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Evidence for Kimberlite-Sourced Bentonite in Upper Cretaceous Strata of North-Central Alberta: A Bedrock Characterization Tool to Aid Diamond Exploration

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Evidence for Kimberlite-Sourced Bentonite in Upper Cretaceous Strata of North-Central Alberta: A Bedrock Characterization Tool to Aid Diamond Exploration

D.R. Eccles

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Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, Alberta
T6B 2X3
Canada

Tel: (780) 422-3767 (Information Sales)
Fax: (780) 422-1918
E-mail: EUB.AGS-Infosales@gov.ab.ca
Website: www.ags.gov.ab.ca

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Acknowledgments

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Sedimentary cores in the vicinity of the Buffalo Head Hills kimberlite field were donated by Ashton Mining of Canada Inc. and their joint venture partners EnCana Corporation and Pure Gold Minerals Inc. Without these cores, this study would not have been possible. Thank you.

Glen Prior of the Alberta Geological Survey and emeritus professor Jack Lerbekmo with the University of Alberta, Earth and Atmospheric Sciences Department, are thanked for editorial comments that improved the significance of this report.

Abstract

Past characterization of bentonite in Alberta has revealed a dominant intermediate to felsic volcanic parental source. Recent metallogenic evaluations of sedimentary rocks in northern Alberta suggested that anomalously thick, discontinuous bentonite layers may be the result of localized volcanic events. From a diamond exploration perspective, this has interesting implications, given the recent discovery of kimberlite pipes in the Western Canada Sedimentary Basin.

As part of an initiative to study kimberlite-hostrock relationships in northern Alberta, seven separate bentonite horizons were collected for study from sedimentary cores obtained by past testing of kimberlite targets in the Buffalo Head Hills kimberlite field of north-central Alberta. The main objective of the study is to characterize bentonite in the vicinity of kimberlite pipes and determine whether bentonite and tuff successions deposited in Alberta can be related to kimberlite and/or alkaline source events.

Physical and geochemical data and interpretation presented in this report provide strong evidence for the first known documentation of kimberlite-sourced bentonite in northern Alberta. Two kimberlitic bentonites hosted in marine mudstones are unambiguously differentiated from intermediate to felsic volcanic-derived bentonite, having similar ultramafic and trace-element geochemical compositions to whole-rock kimberlite from the northern Alberta kimberlite province.

Based on the conclusion that bentonites in Alberta exhibit kimberlite source affinities, it is recommended that bentonites are not ignored in field investigations in the Western Canada Sedimentary Basin. Bentonite characterization and geochemistry can provide a quick and cost-effective means of testing the kimberlite potential of an area.

1 Introduction

Classic definitions of bentonite suggest formation by the in situ devitrification and accompanying chemical alteration of glassy igneous material, usually volcanic ash (e.g., Ross and Shannon, 1926; Jackson, 1997, p. 63) with the resulting material composed essentially of smectite group clay minerals (dominantly montmorillonite) with variable amounts of biotite, feldspar, quartz, zircon, apatite and volcanic rock fragments. Genetic connotations (i.e., glass) implicated by this definition, however, have resulted in confusion because similar minerals and mineral assemblages can have different origins. Hence, bentonite can be defined simply as montmorillonite-rich clay (e.g., Byrne, 1955; Ross, 1964) and it is in this sense that the term bentonite is used in this report.

Bentonite is common in the Cretaceous and Paleocene sedimentary rocks throughout most of Alberta (Scafe, 1975) and has provided researchers with material for geochronological dating (e.g., Folinsbee et al., 1961, 1963, 1964, 1965; Lerbekmo, 1963; Nascimbene, 1965; Thomas et al., 1990; Payenberg et al., 2002) and a powerful stratigraphic correlation tool (e.g., Ritchie, 1960; Elder, 1988).

