatites being one of the classes. Further

Table 1: The Five Classes of Granitic Pegmatites (modified from Černý and Ercit, 2005).

Class	Typical Minor Elements	Metamorphioc host rocks	Relationship to granites	Structural features
Abyssal	U, Th, Zr, Nb, Ti, Y, REE, Mo, rarely Be, poor (to moderate) mineralization	(Upper amphibolite to) low to high P granulite facies; ~400-900 MPa, ~700°-800°C	none(?) (segregations of anatectic leucosome?)	Conformable to mobilized crosscutting veins
Muscovite	Mineralization absent; micas and ceramic minerals	High-P, Barrovian amphibolite facies (kyanite-sillimanite) ~500-800 MPa, ~650°-580°C	None (anatectic bodies) to marginal and exterior	Quasiconformable to crosscutting
Muscovite-rare element	Li, Be Y, REE, Ti, U Th, Nb>Ta, rarely Li, Be; poor mineralization	Moderate to high P (T) amphibolite facies; ~300-700 Mpa, ~650°-520°C	Interior to exterior; poorly defined	Quasiconformable to crosscutting
Rare-element	Li, Rb, Cs, Be, Ga, Sn, Hf, Nb-Ta, B, P, F, or Be, T, REE, U, Th, Nb>Ta, F; poor to abundant mineralization; gemstock; industrial minerals	Low P, Abukuma amphibolite (to upper greenschist) facies (andalusite-sillimanite); ~200-400 Mpa, ~650°-500°C	(Interior to marginal to) exterior	Quasiconformable to crosscutting
Miarolitic	Li, Be, B, F, Ta>Nb, or Be, Y, REE, Ti, U, Th, Zr, Nb>Ta, F; poor mineralization; gemstock	Shallow to subvolcanic; ~100-200 MPa	Interior to marginal	Interior pods and crosscutting dikes

Table 2: Classification of Granitic Pegmatites of the Rare-element Class (modified from Černý and Ercit, 2005) Underlined = elements with economic potential

Pegmatite type (feldspar + mica content)	Pegmatite subtype	Geochemical signature	Typical minerals
Rare earth (KF>plg to ab; bi>ms)	Allanite-monazite	(L)REE, U, Th, (P, Be Nb>Ta)	allanite, monazite
Beryl (KF>ab; ms>bi)	Beryl-columbite	Be, Nb-Ta, (±Sn, B)	beryl, columbite-tantalite
Complex (KF- ab; ms-le)	Spodumene	Li, Rb, Cs, Be, Ta-Nb (Sn, P, F, ±B)	spodumene, beryl, tantalite, (amblygonite), (lepidolite) (pollucite)
	Petalite	Li, Rb, Cs, Be, Ta>Nb (Sn, Ga, P, F, ±B)	petalite, beryl, tantalite, (amblygonite), (lepidolite)
	Lepidolite	F, Li, Rb, Cs, Be, Ta>Nb (Sn, P, F, ±B)	lepidolite, topaz, beryl, microlite, (pollucite)
	Elbaite	Li, B, Rb, Sn, F, (Ta, Be, Cs)	elbaite, microlite, (beryl, tantalite, hambergite)
	Amblygonite	P, F, Li, Rb, Cs, Be, Ta>Nb (Sn, ±B)	amblygonite, beryl, tantalite, (lepidolite), (pollucite)
Albite-Spodumene (ab>Kf; [ms, lep])		Li (Sn, Be, Ta-Nb, ±B)	spodumene, (cassiterite), (beryl), (tantalite)
Albite (ab>>Kf; [ms, lep])		Ta,-Nb, Be (Li, ±Sn, B)	tantalite, beryl, (cassiterite)

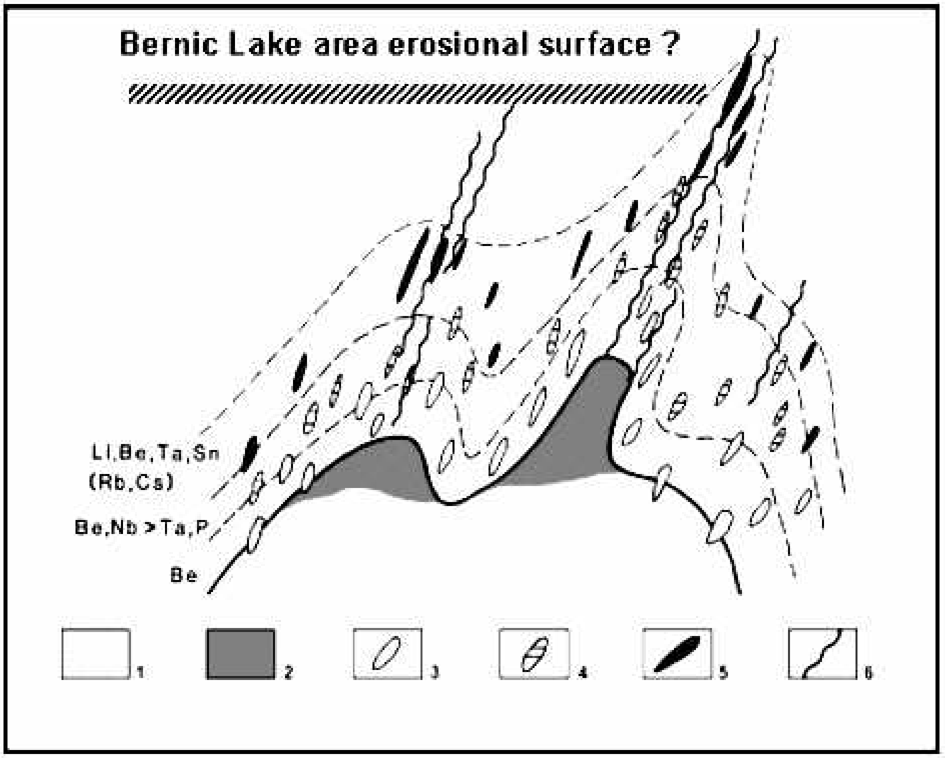

Figure 4: Schematic section of a zoned fertile granite-pegmatite system. 1) fertile granite; 2) pegmatite granite; 3) barren to beryl bearing pegmatites; 4) beryl-type, columbite- to phosphate bearing pegmatites; 5) complex spodumene (or petalite) bearing pegmatites with Sn, Ta, ± Cs; 6) faults (modified from Černý, 1989b).

classification by Černý into type and subtype (Table 2) . This break down is morphological and mineralogical. The primary target in the Tanco exploration program, using this classification scheme, is the rare-element class, petalite or spodumene subtype (previously referred to as the LCT family, complex type, petalite or sodumene subtype of granitic pegmatite). The vast literature on pegmatites precludes further coverage in this paper. Briefly pegmatite emplacement and interaction in the Bernic Lake area will be examined.

Figure 4 illustrates pegmatite emplacement in concentric zones or shells about the source pegmatitic granite. The poorly evolved, simple beryl bearing pegmatites occur closest to the source and the complex, lithium-tantalum bearing pegmatites furthest from the source (Trueman and Černý, 1982 and Černý, 1989b). The shape of this zonation is dependent upon the structural conduits and traps available to the migrating pegmatitic melt (Černý, 1989b) and may be modified by post-emplacement structural deformation.

Although neither the parental granite nor pegmatitic granite from which the Bernic Lake pegmatites were generated has yet to be found, it has been suggested by Černý et al. (1981) to exist at depth, in the vicinity of the mid-point of the north shore of Bernic Lake. This work has been based on the fractionation measurements of cesium, lithium and rubidium in feldspars and micas of the pegmatite bodies in relationship to the estimated source. The suggested Bernic Lake erosional level illustrated in Figure 4 is based on the depth of the more highly evolved pegmatites of the Bernic Lake group and their degree of fractionation as determined from pegmatite mineralogy and from potassium feldspar analyses (Černý et al., 1981).

