PETROGENETIC CONSIDERATIONS FOR THE LATE CRETACEOUS NORTHERN ALBERTA KIMBERLITE PROVINCE

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INTRODUCTION

To January 2003, 48 kimberlite and ultrabasic pipes have been discovered in three separate areas of northern Alberta (Figure 1). Because the northern Alberta pipes are removed spatially and tectonically from other kimberlite occurrences in western North America, they are referred to herein as the 'northern Alberta kimberlite province' (NAKP), and include

- Mountain Lake cluster (ML): 2 pipes discovered in 1989-1990 by Monopros Limited (the then Canadian subsidiary of De Beers)

- Buffalo Head Hills field (BHH): 38 pipes discovered between 1997 and January 2003 by Ashton Mining of Canada Inc., in a joint venture with EnCana Corporation and Pure Gold Resources Ltd.

- Birch Mountains field (BM): 8 pipes, which includes 7 pipes discovered in 1998 by Kennecott Canada Exploration Inc., Montello Resources Ltd. and Redwood Resources Ltd., and 1 pipe discovered in December 2000 by New Blue Ribbon Resources Ltd.

These fields are located in or marginal to the inferred 2.0 to 2.4 Ga Buffalo Head accreted terrane (Figure 1). Near the fields, the basement rocks are overlain by approximately 2,200 m (ML), 1,600 (BHH) and 500 m (BM) of Phanerozoic sedimentary rocks. Finally, Quaternary deposits, particularly those from the last southwestward Late Wisconsin (25-12 ka BP) glacial event, form the local landforms over virtually all of northern Alberta.

This is the first study to compare the three northern Alberta fields and to document the physical and geochemical characteristics of the pipes. To place these data in context, comparisons are made between the NAKP fields, and to kimberlite and other alkali rock types worldwide.

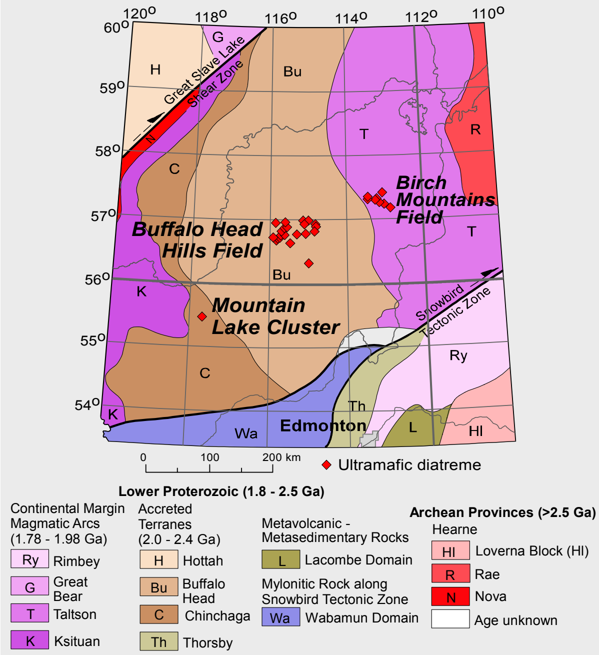

Figure 1. Inferred Precambrian basement terranes in northern Alberta (from Ross et al., 1994).

ABBREVIATED METHODOLOGY

Eighty-three samples, including ten randomly picked duplicates, were sampled from 25 pipes in all three fields:

- ML: 17 samples from 2 pipes
- BHH: 30 samples from 16 pipes
- BM: 36 samples from 7 pipes

All 83 samples were analyzed for whole-rock geochemistry (major and trace elements). Based on these results a subset of ten samples from five pipes was selected for detailed petrographic and isotopic interpretation. The subset includes samples from the K4 and K6 pipes in the BHH, and Legend, Phoenix and Kendu pipes in the BM. Electron microprobe analytical data for olivine, phlogopite, spinel and ilmenite grains from the same samples used in this study are included in Creighton and Eccles (2003, this abstract volume).