Past characterization of bentonite in Alberta, which focused predominantly on the southern Alberta Plains and Foothills regions, suggested bentonite is extensive in areal distribution and, for the most part, maintains stratigraphic continuity. For example, the Dorothy-Trefoil bentonite is traceable for about 20 km along the Red Deer River (Scafe, 1975; Lerbekmo, 2002). In contrast, a recent metallogenic evaluation of sedimentary rocks in northern Alberta (Dufresne et al., 2002) reported that several anomalously thick, discontinuous bentonite layers do not fit that mould, and suggested bentonite distribution may be the result of modification by either secondary sedimentological processes or more localized volcanic events. Mineralogical evidence supports this; for example, discontinuous bentonite layers in the Second White Specks Formation in the Birch Mountains area of northeastern Alberta contains Mg-Fe-rich chromite, picroilmenite, Ti-rich pyrope garnet and chrome diopside that may have been derived from xenocrystic material associated with kimberlite or other alkaline intrusive events (Dufresne et al., 2002).

From the diamond exploration perspective, thick successions of mid-Cretaceous to Tertiary bentonite and tuff in the Alberta basin is interesting because this period coincides with the most extensive and voluminous period of diamondiferous kimberlite magmatism in the world. This holds true for western North America, where diamondiferous kimberlite from Alberta, North West Territories and Saskatchewan has been dated as mid-Cretaceous to Early Tertiary in age. Hence, an important question to ask is, "Are some of the bentonite and tuff successions deposited in Alberta related to kimberlite and/or alkaline source events?"

This supposition has not been sufficiently tested, predominantly because kimberlite typically occurs in ancient cratonic settings dominated by prolonged erosional histories, and thus, proximal and distal kimberlite volcaniclastic deposits (i.e., extra-crater kimberlite) are rarely observed. Relict parts of kimberlite pyroclastic rings may be preserved within sedimentary successions at Kasami, Kenieba Field, Mali (Hawthorne, 1975) and at Igwisi, Tanzania (Sampson, 1956; Reid et al., 1975), but the discovery of kimberlite in the Western Canada Sedimentary Basin (WCSB) has enabled scientists to study kimberlite-sedimentary hostrock relationships in detail.

Mid- to Upper Cretaceous crater facies rocks in the Fort à la Corne area of central Saskatchewan and Buffalo Head Hills and Birch Mountain areas of northern Alberta are dominated by primary lapilli-rich pyroclastic kimberlite and resedimented volcaniclastic kimberlite (Lehnert-Thiel et al., 1992; Scott-Smith et al., 1994; Kjarsgaard, 1995; Nixon, 1995; Leckie et al., 1997; Nixon and Leahy, 1997; Carlson et al., 1999; Skelton et al., 2003; Eccles, 2004; Eccles et al., 2004; Zonneveld et al., 2004). Hence, these kimberlite provinces provide the ideal setting to test whether bentonite resulting from proximal and/or distal air fall deposits can maintain the unique source magma chemistries exhibited by kimberlite. If this is the case, and if secondary influences (e.g., prolonged weathering and diagenesis) have not had a profound affect on bentonite development and preservation, then bentonite characterization in other parts of the WCSB may lead to the discovery of new occurrences of kimberlite.

2 Bentonite Samples: Background, Collection and Description

The Buffalo Head Hills kimberlite field, which is located in north-central Alberta, was discovered in 1997 by Ashton Mining of Canada Inc., together with joint venture partners EnCana Corporation and Pure Gold Minerals Inc. (northern Alberta diamond joint venture). To the end of March 2005, 38 occurrences of kimberlite have been discovered in this region. The K5, K7A and K14 kimberlites from the Buffalo Head Hills have reported emplacement ages of between 86±3 and 88±5 Ma by U-Pb on perovskite (Carlson et al., 1999; Skelton et al., 2003). Inferred sizes of the pipes based on aeromagnetic signatures and drilling, range from less than 1 ha to approximately 45 ha (Carlson et al., 1999). At least three of the kimberlites (K14, K91 and K252) contain estimated diamond grades of >11 carats per hundred tonnes (cpht) based on 22.8 to 479.0 tonne (t) samples, with the best result coming from a preliminary K252 mini-bulk (22.8 t) sample with a grade of 55 cpht (Ashton Mining of Canada Inc., 2001).