The Tanco pegmatite occurs at a depth of 25 to 120 metres with only a small portion of the pegmatite subcropping at the bottom of Bernic Lake approximately 25 metres below the surface of the lake. The Dibs, and Bernic 380 pegmatites are situated at vertical depths of 80 and 115 metres, respectively. These buried targets require exploration techniques to detect prospective pegmatites at depth.

Exploration for Rare-Element Pegmatites

The lack of exposed significant pegmatites in the Bernic Lake area has directed Tanco's exploration programs towards the search for buried pegmatites. Accordingly, exploration methodologies have been assessed that address this exploration scenario.

The primary target for Tanco.s exploration program is a buried, granitic pegmatite of the rare-element class, petalite or spodumene subtype LCT family, complextype, petalite-or spodumene-subtype pegmatite (Černý, 1991) hosting an economic tantalum resource. According to Černý (1989a), this class of pegmatite offers the best potential for a large tantalum resource with respect to both total pounds contained tantalite (Ta_2O_5) with a good tantalum to niobium ratio (Ta/Nb>1). Tanco also considers lithium and cesium as exploitable elements.

Exploration lithogeochemistry was first used by Tanco in the 1970.s. This was directed from the work of Beus et al. (1968) who was commissioned by Tanco to develop an exploration tool. Tanco has continued to test and adapt different tools and techniques to identify those best suited to its exploration environment. The objective has always been to find a cost-effective method that permits good aerial coverage and reliability while making use of suitable and abundant sample media. Rock, soil and vegetation geochemical methods have been tested over known pegmatites.

The commercial development of the selective and partial extractions in the 1990.s, provided multielement analyses with low detection limits at an acceptable cost. Testing of the Enzyme Leach[SM] over both the Tanco and Dibs pegmatites showed the method to be an effective tool to the degree that today, this method has replaced lithogeochemistry as Tanco.s primary survey tool. More recent ventures into geochemical research have suggested that the best geochemical exploration approach is one that combines several methods such as rock and soil geochemistry.

Theory of Lithogeochemistry in Pegmatite Exploration

The emplacement of rare-element pegmatites is accompanied by both the alteration of the adjacent host-rock and the development of an alkali-enriched, exomorphic aureole within the surrounding host rock (Galeschuk and Vanstone, 2004). Utilizing primary exomorphic aureoles as a pegmatite exploration tool requires that the elements making up the aureole originate from the source pegmatitic melt, are mobile and form thick aureoles. This generally means that they are independent of the host rock type. Detection of these aureoles can be accomplished by systematically sampling unweathered host-rock.

The best elements to test the aureole thickness and intensity are Li, Cs, B, Sn, Be and Rb with the latter element forms smaller, less intense aureoles (Beus et al., 1968). Ovchinnikov (1976) determined that the thickest and most contrasting aureoles were formed by the rare-alkali elements. In a study of the aureoles of three pegmatites hosted by quartz-mica-schist in the Black Hills, South Dakota, USA, Shearer et al. (1986) also determined that the rare alkalis were the most mobile of the elements with the relative motilities being Li>Rb>Cs.

The thickness of the pegmatite aureole can be variable and is affected by the structure and composition of the wall rock, as well as both the composition and attitude of the pegmatite. Beus et al. (1968) found that the aureole generated by a subhorizontal pegmatite crosscutting sandy schisthosted, was up to four times thicker for a tantalumbearing pegmatite source than for the simpler, berylcolumbite- subtype pegmatite. The same study also determined that the aureoles were thicker within a sedimentary host than within a granitic host. The work indicated that the lithium aureole within sandy shale and from a sub-horizontal pegmatite could be detected up to 300 metres above the hangingwall contact. The cesium aureole only extended out 150 metres whereas the rubidium aureole was limited to 40 metres.

There is a lack of agreement on the relative mobilities of the rare alkalis. The results of Beus et al. (1968) suggested a relative mobility of Li>Cs>Rb, whereas Shearer et al. (1986) determined the relative mobilities in the Black Hills, S.D. as being Li>Rb>Cs. Testing of the Tanco aureole by Trueman (1978) indicated that Li formed a strong anomaly and that Rb was more erratic. Cesium was not detected in this study, but this was probably due more to the 10 parts per million (ppm.) detection limit used at the time, than an actual absence of cesium. This work indicated a relative mobility of Li>Rb>Cs. A later study of the Tanco aureole by Meintzer et al. (1989) found that Li and Rb were the preferable elements due to their more extensive mobility away from the source pegmatite. Cesium, however, was not included in this study. A 2000 review of the surface expression of the Tanco aureole carried out by Tanco personnel (unpublished data) showed that the lithogeochemistry of the host rock over Tanco was anomalous to highly anomalous in lithium with some of the samples being anomalous to highly anomalous in combined Li, Rb and Cs.

The testing carried out over the Tanco pegmatite by Trueman (1978) showed that the size and intensity of the aureole was well expressed by lithium; less intense and erratically by rubidium and cesium was barely expressed. The testing carried out by Tanco in 2000 detected lithium, rubidium and cesium at a vertical depth ranging from 100 to 120 metres. Drill testing of lithogeochemical anomalies in the Bernic Lake area by Tanco has indicated that Li, Rb and Cs can be detected in metagabbro host rocks at least 80 metres above a petalite-bearing pegmatite (Vanstone, 2000a, 2000b). Based on the studies of the aureole over the Tanco pegmatite, the thickness of the aureole appears to be in the 100 to 120 metre range with lithium the most mobile and cesium the least mobile.

Tanco.s Lithogeochemical Program

The use of lithogeochemistry as a detection method for buried pegmatites was first tried by Tanco, at Bernic Lake in 1976, on the advice and guidance of A.A. Beus, with the initial survey work focused on characterizing the Tanco pegmatite aureole (Trueman, 1978). This orientation survey was followed by a regional lithogeochemical survey from 1977 to 1982 during which the sampling was mainly confined to the Bernic Lake formation, the host of the Bernic Lake pegmatite group.
Lithogeochemical sample programs are planned and based on sample distribution. Sample spacing is determined by considering the size of the expected pegmatite body. Any pegmatite not detected by the survey would be of insufficient volume to justify exploitation. To ensure a higher degree of data reliability, only fresh rock is sampled, even though test sampling of glaciated surfaces has indicated minor weathering has little affect on the analytical results (Trueman 1978). Tanco has commonly used a 25-metre sample interval along lines 100 metres apart. For larger projects where cost was a factor, sample spacing has been increased to 50 or 100-metres with a staggered sample pattern, used from line to line.

Down-hole lithogeochemistry has become common practice in diamond drilling programs, especially when no pegmatites are