GEOLOGY OF THE DIATREMES

MORPHOLOGY

Because of the shallow depth and volume of natural gas in northern Alberta, protective equipment is generally required for holes that drill greater than approximately 200 m depth. Hence, the shallow depth to which these intrusions have been drilled limits our knowledge of their exact morphologies.

The size of the pipes, as inferred from geophysical surveys, varies between <1 to 45 ha. The pipes are typically covered by up to 130 m of surficial material and bedrock, although several pipes are known to crop out, including the ML south pipe and BHH K5 and K6 pipes.

EMPLACEMENT AGES

The emplacement age of the NAKP is Late Cretaceous (Turonian/Coniacian to Maastrichtian). The K5, K7A and K14 kimberlites from the BHH pipes have reported emplacement ages of between 86±3 to 88±5 Ma by U-Pb perovskite (Skelton et al., 2003; Heaman et al., in press). The BM pipes are younger: that is the Phoenix, Dragon, Xena, Legend and Valkyrie pipes have emplacement ages of between 70.3±1.6 to 77.6±0.8 Ma as determined by U-Pb perovksite and Rb-Sr phlogopite (Aravanis, 1999; this study). The ML pipes are similar in emplacement age to the BM; palynological results of Wood et al. (1998) and Leckie et al. (1997) are consistent with an emplacement age between 76 and 68 Ma.

TEXTURAL CLASSIFICATION

Pyroclastic kimberlitic (PK) rocks are by far the dominant textural rock type in the northern Alberta kimberlite province followed by less common resedimented pyroclastic kimberlitic (RVK) rocks. The PK rocks are generally described as juvenile lapilli-bearing olivine (crystal) tuffs. Bedded and graded layers are composed of stratified tuffs with alternating layers of coarse lapilli-sized (2-64 mm) and laminae of finer ash-sized (<2 mm) tuffs, and/or cycles of kimberlite interlayered with mudstone with gradational lower contacts between kimberlite and underlying mudstones (Skelton and Bursey, 1998; Aravanis, 1999). The observed macrocryst suite of minerals includes rounded, typically <1 cm wide, forsteritic olivine with a minor component of phlogopite and ilmenite. The groundmass is dominated by subhedral olivine microphenocrysts (<0.25 mm) set in a fine-grained serpentine- and often carbonate-rich groundmass occurring together with one or more of the following primary minerals: phlogopite, perovskite, spinel, ilmenite and apatite. Spherical- and amoeboid-shaped juvenile lapilli are either isolated in the olivine crystal tuff (Figure 2A) or occur together with ash- to lapilli-sized juvenile pyroclasts. The coexistence of several types of lapilli may be the result of multiple eruption episodes that have subsequently mixed.

Petrographic textures from the Kendu pipe samples are suggestive of rocks originating from deeper within the volcaniclastic pile in comparison to the unmistakable crater-type textures observed in the majority of the northern Alberta kimberlite province pipes. Kendu rocks are characterized by an abundance of juvenile, serpentine- and phlogopite-rich magmaclasts of earlier-crystallized fragments set in a non-uniform, often segregation-textured matrix of groundmass minerals (dominantly serpentine and calcite). Lapilli from the Kendu pipe are similar in texture to diatreme-facies pelletal lapilli, in which kernels of olivine pseudomorphs are surrounded by serpentine-rich microlitic material with opaque minerals and tangentially aligned fine-grained (<0.01 mm long) phlogopite (Figure 2B). Clasts of anorthite-rich