As part of an initiative to study kimberlite-hostrock relationships in northern Alberta, the northern Alberta diamond joint venture donated approximately 675 m of sedimentary core that collectively records a continuous vertical Upper Cretaceous sedimentary section approximately 190 m thick. The cores are from drillholes that targeted eight known kimberlites within the Buffalo Head Hills kimberlite field (kimberlites K1, K5, K6, K14, K19, K91, K296 and K300; Figure 1; Appendix 1).

Seven separate bentonite horizons were located in cores from holes drilled into kimberlites K1 and K14 (Figure 1). A descriptive overview of the bentonite samples is presented in Table 1. The bentonite sample locations are shown on their corresponding drill logs from Skelton and Bursey (1999) in Appendix 1. Bentonites RE04-KHR-B001, RE04-KHR-B002 and RE04-KHR-B003 were sampled from drillhole DDH97-1A-3 and occur within a narrow zone (54 m to 55 m), where they mark distinct lithological changes between dark-grey, platy shale and black, blocky shale. The other four samples (RE04-KHR-B004 to RE04-KHR-B007) were collected from four separate drillholes that tested the K14 kimberlite.

In general, the bentonites are tan to yellow-brown, have blocky to waxy texture and range in thickness from 2.3 cm to 20 cm. Their contact with host lithologies, dominantly mudstone, is sometimes diffuse, but such that the collection of homogenous, clean, representative bentonite is possible.

Samples RE04-KHR-B005 and RE04-KHR-B007 can be differentiated from the other bentonites by the presence of micaceous flakes up to 1.5 mm in diameter that can be seen with the naked eye or through a low power (10x) hand lens. In addition, RE04-KHR-B005 and RE04-KHR-B007 are the only two samples that effervesce when subjected to 10% HCl and exhibit strong and moderate to strong 'fizz reactions', respectively. Carbonate enrichment is supported by standard powder x-ray diffraction analysis, which shows RE04-KHR-B005 and RE04-KHR-B007 are the only bentonites with contributions from calcite and dolomite (Table 1). Calcite and dolomite are a common component in northern Alberta kimberlite province kimberlites (Eccles, 2004).

In addition to the bentonite, two small intersections of resedimented volcaniclastic kimberlite were discovered in drillhole DDH97-14-C3 between 81.38 m and 81.54 m and at 82.09 m. One sample (RE04-KHR-K001) of tan-coloured, competent, olivine pseudomorph-rich kimberlite with minor (<5 vol. %)

Figure 1. Bedrock geology and location of kimberlite pipes in the Buffalo Head Hills kimberlite field.