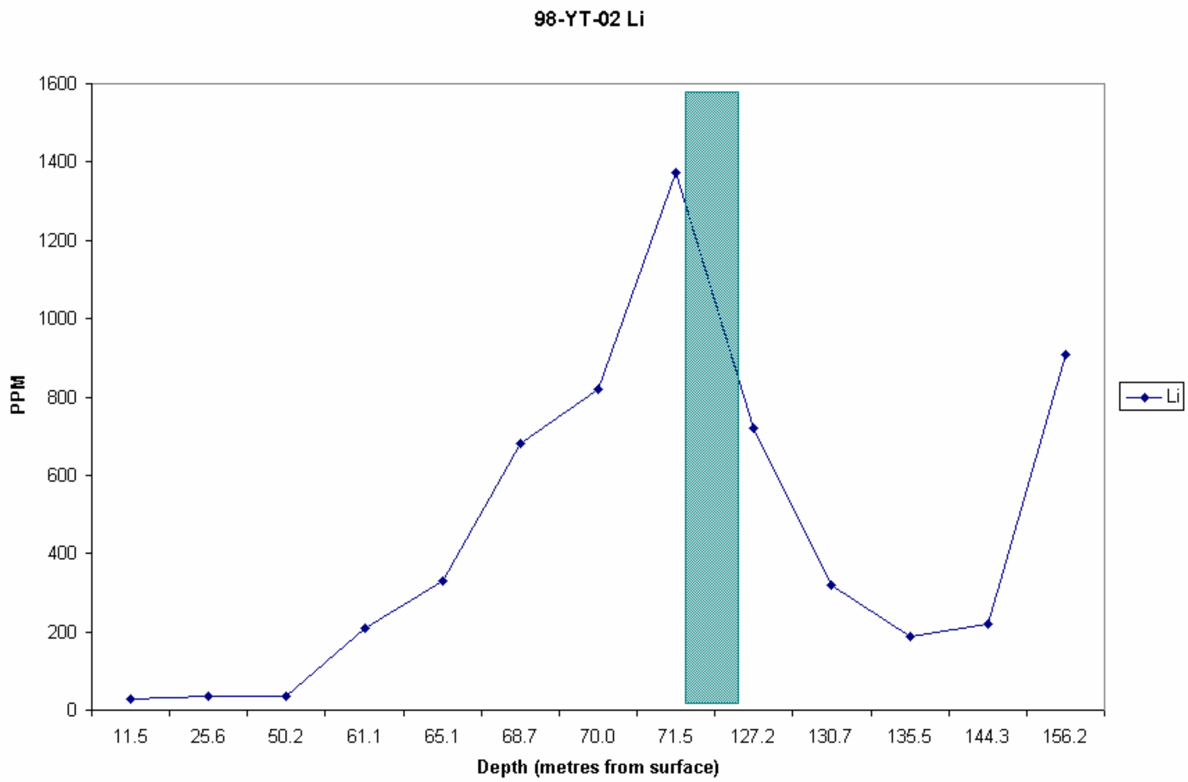

Figure 5: Downhole lithium geochemical profile – DDH 98-YT-02.

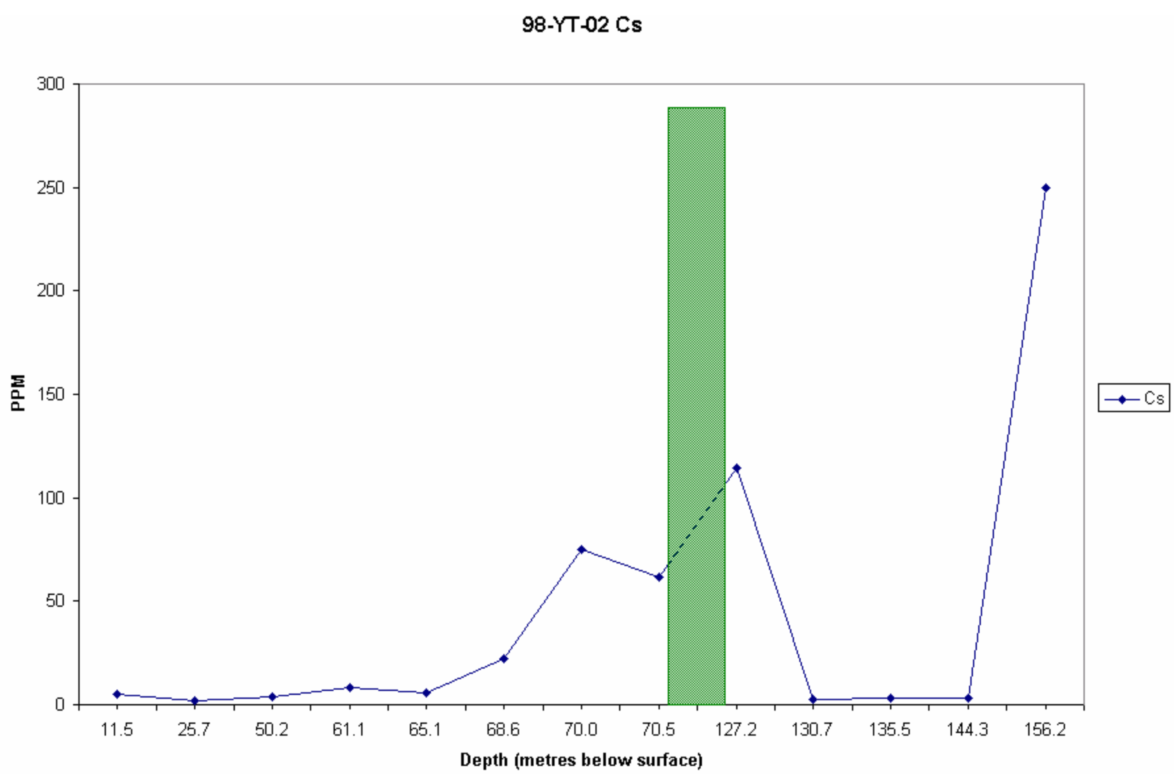

Figure 6: Downhole cesium geochemical profile – DDH 98-YT-02.

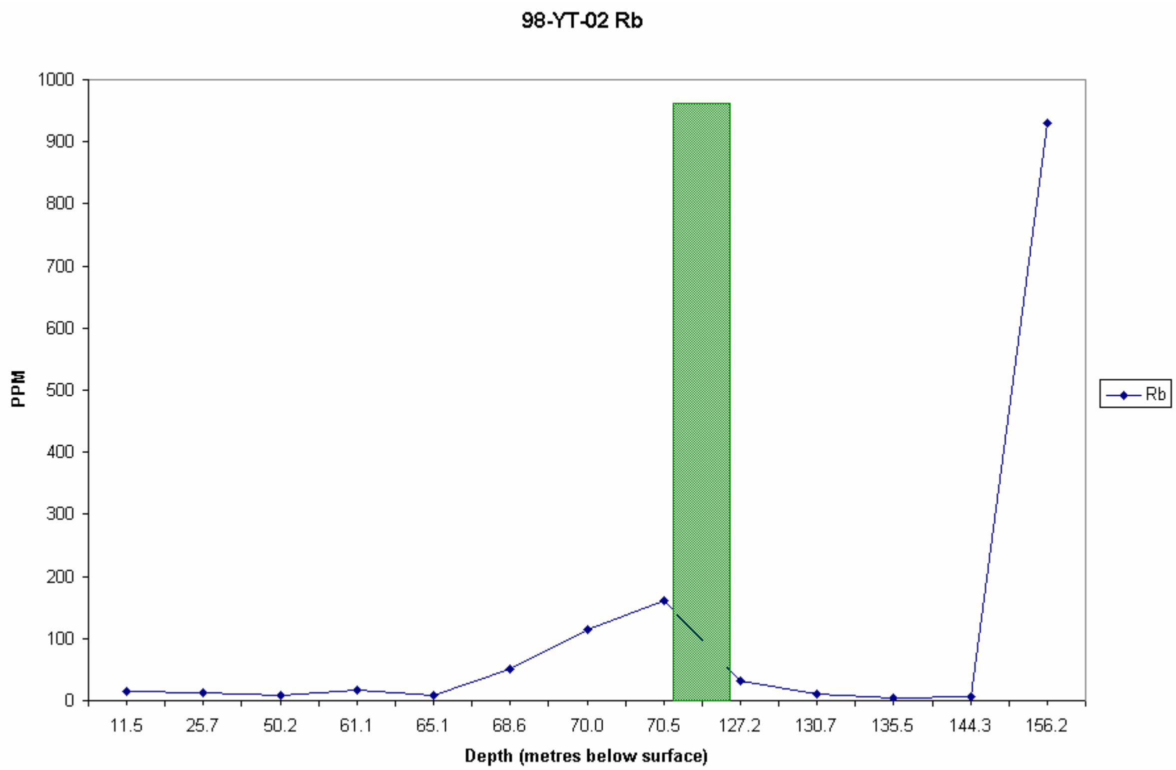

Figure 7: Downhole rubidium geochemical profile – DDH 98-YT-02.

