Biogeochemical methods to explore for carbonatites and related mineral deposits: An orientation survey, Blue River area, British Columbia, Canada

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1. Introduction
Carbonatites host economic deposits of niobium (Nb), rare earth elements (REE), phosphate, baddeleyite (natural zirconia), vermiculite, and fluor spar, and historically, supplied copper, uranium, carbonate (for cement industries) and sodalite (Pell, 1994 and Simandl, this volume).

The Upper Fir carbonatite is in southeastern British Columbia, approximately 200 km north of Kamloops (Fig. 1). It is one of many known carbonatite occurrences in the British Columbia alkaline province, which follows the Rocky Mountain Trench and extends from the southeastern tip of British Columbia to its northern boundaries with the Yukon and Northwest Territories (Pell, 1994). The Upper Fir is a strongly deformed carbonatite with an indicated mineral resource of 48.4 million tonnes at 197 ppm of Ta2O5 and 1,610 ppm of Nb2O5, and an inferred resource of 5.4 million tonnes at 191 ppm of Ta2O5 and 1760 ppm of Nb2O5 (Kulla et al. 2013). The Nb, Ta, and vermiculite mineralization is described by Simandl et al. (2002, 2010), Chong, et al, (2012), and Chudy (2014).

In this document we present the results of an orientation survey designed to determine the biogeochemical signature of a typical carbonatite in the Canadian Cordillera. This survey suggests that needles and twigs of White Spruce (Picea glauca) and Subalpine Fir (Abies lasiocarpa) are suitable sampling media to explore for carbonatites and carbonatite-related rare earth elements (REE), niobium (Nb), and tantalum (Ta) deposits.

2. Orientation Survey
2.1. Sampling and analytical procedures
All vegetation samples were collected on August 23, 2010. Sampling was completed in less than 3 hours on a single day to avoid seasonal and diurnal variations. Branch tips about 10 cm long were collected from trees 5 to 7 m tall at heights of about 1.7 m. The sample sites are a well-drained hillside. Samples were immediately placed in Kraft sample bags which were approximately 500 to 700 cm3 in volume.

All samples were dried at 80°C for 24 hours. Needles were then separated from twigs. Twigs were milled using a Wiley mill, and a 1 g split was digested in nitric acid (HNO3) and then in aqua regia, and analyzed using inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectroscopy (ICP-AES) methods to ultra-low detection limits. A 50 g quantity of dry needles wasashed using controlled ignition at 475°C for 24 hours. A 0.25 g quantity of the needle ash was then digested in HNO3, and analyzed using the same ICP-MS/ICP-AES methods. Weights of samples before and after ashing were recorded.

Analyses were conducted at Bureau Veritas Minerals (formerly Acme Laboratories) in Vancouver, British Columbia. The same suite of elements was selected for both twig and needle samples: K, Na, Ca, Mg, Fe, Al, Mn, Cr, Ti, Si, P, Ba, Mo, Cu, Pb, Zn, Cd, Ni, Co, Se, As, Sr, Zr, Au, Ag, Pd, Pt, Li, Be, B, V, Ga, Ge, Rb, In, Sn, Re, Sb, Te, Cs, Hf, W, Hg, Tl, Bi, Th, U, Nb, Ta, Sc, Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.

2.2. Summary of results
At Upper Fir, La, Ce, Pr, Nd, Sm, Dy, Fe, Nb, Ta, P, and Y were identified as the most promising pathfinder elements. Concentrations of Ta and heavy REE (with the exception of Dy and Y) are near or below the lower limit of detection in Spruce twigs that were not treated by ashing. In 2011, the ashing procedure concentrated most trace elements in needles to levels well above the lower limit of detection. Ashing of both twigs and needles before analysis is recommended for future surveys. All samples of twigs, with the exception of sample BR-18, in which Ta was detected in concentrations higher than 0.002 ppm are spatially related to carbonatite or related altered rocks, commonly referred to as fenites (Fig. 2; Fajber et al., 2015). Although Ta is described as an unreliable biogeochemical pathfinder by Dunn (2007), Ta concentration in sample BR-18
is unlikely to be spurious because it coincides with elevated concentrations of Nb, Ce and P (Fig. 2). It may correspond to a blind (near-surface, overburden-covered) extension of the carbonatite or an old drill site. Since 2011, when our samples were analyzed, the lower limit of detection for ash analysis has been reduced by half (Bureau Veritas Minerals, 2015). Because of this advancement, some of the elements we rejected in 2011 because of low concentrations may now be considered suitable pathfinders.

Twigs from a given sample contain consistently higher concentrations of pathfinder trace elements than the needles from the same sample, therefore twigs appear to be a better sampling medium. Based on our limited data (21 sample sites not counting duplicates) our survey suggests that a full-scale
survey should provide comparable results to those obtained by the soil geochemistry carried out by the Commerce Resources Corp. and described in Dahrouge and Wolbaum (2004).

Unweathered carbonatite rocks and related REE mineralization typically have steep chondrite-normalized REE patterns lacking a Eu anomaly (Fig. 3a; Fig. 6 in Simandl, 2014). Soils and vegetation samples taken above the Upper Fir carbonatite show systematic negative Eu anomalies (Fig. 3b,c). This indicates that presence or absence of a negative Eu anomaly in soil and vegetation can’t be used to distinguish an anomaly caused by buried carbonatite from those caused by peralkaline intrusion, peraluminous granite, or rare metal-bearing pegmatite.

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**References cited**


**Fig. 3.** Chondrite-normalized REE plots. a) Absence of negative Eu anomaly in upper Fir carbonatite rocks. Envelope of three Upper Fir carbonatite analyses. b) Presence of negative Eu anomaly in Spruce needle ash overlying Upper Fir carbonatite (red diamonds; BR-15 and BR-16), fenite (blue squares; BR-20 and BR-21), and metasedimentary rocks (green circles; BR-13 and BR-17). Dotted lines represent projections where Eu concentrations were below the lower limit of detection. c) Soils overlying carbonatites (red, envelope of 5 analyses) contain higher concentrations of REE than those overlying schists and gneisses (blue, envelope of 8 analyses). All soil samples display negative Eu anomalies. Analysis of soil from Dahrouge and Wolbaum (2004). Chondrite normalization according to McDonough and Sun (1995). From Fajber et al. (2015).