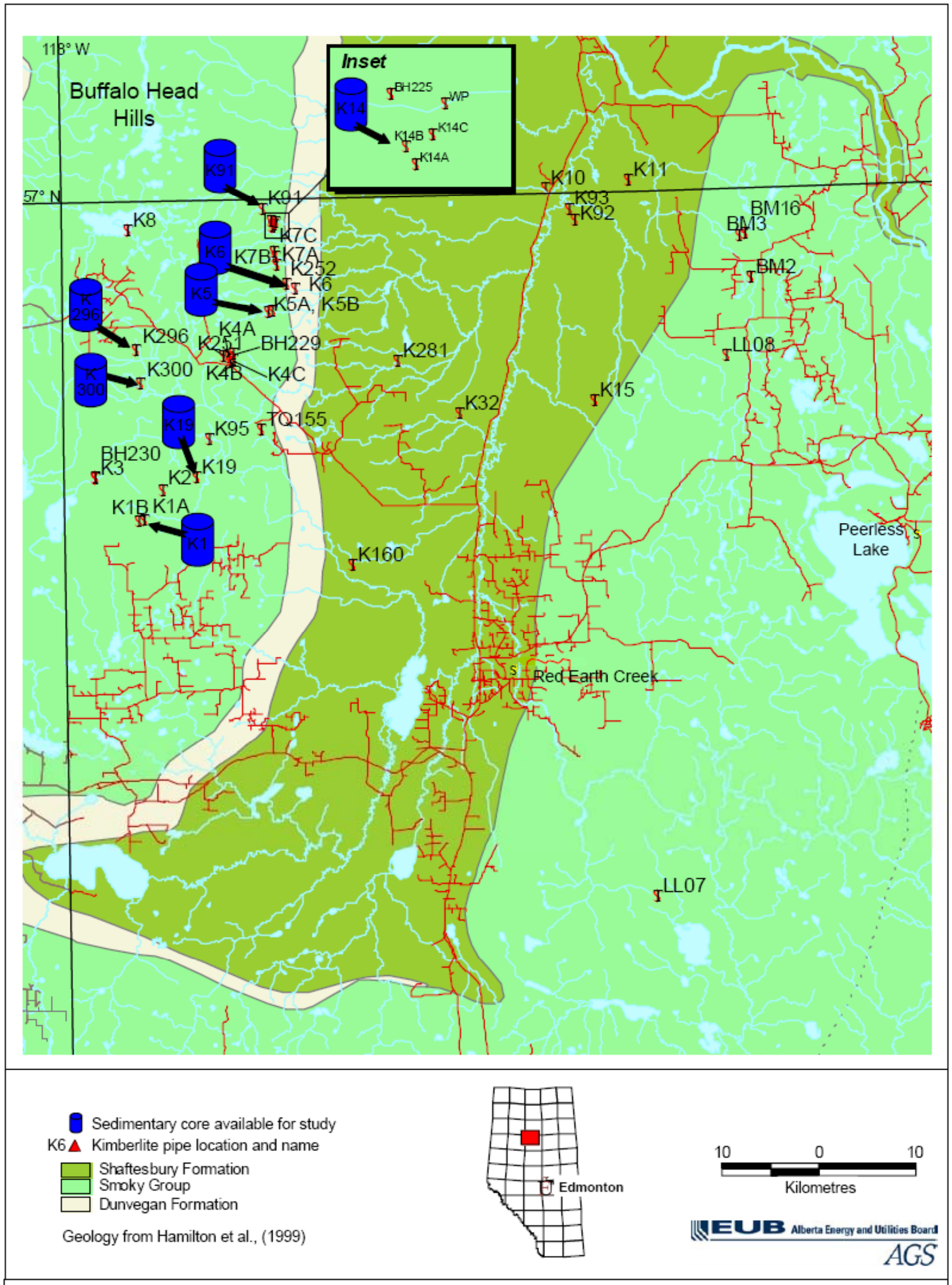

Figure 1. Bedrock geology and location of kimberlite occurrences in the Buffalo Head Hills kimberlite field.

Table 1. Sample description of seven bentonites and one kimberlite collected in the current study.