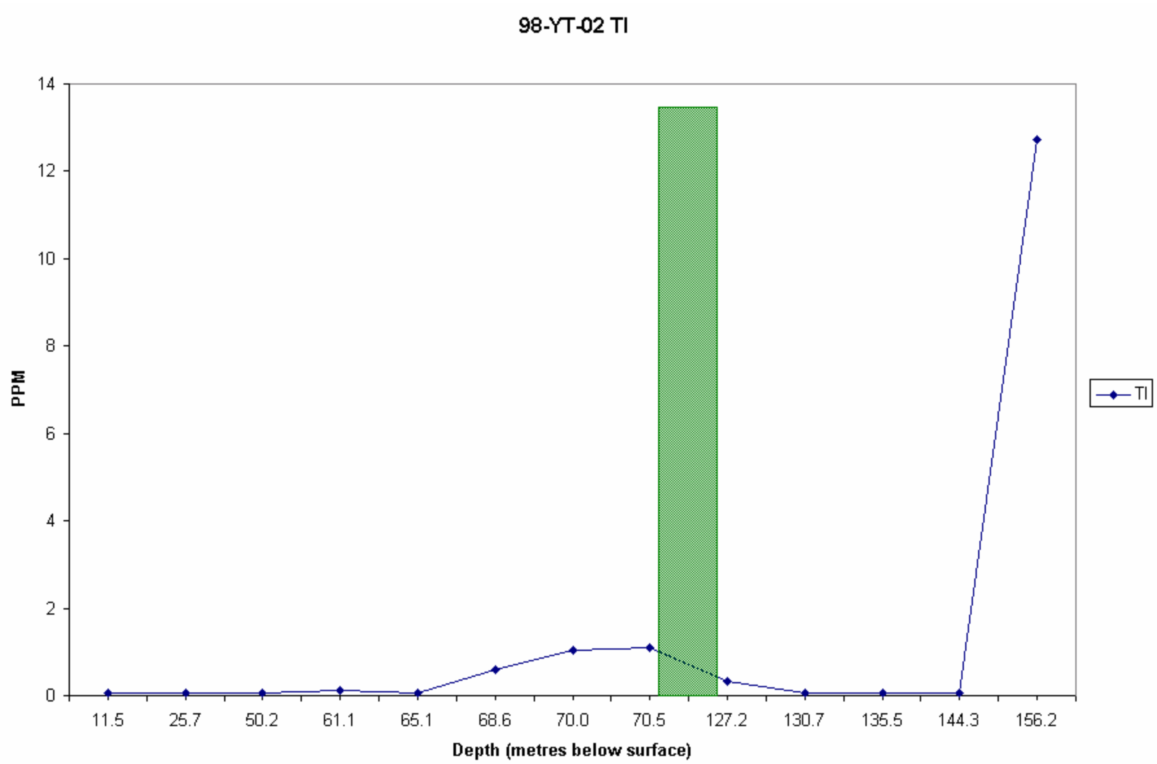

Figure 8: Downhole thallium geochemical profile – DDH 98-YT-02.

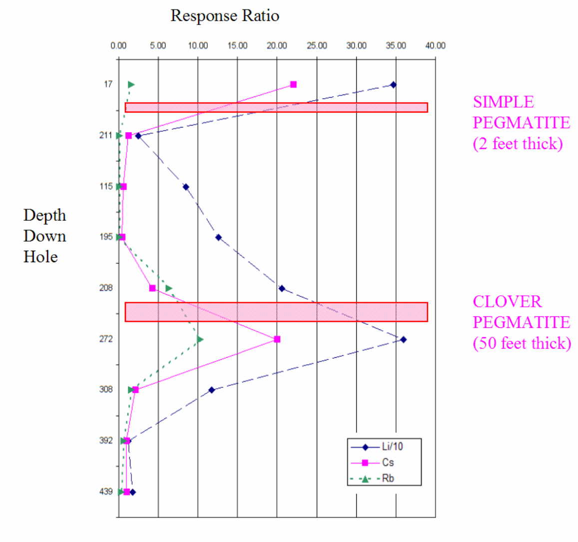

Figure 9: Downhole lithogeochemistry (Li, Cs, Rb) – 06-CL-03.

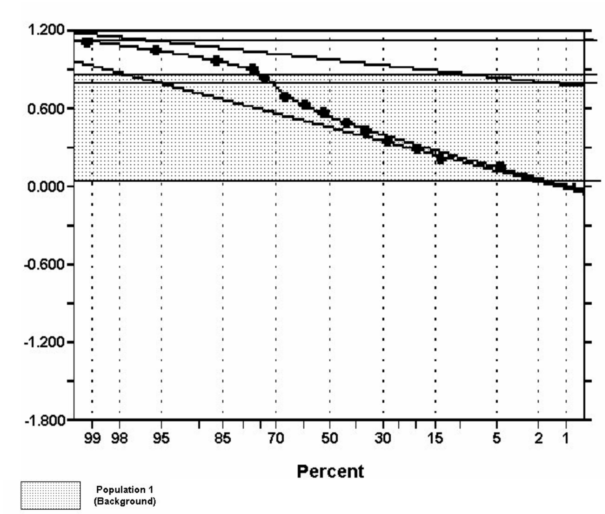

Figure 10: Cesium probability plot of the Bernic Lake Formation metagabbro intrusion.

encountered. The following Figures (5 to 8) profile the elements lithium, cesium, rubidium, and thallium to across a pegmatite. This case study was conducted as part of research on the mobility of elements in relationship to pegmatites (Galeschuk, unpublished). Figures 5 . 8 represent one diamond drill hole that intersected a pegmatite at depth. The bar in each of the graphs represents the pegmatite. Depth is on the x-axis. One can note the increase and decrease of the elements in relationship to the pegmatite. Element concentration varies spatially relative to pegmatite profiles.

A common practice has been to divide the assays against the background values (Figure 9) for each rock type. This provides a response ratio that allows the comparison of other geochemical surveys.

Treatment of Lithogeochemical Data

Proper statistical handling of data is paramount in the interpretation of results. Tanco has generated a regional database for the Bernic Lake area based on over 5,000 regional lithogeochemical survey samples. This data was statistically analyzed using probability plots (Sinclair 1974, 1976, 1991).

The data were first categorized according to the rock type allowing for each rock type (data set) to be analyzed separately. Each data-set was processed using the Probplot program (Stanley, 1987) to produce probability graphs for each data set. The plots allowed the determination of the upper and lower limits for each population within the set (Figure 10). These limits were then used to define the background, possibly anomalous, anomalous and highly anomalous fields for each data set. The possibly anomalous field occurs when the partitioning of the probability graph results in the upper limit of the background field being greater than the lower limit of the anomalous field. The field created by this overlap has the upper background limit defining the upper limit of the field and the lower anomalous limit defining the lower limit of the field. As seen in Figure 5, this field can be very narrow.

Using an algorithm incorporating the relative strength as determined from the probability plots and the relative mobilities of the elements Li, Rb and Cs, each sample within a data set was assigned a code ranging from A1 to C3 (Figure 11). The appropriate symbol for each classified sample was then plotted on a map and the resultant clusters of anomalous samples identified and prioritized. An anomaly displaying elevated levels of all three elements was deemed to have a higher priority than a cluster of samples displaying only elevated lithium.

This methodology was used in the discovery the Dibs Pegmatite in 1996 and 1997. In 1996, while drill testing a portion of lithogeochemical Anomaly "G" (Figure 12), 15 metres of a poorly zoned pegmatite was intersected at a vertical depth of approximately 45 metres (Vanstone, 1997).

In 1997, diamond drill testing of untested lithogeochemical anomalies was carried out in the vicinity of the 1996 discovery. While testing Anomaly "H" (Figure 12), a 34-metre intersection of a wellzoned pegmatite was encountered at a vertical depth of

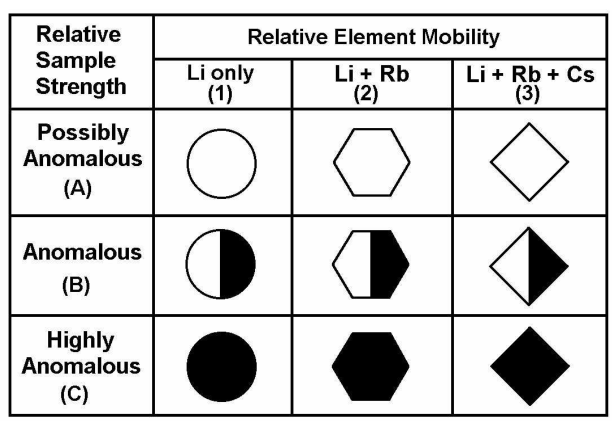

Figure 11: Lithogeochemical sample classification symbols.

