PETROGENETIC CONSIDERATIONS FOR THE LATE CRETACEOUS NORTHERN ALBERTA KIMBERLITE PROVINCE

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INTRODUCTION

To January 2003, 47 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): 37 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.

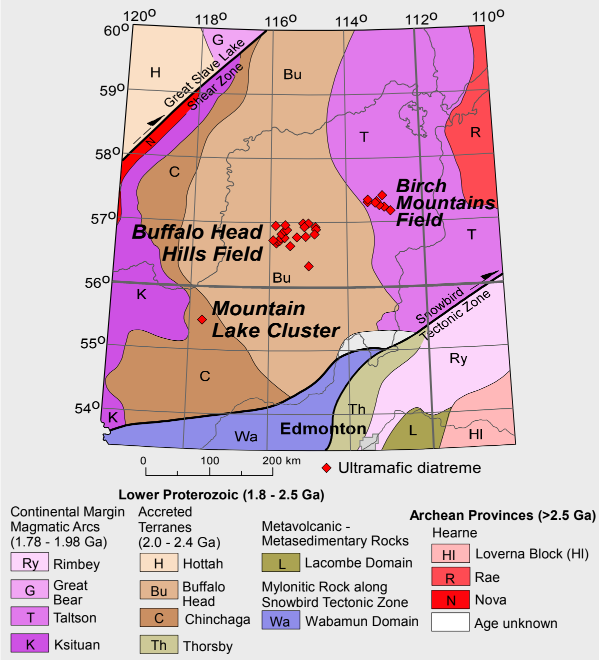

Figure 1. Inferred Precambrian basement terranes in northern Alberta (from Ross et al., 1994).

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

Petrographic examination of selected cores show that three main rock types, with distinct mineralogies, textures, and mantle xenolith and xenocryst content, occur in the NAKP: pyroclastic, resedimented pyroclastic and diatreme volcaniclastic rocks.

Pyroclastic and resedimented pyroclastic rocks are by far the dominant textural rock type in the NAKP and 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 smaller, armoured lapilli and ash (variably-sized single crystal olivine coated by ash). The coexistence of several types of lapilli may be the result of multiple eruption episodes that have subsequently mixed.

Diatreme rocks in the Kendu pipe are characterized by an abundance of phlogopite-rich autoliths of earlier-crystallized kimberlite fragments set in a non-uniform, segregationary-textured distribution of groundmass minerals. Clasts of anorthite-rich 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-

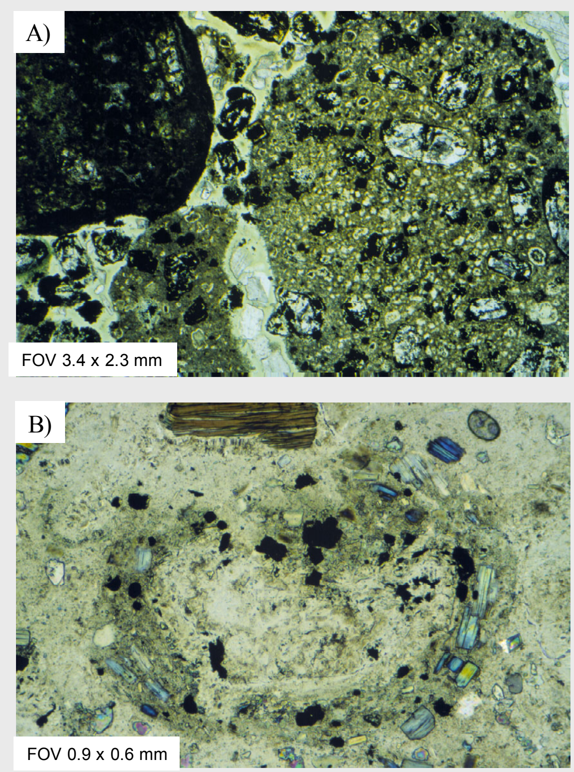

Figure 2. Morphological and textural differences between crater juvenile lapilli (A; Phoenix pipe) and diatreme pelletal lapillus (B; Kendu pipe).

aligned textures. Pelletal lapilli are characterized by kernels of olivine pseudomorphs surrounded by a lizardite-rich microlitic material with opaque minerals and tangentially aligned fine-grained (<0.01 mm long) phlogopite (Figure 2B).