Bentonite sample ID	Drill hole ID	Sample depth: top (m)	Collar elevation (masl)	Sample thickness (cm)	Distance above (+) or below (-) kimberlite (m)	Colour	Texture	Contamination	Reaction to HCl	X-ray diffraction
RE04-KHR-B001	DDH97 1A-3	55.28	686	2.3	-13.5	Yellow to yellow-brown (weathers white-grey)	Blocky; intercalated shale contact	Minor (<5 vol. %) black, platy shale	No reaction	Gypsum - $CaSO_4 \bullet 2H_2O$; jarosite - $(K,H_3O)Fe_3(SO_4)_2(OH)_6$; quartz - SiO2; clay phases;
RE04-KHR-B002	DDH97 1A-3	54.71	687	13.5	-13	Yellow-brown (base) to tan-green (top)	Waxy; distinct contacts	No	No reaction	Clay - montmorillonite; gypsum - $CaSO_4 \bullet 2H_2O$; unidentified intensity peak
RE04-KHR-B003	DDH97 1A-3	54.3	687	5	-12.5	Tan to green-tan	Waxy; distinct contacts	No	No reaction	Clay - montmorillonite; gypsum - $CaSO_4 \bullet 2H_2O$; quartz - SiO_2; unidentified intensity peak
RE04-KHR-B004	DDH97 14-7	171.3	460	2.5	-1.5	Tan-grey	Blocky and waxy; diffuse contacts	No	No reaction	Clay - montmorillonite; quartz - SiO_2; albite - $NaAlSi_3O_8$
RE04-KHR-B005	DDH97 14C-7	30.33	580	18	+ 2.3	Tan to yellow-brown-tan	Crumby, altered; diffuse contacts	Mica flakes up to 1.5 mm in diameter	Strong 'fizz reaction'	Calcite - $CaCO_3$; dolomite - $Ca\ (Mg,Fe)(CO_3)_2$; clay phases
RE04-KHR-B006	DDH97 14B-3	20.65	599	20	+ 0.7	Tan to tan-yellow	Blocky and waxy; intercalated shale contacts	Sporadic intercalataed shale	No reaction	Quartz - SiO_2; albite - $NaAlSi_3O_8$; clay phases; unidentified intensity peaks
RE04-KHR-B007	DDH97 14C-1	64.56	545	11	- 3.9	Yellow to yellow-brown	Crumby, altered; diffuse contacts	Minor (<5 vol. %) sandstone and/or mica	Medium 'fizz reaction'	Siderite - $FeCO_3$; quartz - SiO_2; dolomite - $CaMg(CO_3)_2$; clay phases
Kimberlite sample ID										
RE04-KHR-K001	DDH97 14C-3	81.5	533	16		Tan	Competent, hard, olivine-rich, phlogopite-bearing resedimented volcaniclastic kimberlite; olivine generally altered		Strong 'fizz reaction'	

phlogopite and carbonate enrichment was taken for analysis to enable geochemical comparison with the bentonite.

3 Analytical Methodology

Seven bentonite samples were collected conscientiously to avoid contamination from the overlying and underlying hostrock. The samples were divided into analytical and archival sample splits with the former sent to ACME Analytical Laboratories Ltd. (Acme) in Vancouver, Canada, for the following analyses

- crushed and pulverized with mild steel and preservation of the +150 and -150 mesh fractions;
- Group 4A Whole-Rock and Group 4B Trace Elements by ICP: whole-rock by $LiBO_2$ fusion/dilute nitric digestion then inductively coupled plasma emission spectrometry (ICP-ES), rare-earth elements by $LIBO_2$ fusion/ICP-MS, and precious and base metals by aqua regia digest/inductively coupled plasma mass spectrometry (ICP-MS). This package includes loss on ignition and carbon and sulphur by Leco;
- Group 1EX 4-acid digestion: a 0.25 g split is heated in HNO_3-$HClO_4$-HF to fuming and taken to dryness. The residue is dissolved in HCl. Solutions are analyzed by ICP-MS; and
- Group 1F-MS with Pt, Pd: ICP-MS analysis of a 15 g sample after aqua regia digestion.

Analytical results included quality control (QC) samples inserted by Acme (standards and silica blanks) and Canadian Certified Reference Materials SY-4 (diorite gneiss) and WGB-1 (gabbro), which was inserted by this author and unknown to Acme.

The resultant geochemical data from these analyses are presented in Appendix 2 and discussed below.

X-ray diffraction standard powder method samples were prepared at the Alberta Geological Survey laboratory by grinding the sample to <125 µm with a ceramic mortar/pestle, and then analyzed at the Alberta Research Council using a Siemens D5000 XRD under the following conditions

1) Cu tube filtered with a graphite monochromator;
2) goniometer (2 circle goniometer with independent stepper motors for 0/0 movements);
3) scintillation detector;
4) slits (divergence slit 2 mm, detector slit 2 mm, antiscatter slit 0.6 mm);
5) 45 kV, 30 mA;
6) step size 0.03 degrees; and
7) measuring time dependent on the crystallinity of the sample – indicated by the counts per second and the noise to signal ratio (background noise).