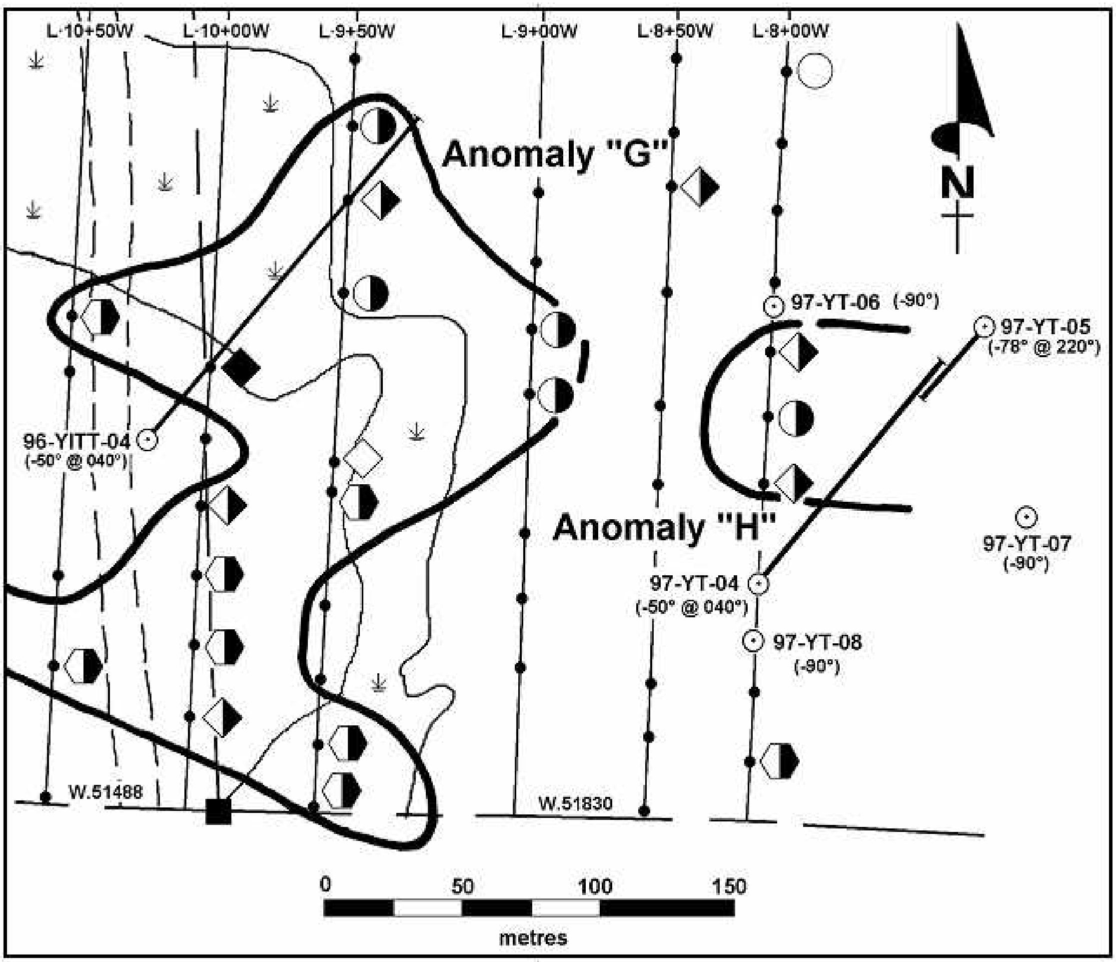

Figure 12: Lithogeochemical anomaly with Dibs pegmatite discovery holes.

approximately 80 metres (Vanstone, 2000a). Follow-up drilling in 1997 and 1998 outlined a cluster of three and probably four, westerly trending, vertically en-echelon pegmatites. The pegmatite shown in Figure 8 is the largest and most easterly known member of this group. Its thickest intersection was 63.4 metres (true thickness) and included 29 metres of a petalite-K-feldspar pegmatite (Vanstone, 2000b).

Lithogeochemical False Anomalies

During exploration programs designed to locate buried pegmatite deposits, false- anomalies were identified. Tanco.s use of lithogeochemical surveys as a primary exploration tool in the search for buried rare-element pegmatites has resulted in the documentation of a number of lithogeochemical anomalies that remain unexplained after drill testing. One such anomaly drilled in 2001 on exploration ground northeast of the Tanco mine site, was subsequently surveyed using the Enzyme Leach^{SM} extraction on soil samples. The soil survey results displayed no evidence of an anomaly.

Possible explanations for the occurrence of these false anomalies are discussed below:

1. It has been suggested that the anomaly represented a relict footwall aureole from a pegmatite that has since been eroded away. With the high level of erosion in the area as indicated by the presence of buried, highly evolved pegmatites, this suggestion does not account for all false anomalies encountered to date.
2. The thickness of the metasomatic aureole over a pegmatite has been under-estimated and hence the drill holes did not penetrate deep enough to intersect the source. Such a scenario has been discounted as the test work in the Bernic Lake area has shown the maximum extent of the metasomatic aureole above a pegmatitic source to be approximately 120 metres, whereas the drill holes have generally gone to a depth of 150 to 175+ metres. Additionally, when drill testing an Enzyme Leach^{SM} anomaly in the Separation Lake area, Ontario, pegmatites were intersected starting at a vertical depth of approximately 160 metres (Galeschuk, 2001). A subsequent re-evaluation of the data for this area showed no corresponding lithogeochemical anomaly.
3. The anomalous values are generated by alkalienriched metasomatic fluid migrating along the fractures and

sub-horizontal joint sets resulting in limited metasomatic aureoles along these fluid pathways. During glaciation, these same joints and fractures would have influenced the plucking of blocks of country rock thus leaving the fracture aureole exposed. Analysis of samples taken from these surfaces would indicate elevated rare-alkali elements and result in the identification of an anomaly. Research (Galeschuk, unpublished) has shown that even though there are elevated lithophile elements in fracture minerals, there are greater values associated in the host rock minerals associated with pegmatites.

Soil Geochemistry Using Enzyme Leach^SM

Although the Dibs Pegmatite is not currently considered to be economically viable, it has become a research site for testing rare-element pegmatite exploration techniques. From the research and testing work, the Dibs pegmatite is once again being examined for its economic potential. The main focus of this testing has been soil geochemistry, specifically, the Enzyme Leach^SM technique. Over the past several years, soil geochemistry has become the principal exploration tool employed by Tanco. The Enzyme Leach^SM, combined with rock geochemistry, structural and geological mapping comprises Tanco's general program of field exploration for buried rareelement pegmatites. Some researchers have suggested that this technique is not employable on a grid system. Tanco has found that with proper interpretation, this technique can be used both on property grids and as a regional exploration tool.

Description of the Enzyme Leach^SM Technique

The Enzyme Leach^SM method is a selective leach extraction that employs an enzyme reaction to preferentially dissolve amorphous manganese dioxide in B-horizon soil samples (Clark, 1993 and 1995a). Amorphous manganese oxides are excellent ionic traps for trace elements that migrate through the substrate from sources at depth (Clark, 1997). Conventional soil geochemistry based upon strong leaching techniques typically represents the composition of the overburden and the constituent minerals, and not the geochemistry of the underlying bedrock. In glaciated terrains where the overburden is exotic and transported from some distant eroded source, anomalies may not necessarily be due to a buried bedrock source. With a very weak analytical selective leach such as the Enzyme Leach^SM method, trace element signatures of geological bodies and features within the bedrock can be identified by means of surface sampling of the overburden (Clark, 1997). Enzyme Leach only digests loosely attached elements and releases them into solution. The theory is that these elements are derived directly from underlying bedrock. This revelation of subsurface geology captured in a surface sample, has become a valuable tool in Tanco.s pegmatite exploration programs in the Bernic Lake area.