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 Legend and Phoenix kimberlites from the BM are highly carbonatized, relatively devoid of olivine macrocrysts, have higher concentrations of late-stage minerals

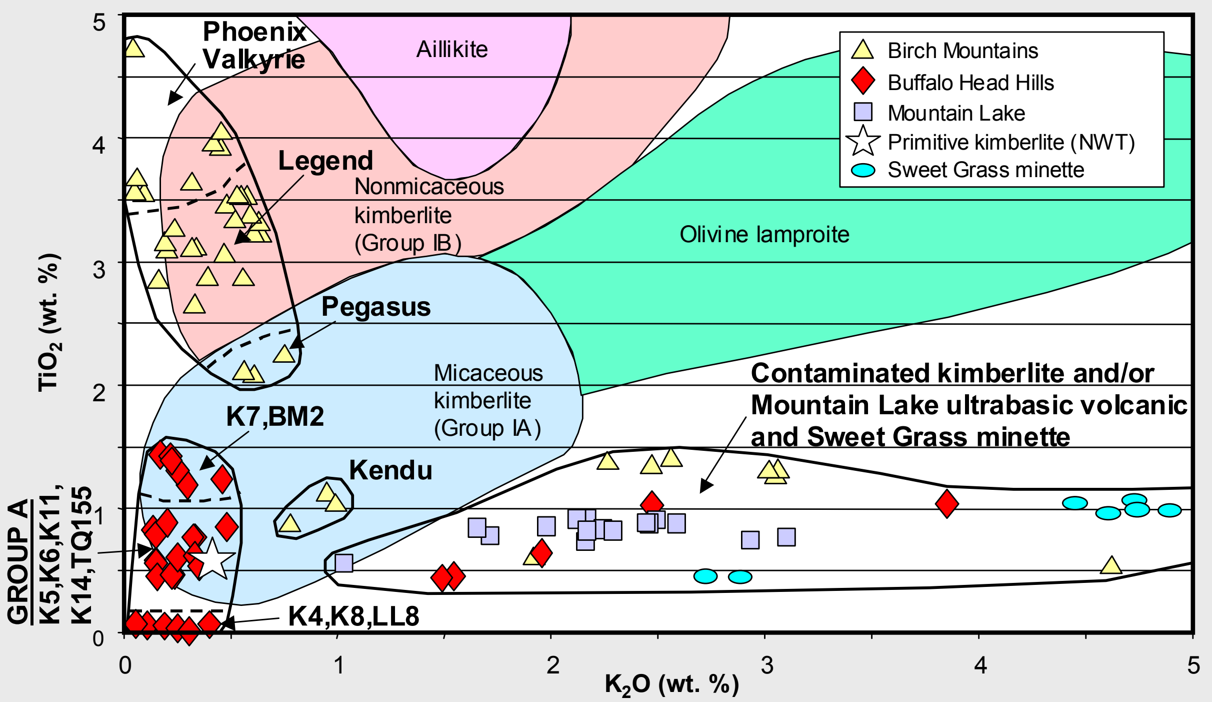

Figure 3. TiO_2 versus K_2O for Alberta diatreme whole-rock compositions. Fields for kimberlite and related rock types are from Taylor et al. (1994), primitive Northwest Territories kimberlite from Price et al. (2000) and Berg and Carlson (1998), and Sweet Grass (southern Alberta) minette from Kjarsgaard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

phlogopite, apatite and ilmenite, higher high field strength elements (HFSE) and lower NiO content, 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 basanite (olivine potassic basalt), the southern Alberta Sweet Grass olivine minettes and Montana alnöite. Our conclusion is in 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

Intra-field geochemical variations are also evident. 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, corresponding to the most primitive geochemical signature. In the BM, 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).

The 'anomalous' geochemical signature of the K4 and Kendu pipes relative to their respective fields may be related directly to physical properties of the magma. For example, the K4B pipe has the highest abundance of olivine (up to 65 vol. %) and therefore, the 'primitive' whole-rock geochemical signature must be directly related to high olivine content that may result from subaerial winnowing of olivine from the ash plume (i.e., pyroclastic subaerial fall deposits). The Kendu pipe differs physically from all other pipes investigated because it is the only pipe containing diatreme volcaniclastic rocks.

Alternatively, the K4 and Kendu pipes may define kimberlite magma end-members for their respective fields. Especially since both pipes are characterized by low overall incompatible element values and have chondrite-normalized rare-earth element distribution 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.

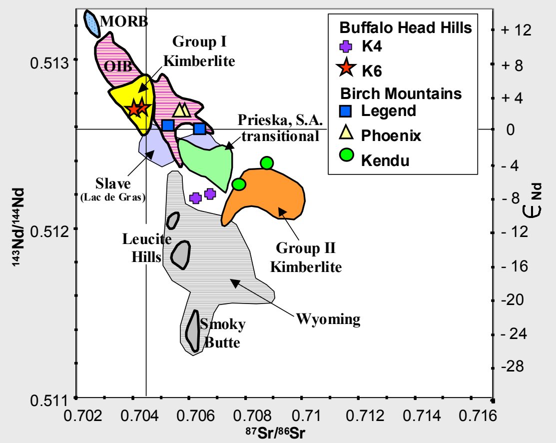

Figure 4. Isotopic composition of Nd-Sr from selected pipes in northern Alberta. Group I and II kimberlite fields from Smith (1983); Prieska transitional kimberlite field from Skinner et al. (1994); Slave – Lac de Gras field from Dowall et al. (2000); Wyoming ultrapotassic field from Vollmer et al. (1984)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

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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