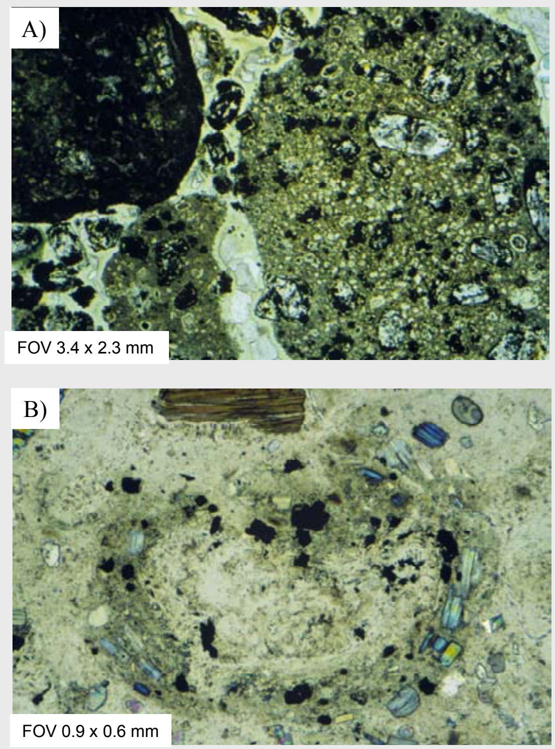

Figure 2. Morphological and textural differences between amoeboid-shaped juvenile lapilli (A; Phoenix pipe) and pelletal lapillus (B; Kendu pipe).

basement rock and mantle xenoliths (eclogite more abundant than lherzolite) and xenocyrsts are also present. The xenoliths are rounded to non-rounded (some with irregular, diffuse boundaries), and are often surrounded by halo's of microcrystalline kimberlite with flow-aligned textures.

ALTERATION AND CONTAMINATION

The degree of alteration and contamination by country rock varies between individual pipes. Most of the microphenocrystal olivine is completely replaced by serpentine and/or calcite. Using the kimberlite contamination index (C.I.) of Clement (1992; C.I. = SiO_2+Al_2O_3+Na_2O/MgO+K_2O), all of the ML, 33% of the BM, and only 7.5% of the BHH samples had a C.I. of greater than 1.5.

The low C.I. of the majority of the samples from the BHH and BM suggests that bulk-rock geochemistry may be useful in assessing the character of volcaniclastic rocks. The high C.I. in the ML samples are more likely a function of the magma type rather than solely a result of more extensive crustal contamination (see below).

DISCRIMINATION BETWEEN FIELDS

Although there is variability between pipes within the larger fields, integration of textural and whole-rock geochemical data does allow for the distinction between NAKP fields.

BUFFALO HEAD HILLS AND BIRCH MOUNTAINS FIELDS

The BHH and BM kimberlites have close geochemical affinities with Group I South African kimberlite (e.g., Figure 3). Based on petrography and whole-rock geochemistry, pipes in the BHH represent the most primitive kimberlite (i.e., Group IA kimberlite) in this dataset. Physically, the BHH generally differ from the BM because they contain less carbonate, have a smaller modal abundance of late-stage minerals such as phlogopite and ilmenite, and have a higher modal volume of fresh, coarse olivine. Consequently, the majority of samples from the BHH have the lowest concentrations of SiO_2, Al_2O_3, V, Y, Pb, Sr and Ga, and the highest values of MgO, Mg#, Cr and Ni in this dataset, and have similar geochemical properties to primitive kimberlite from the Northwest Territories (e.g., Figure 3).

In contrast to the BHH samples, the BM kimberlites are highly carbonatized, relatively devoid of olivine macrocrysts, have higher concentrations of late-stage minerals phlogopite, apatite and ilmenite, higher high field strength elements (HFSE) and lower NiO content,