Elemental determinations are performed on the leach solution using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) for a standard package of 63 elements. Table 3 displays the elements that are offered in the standard Enzyme Leach^SM package and the corresponding detection limits. The ICP-MS instrumentation allows for a detection limit in the partper-billion (ppb.) range that in turn, facilitates the determination and examination of very subtle elemental anomalies.

Table 3: Trace elements provided in the standard (2001) Enzyme Leach^SM package (www.actlabs.com).

Element Name	Chemical Symbol	Detection Limit (ppb)	Element Name	Chemical Symbol	Detection Limit (ppb)	Element Name	Chemical Symbol	Detection Limit (ppb)
Lithium	Li	2	Niobium	Nb	1	Dysprosium	Dy	0.1
Beryllium	Be	2	Molybdenum	Mo	1	Holmium	Ho	0.1
Chlorine	Cl	2000	Ruthenium	Ru	1	Erbium	Er	0.1
Scandium	Sc	100	Palladium	Pd	1	Thulium	Tm	0.1
Titanium	Ti	100	Silver	Ag	0.2	Ytterbium	Yb	0.1
Vanadium	V	1	Cadium	Cd	0.2	Lutetium	Lu	0.1
Chromium	Cr	20	Indium	In	0.1	Hafnium	Hf	0.1
Manganese	Mn	1	Tin	Sn	0.8	Tantalum	Ta	0.1
Cobalt	Co	1	Antimony	Sb	0.1	Tungsten	W	1
Nickel	Ni	3	Tellurium	Te	1	Rhenium	RE	0.01
Copper	Cu	3	Iodine	I	2	Osmium	Os	1
Zinc	Zn	10	Cesium	Cs	0.1	Platinum	Pt	1
Gallium	Ga	1	Barium	Ba	1	Gold	Au	0.05
Germanium	Ge	0.5	Lanthanium	La	0.1	Mercury	Hg	1
Arsenic	As	1	Cerium	Ce	0.1	Thallium	Tl	0.1
Selenium	Se	5	Praseodymiun	Pr	0.1	Lead	Pb	1
Bromine	Br	5	Neodymium	Nd	0.1	Bismuth	Bi	0.8
Rubidium	Rb	1	Samarium	Sm	0.1	Thorium	Th	0.1
Strontium	Sr	1	Europium	Eu	0.1	Uranium	U	0.1
Yttrium	Y	0.5	Gadolinium	Gd	0.1			
Zirconium	Zr	1	Terbium	Tb	0.1			

Soil Geochemistry Survey Methods

As with most soil geochemical sampling methods it is important to have a very good knowledge of the soil profiles of the survey area. Standard soil sampling techniques are performed on B-horizon soils, which offer the most reliable and consistent analytical results. Sampling is performed using a shovel and trowel.

The top of the B-horizon is the point below which there is limited organic material and where oxide coatings are found on the mineral grains (Clark, 1995b). In situations where the B-horizon is not developed, the site is skipped or moved. Since proper sampling is a critical step in obtaining reliable results, care must be taken in the field to avoid cross-contamination not only between sample sites, but also between soil horizons at a sample site.

Sample depth is also a consideration in the field. Sample consistency is important. Tanco uses 10-15 centimetres below the A-horizon and B-horizon soil contact as a sample depth. Different geochemical signatures are obtained at different levels within the soil profile. It has been shown by 3-D soil research carried out over the Dibs pegmatite (Galeschuk, unpublished) that some elements increase downward in the soil profile while some elements decrease. Figure 13 and 14 are examples of this. For example copper can been be seen increasing downward in the soil profile. If sample depth protocol is not adhered to then it would easy to obtain a false anomaly.

In Figure 14, cadmium decreases downward in the soil profile. All elements act differently in the soil profile with regard to depth. In considering variability of elements with depth, orientation surveys are required to establish optimum sampling depth. In Figure 15 there is a chlorine depletion in all soil depths in the profile over a target pegmatite.

An orientation survey aids in determining the appropriate sample depth for the commodity elements of interest. This would determine at what sample level would give the strongest geochemical signature. In regard to sample depth for the lithophile elements for pegmatite exploration, Figure 16 displays that 10 cm depth would be best to get the strongest geochemical signature.

Figure 16 shows that the best sample depth to obtain a strong lithophile geochemical signature would be in the upper B-horizon or in the lower B-horizon. Tanco arbitrarily chose 10 to 15 cm as an effective sampling depth. For purposes of consistency this depth is still used.

With the Enzyme Leach[SM] technique, volatilization is a critical aspect that must be avoided in order to get reliable assay results. Volatilization of metal-bearing compounds can occur should the soil samples be allowed to get heated past 40°C (Fedikow, 1997). This problem can be overcome by ensuring that samples are always stored in a cool place prior to being shipped to the laboratory.

Care is taken in the method used to transport the samples (courier, trucking service, etc.). The quickest process lends itself to a reduced chance of problems.

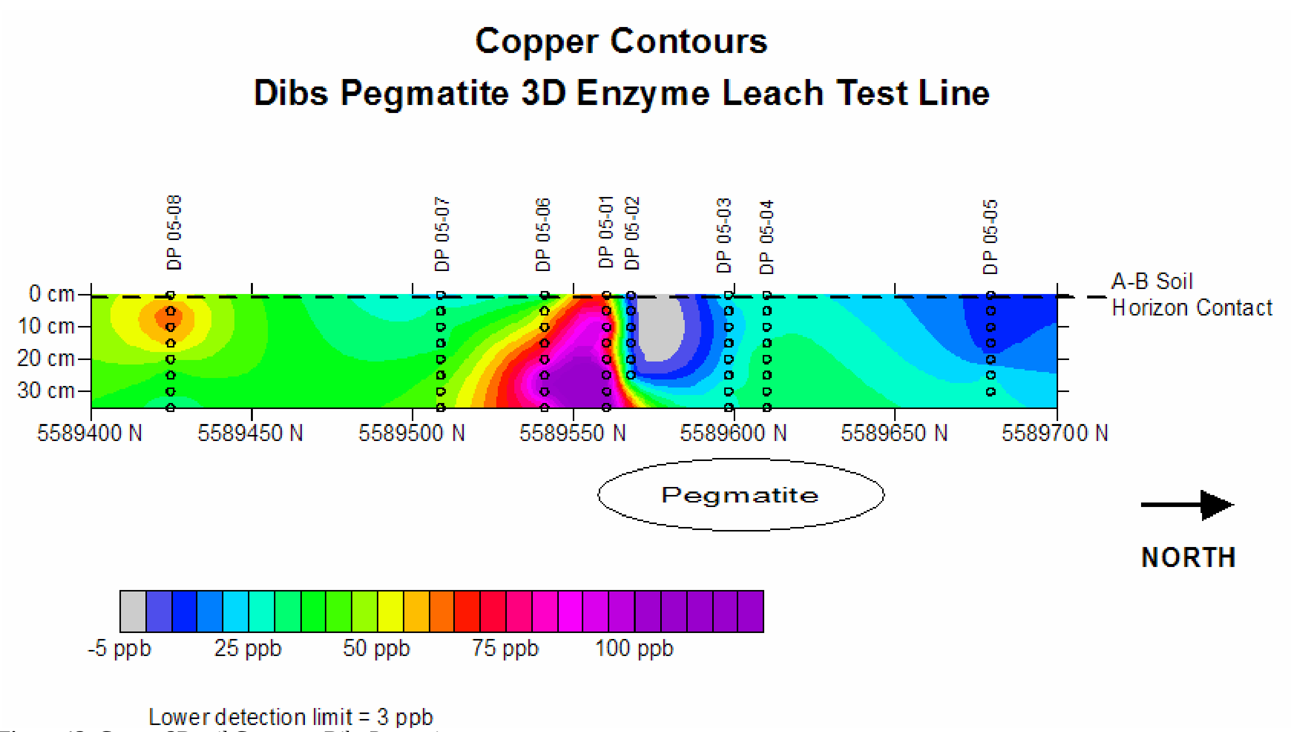

Figure 13: Copper 3D soil Contour – Dibs Pegmatite.

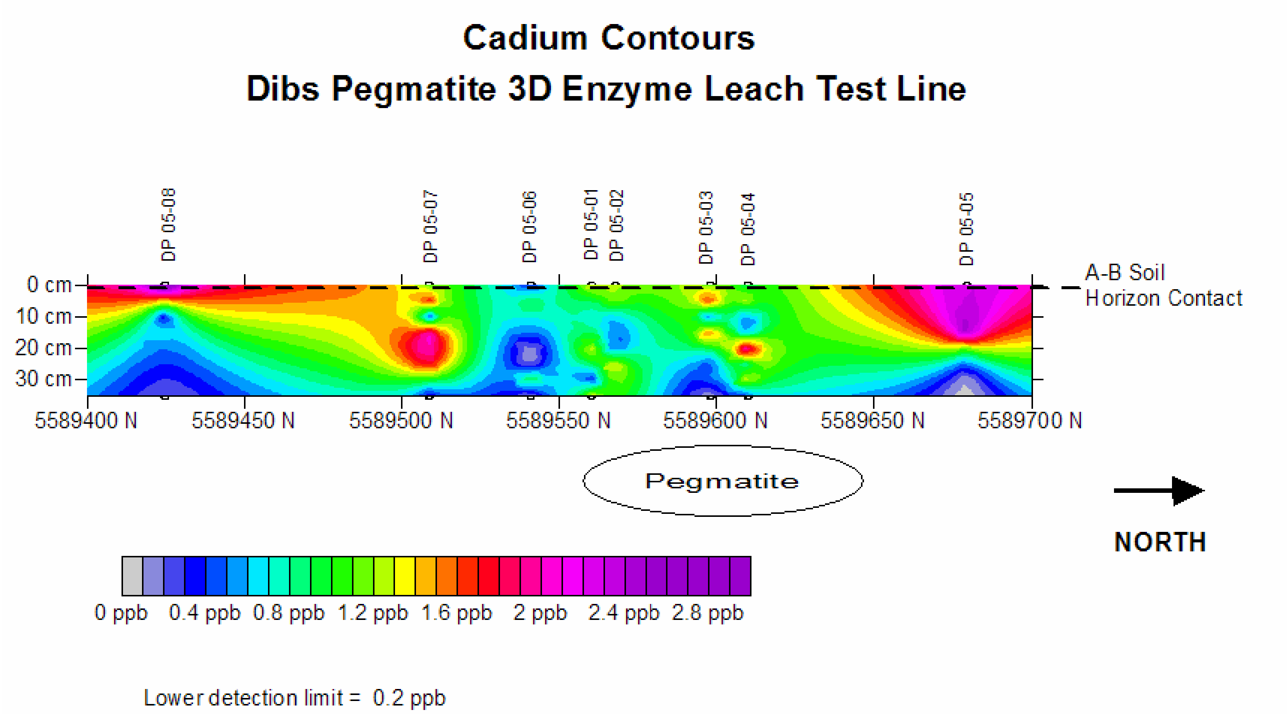

Figure 14: Cadium 3D Soil Contour – Dibs pegmatite.

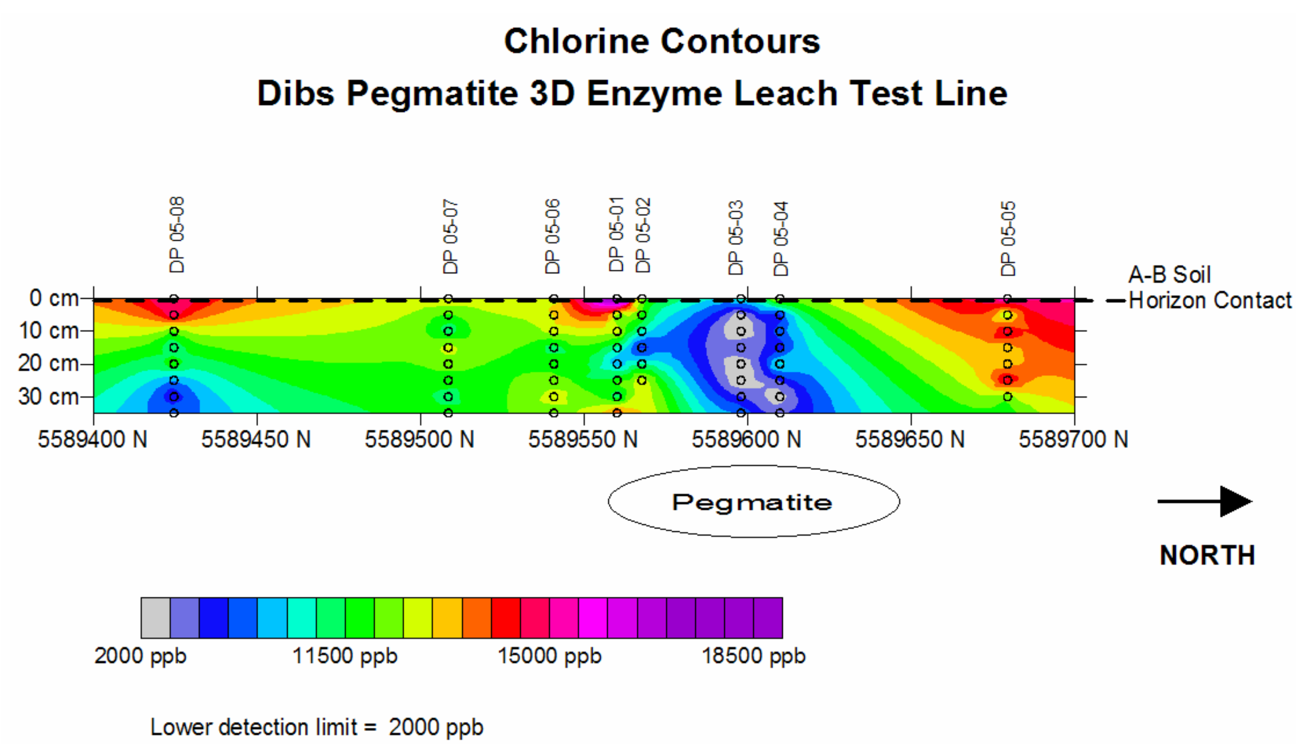

Figure 15: Chlorine 3D Soil Contour – Dibs pegmatite.