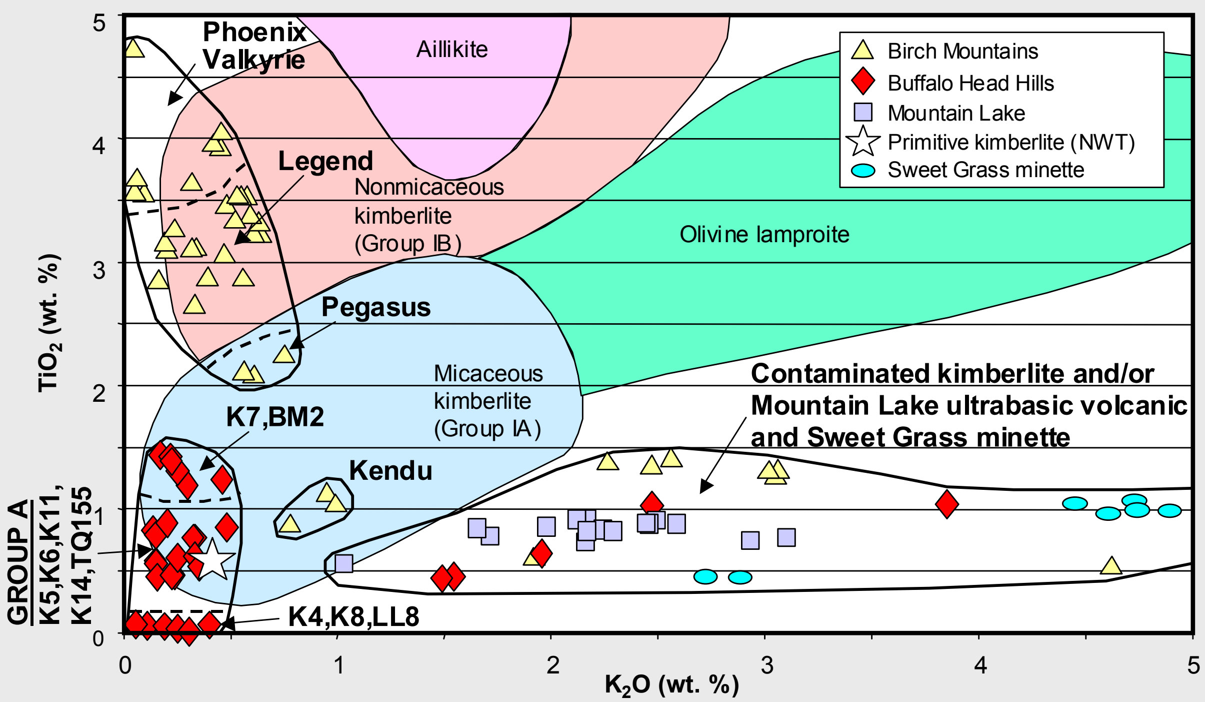

Figure 3. TiO_2 versus K_2O for Alberta diatreme whole-rock compositions. Fields for kimberlite and related rock types are from Taylor et al. (1994), primitive Northwest Territories kimberlite from Price et al. (2000) and Berg and Carlson (1998), and Sweet Grass (southern Alberta) minette from Kjarsgaard (1994) and Buhlmann et al. (2000).

all of which are consistent with a more evolved nature (i.e., Group IB kimberlite).

On the $^{87}Sr/^{86}Sr$ versus $^{143}Nd/^{144}Nd$ (ε_{Nd}) diagram (Figure 4), BHH K6 kimberlite falls within the field for South African Group I kimberlites, whereas the BM Legend and Phoenix kimberlites have similar ε_{Nd} values (between 0 to +1.9), but distinctly higher $^{87}Sr/^{86}Sr$ values (0.7051 to 0.7063) in comparison to kimberlite K6.

MOUNTAIN LAKE CLUSTER

Based on whole-rock geochemical analysis of the freshest (least contaminated) samples, the ML does not exhibit an archetypal kimberlite geochemical signature, but rather a hybrid with geochemical affinities to alkali olivine basalt or basanite. Our conclusion is in general agreement with Leckie et al. (1997), and Skupinski and Langenberg (2002) who suggested an alkaline ultrabasic volcanic origin with some petrologic affinities to alnöitic magmas for ML.

INTRA-FIELD VARIABILITY

The dominant process of magmatic differentiation in the NAKP is crystal fractionation and accumulation of olivine, which acts as the main differentiation process between primitive and evolved Group I-type kimberlite in the NAKP. The BM pipes are further differentiated by varying degrees of partial melting and/or variable degrees of source enrichment (mantle metasomatism) in the sub-continental lithosphere.

In the BHH, the K4 complex, together with samples from kimberlites K8 and LL8, have the lowest TiO_2 (Figure 3) and highest Ni and Mg# in this dataset. The 'anomalous' geochemical signature of the K4B pipe is associated with the abundance of olivine (up to 65 vol. %) and therefore, the 'primitive' whole-rock geochemical signature must be directly related to accumulation of olivine. In the BM, the Phoenix pipe, which has the highest TiO_2 and LREE and lowest Ni and Mg#, represents the most evolved kimberlite characterized by olivine extraction.

The major element composition of the Kendu pipe is intermediate between those of the majority of the kimberlite samples from BHH and BM and the ML alkaline ultrabasic rocks (e.g., Figure 3) and thus, derived from a melt that is compositionally between the kimberlite- and ML-types.

The K4 and Kendu pipes are characterized by low overall incompatible element values and have chondrite-normalized rare-earth element distribution

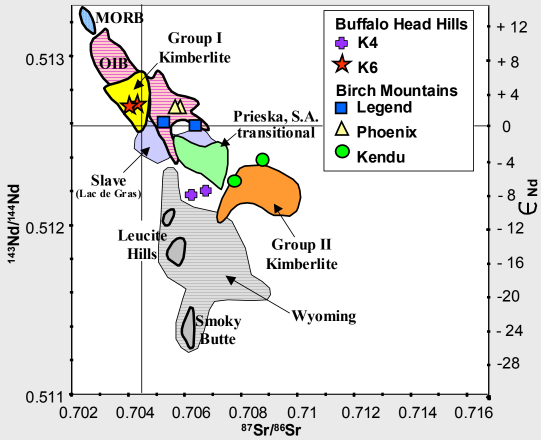

Figure 4. Isotopic composition of Nd-Sr from selected pipes in northern Alberta. Group I and II kimberlite fields from Smith (1983); Prieska transitional kimberlite field from Skinner et al. (1994); Slave – Lac de Gras field from Dowall et al. (2000); Wyoming ultrapotassic field from Vollmer et al. (1984) and O'Brien et al. (1995).

patterns that are less fractionated, with shallower slopes than the majority of the kimberlite samples from the BHH and BM. In addition, K4 and Kendu have higher $^{87}Sr/^{86}Sr$ and lower ε_{Nd} than the Bulk Earth and plot in the bottom right quadrant of the Nd-Sr diagram (Figure 4). We suggest, therefore, the K4 and Kendu pipes contain either a contribution from old, LREE-enriched (low Sm/Nd) lithosphere that is absent from the other magmas, are crustal contaminated, or both.

DIAMOND CONTENT

Most of the BHH pipes with elevated diamond contents, i.e., those pipes that Ashton has mini-bulk sampled, have similar geochemistry (e.g., Group A on Figure 3). In general, this group contains low TiO_2 (0.45–1.2 wt. %), Nb (108–189 ppm), SiO_2 (26.8–33.5 wt. %) and Al_2O_3 (1.61–2.77 wt. %), and high MgO (26.7–38.1 wt. %), Mg# (87–90 mol. %), Cr_2O_3 (0.11–0.22 wt. %) and Ni (1007–1621 ppm).

CONCLUSIONS

The integration of petrography and whole-rock geochemistry of minimally contaminated volcaniclastic rocks may be used successfully as a tool to aid in the classification of ultramafic rocks in northern Alberta. The BHH and BM kimberlite fields resemble Group I South African kimberlites and can be distinguished from one another by their primitive to evolved magmatic signatures. This conclusion is important from a diamond exploration viewpoint because the majority of the BHH kimberlites are diamondiferous, whereas the BM pipes are for the most part barren of diamonds.

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