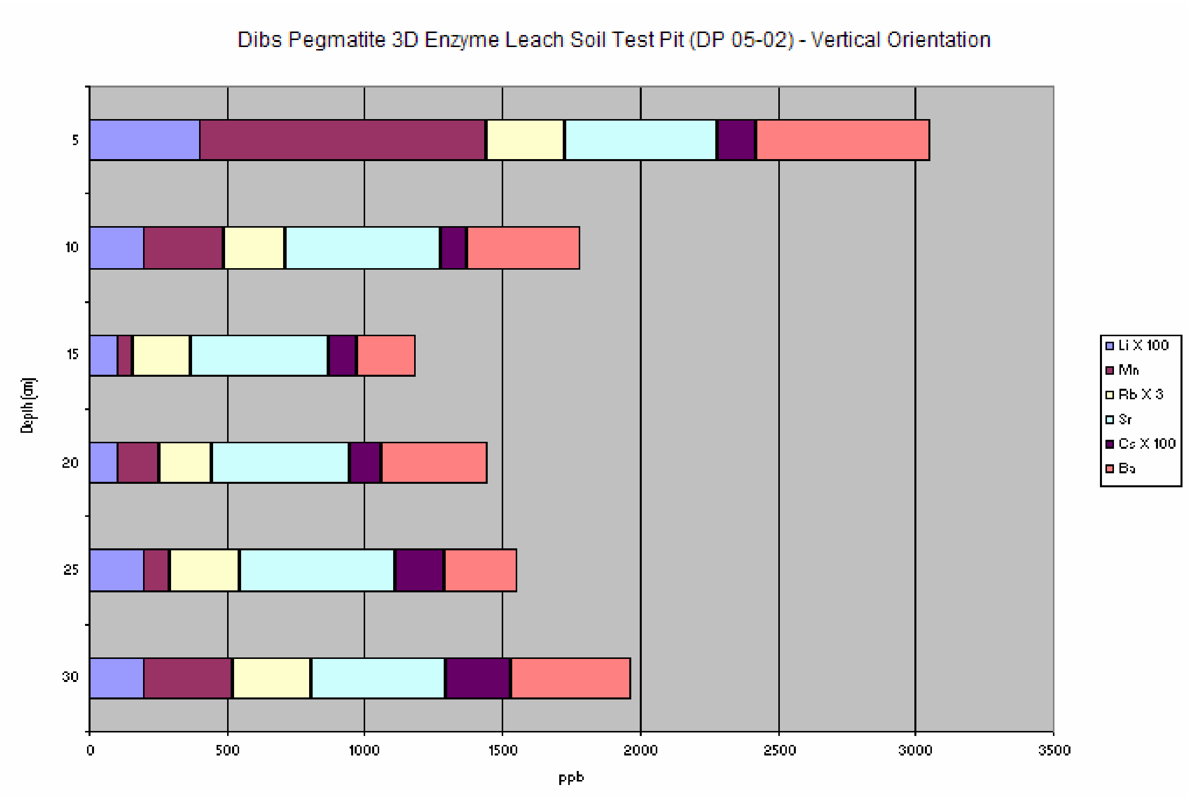

Figure 16: Lithophile Concentrations With Regard to Depth – Dibs pegmatite.

Soil sampling, using the Enzyme Leach^{SM} method, can be performed as single traverse lines (orientation survey), or multiple lines on a property scale or regional scale reconnaissance surveys. Tanco utilized single line traverses for testing over the Tanco and Dibs pegmatite. As a result of this work, subsequent soil surveys were conducted on a detailed property scale and regional scale. Regional surveys using a 200 metre staggered sample pattern have recently been completed on the majority of Tanco's land holdings in the Bernic Lake area. Some of the anomalies identified from the regional survey represent future exploration targets. Unlike lithogeochemical data, Enzyme Leach^{SM} data from different surveys should not be combined for interpretive purposes; each survey should be interpreted separately.

To compare surveys taken during different season, it is advised that the data sets get leveled. A method to accomplish such leveling is to use response ratios. This is achieved by dividing the background of each element against the elemental assays. Background can be obtained by a variety of statistical methods. Once response ratios are established, they can be contoured.

Pattern Recognition in Enzyme Leach^{SM} Surveys

Pattern recognition is key to interpreting Enzyme Leach^{SM} results (Clark, 1997). Four basic anomaly patterns, mechanical dispersion, oxidation anomalies (referred to as haloes, depletions and .rabbit-ears.), apical anomalies and combination anomalies, have been documented (Clark, 1997). Pegmatites can be characterized by more than one anomaly pattern (Galeschuk and Vanstone, 2005). It is important to sample significantly into background in order to recognize anomalies in Enzyme Leach^{SM} analytical data. Geology, ore deposit models, structure and alteration has to be taken into consider in planning a sampling program and in the interpretations. Variability seen in anomaly patterns can be partially explained by depth of burial of the source (Fedikow, 2001).

Soil surveys conducted on a grid sample pattern can be processed by contouring the individual elements. Critical to the interpretation of Enzyme Leach^{SM} data is the contrast or the magnitude of the variability between sample points and not necessarily the absolute elemental values of the samples. When a single line traverse is performed, the elemental values can be plotted on an X-Y line graph.

The work performed by Tanco, especially over the Dibs Pegmatite (Galeschuk, 2003), has set response criteria for each element in the Enzyme Leach^{SM} standard analytical package. These results are not definitive as this work is still early in its development. Changes in regard to elemental response characteristics and morphology of anomalies with regard to buried pegmatites, are to be expected as the future work is conducted on additional LCT-family pegmatites.

Table 4 represents an initial summary of the geochemical patterns over a LCT-family type pegmatite (Dibs pegmatite). More than 13 elements marked with an asterisk ("*") appear to

Table 4: Summary of geochemical responses of trace elements in B-horizon soils using the Enzyme Leach method as an exploration tool for LCT-family rare-element pegmatite (case study: Dibs pegmatite, southeastern Manitoba).

LCT-type Pegmatite Enzyme Leach Geochemical Responses

Apical Reponses

Weak to Moderate	Moderate to Strong
Cl	Mo*
Ga	W* (isolated)
Ge	In (isolated)
Nb*	Sn (isolated)
Ta	Mn*
Li**	Sr*

Depletion/Halo Responses

Br (flanked)	Co	Tl (flanked)
I (flanked)	Ni*	Y*
Se	Cu	Zr*
Sb	Zn*	Hf*
Th*	Pb(flanked)	REE's*
U*	Cd	

Combination Anomalies

V	Rb**
As	Cs**
Re	Ba
Ti	

No Associated Responses

Ag	Te	Hg	Sc
Bi	Au	Cr	PGE's

* = Consistent trace elements in pegmatite exploration
** = All very strong apical peaks should be examined

be very consistent trace elements for the purpose of pegmatite exploration.

The double asterisk ("**") flagged elements are essentially the lithophile elements. Tantalum typically occurs at very low concentrations in an enzyme leach digest of the soil and thus any anomaly is generally subtle. The element variability over the pegmatite has been shown to be complex.

Combination anomalies are the most difficult to interpret as they appear to have both apical and halo response over the pegmatite. The apical anomaly patterns, especially the strong ones, are the easiest patterns to interpret. All elements are contoured for ease of interpretation.

SUMMARY

Lithium, rubidium and cesium are the preferred elements for lithogeochemical exploration programs for buried rare-element pegmatites of the LCT-family. This is a function of element mobility. The data can be obtained by analyzing a rock sample for a standard commercial trace element package, such as the ICPMS method. It is important to statistically treat the data to determine anomalies. Interpretation of the sample results combines statistical analysis such as probability plots and the relative mobility of the three elements. The limitations of the lithogeochemical method includes the reliance on the presence of outcrop or drill cores, a limited ability to recognize deeply emplaced pegmatites and the incidences of false anomalies. Erosion levels, with regard to pegmatite emplacement, can be a factor.

For the Enzyme Leach^{SM} extraction on B-horizon soils, the most consistent and definitive trace elements for the exploration of the complex type of the rare-element class of pegmatites appear to be the Sr, Mo, Mn with accompanying responses of other trace elements as mentioned in Table 2. All strong apical responses of the lithophile elements and high-field strength elements, Ti, Nb and Ta, should be examined and interpreted as anomalous and associated with buried rare-element pegmatites. The apical responses of W, In and Sn are also excellent trace-element indicators of buried LCT-family pegmatites, but tend to be sporadic in their occurrence. The halo responses of the Th, U, Ni, Zn, Y, Zr, Hf and the rare-earthelements are good, consistent indicators for the presence of buried pegmatite deposits. The elements that have apical responses over buried pegmatites are naturally easier to work with as an exploration tool as the apical response should be directly above the pegmatite. The elements that have a halo or combination response over a buried pegmatite are, at times, more difficult to interpret and thus are generally used as a secondary examination tool to confirm that the anomaly may be related to a buried pegmatite body. Variations in geochemical signatures are bound to change with changes in pegmatite mineralogy.

Tanco has been, and will continue, to explore for economic deposits of rare-element pegmatites. Since it appears that any economically viable tantalum deposit in the Bernic Lake area will be buried, exploration tools that can give an indication of geology at depth are considered extremely valuable. Geochemistry is used in conjunction with geological and structural mapping in an integrated exploration approach.

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