Diffraction data were collected and processed using Siemens DIFFRAC AT Basic and Search/Match Software for semi-quantitative measurement of the phase concentration based on the relative peak intensity.

4 Geochemical Results

Lerbekmo (1968) and Scafe (1975) suggested the most common parent material to bentonites located in western Alberta is from intermediate to felsic volcanic eruptions with a gradual change towards more siliceous volcanism in the late Upper Cretaceous (Belly River Formation equivalent) to earliest Paleocene. Eccles et al. (1998) and Dufresne et al. (2002) have also documented intermediate to felsic source compositions in bentonite from northern Alberta. In the present study, five of the seven bentonite samples analyzed have source compositions similar to those described by the aforementioned authors and will only be discussed in minor detail below. More importantly, two bentonite samples have geochemical signatures diagnostic of kimberlite, and thus, attention is focused herein on the documentation of the first kimberlitic bentonites discovered in Alberta.

Kimberlites are rich both in elements of ultramafic affinity (Mg, Co, Ni, Cr) and in incompatible elements (e.g., light rare-earth elements [LREE], P, Nb), which gives these rocks their characteristic geochemical signature. Table 2 displays these elements for the current bentonite analyses, together with the kimberlite sample (RE04-KHR-K001) and previous selected whole-rock geochemical analysis of Buffalo Head Hills kimberlites (Eccles, 2004), for comparative purposes. Bentonites RE04-KHR-B005 and RE04-KHR-B007 have significantly higher values of ‘kimberlite-affinity elements’ in comparison to the other bentonites, particularly for Mg, Cr, Nb, LREE and Ni, and thus, have compositions that are undeniably closer to kimberlite than intermediate to felsic volcanic rocks.

Chondrite-normalized REE patterns are often used as a diagnostic geochemical indicator of kimberlite because these rocks represent products of either very low degree partial melting or larger degrees of partial melting of an enriched source. Hence, kimberlite is uniquely characterized by a simple, steep linear REE distribution pattern that displays strongly dominant light REE enrichment (La enriched 100 to 1000 times chondrite) and heavy REE depletion so that La/Yb ratios for most kimberlites are >80 (e.g., Mitchell, 1986). Figure 2a shows that RE04-KHR-B005 and RE04-KHR-B007 have completely different REE patterns than the other five bentonite samples, the later of which are more characteristic of intermediate to felsic rock types. Alternatively, RE04-KHR-B005 and RE04-KHR-B007 have kimberlitic chrondrite-normalized REE patterns, as indicated by their similarity to kimberlite sample (RE04-KHR-K001) and the field for northern Alberta kimberlite province kimberlites. The curving HREE, which is particularly evident in bentonite RE04-KHR-B007 and kimberlite RE04-KHR-K001, is likely related to contamination.

The La/Yb ratios of bentonites RE04-KHR-B005 and RE04-KHR-B007 are 250 and 107, respectively; significantly higher than the other bentonite samples, which have La/Yb ratios of between 14 and 21 (Table 2). RE04-KHR-B005 is well within the range of La/Yb ratios from the K14 kimberlite (228 to 280) and the Buffalo Head Hills kimberlite field average (214; Eccles, 2004). RE04-KHR-B007 is comparable to the kimberlite sample RE04-KHR-K001 (La/Yb of 119).

In a comparison of the potential for contamination of the bentonite samples with kimberlite affinities, bentonite RE04-KHR-B007 has higher SiO_2 (24.3 wt. %) and Al_2O_3 (8.9 wt. %) compositions than RE04-KHR-B005 (20.8 wt. % and 1.9 wt. %, respectively; Appendix 2). This suggests that bentonite RE04-KHR-B007 has some contribution from its host mudstone. As a test of contamination in the marine environment, bentonite REEs are normalized to the North American Shale Composite of Gromet et al. (1984). Again, bentonites RE04-KHR-B005 and RE04-KHR-B007 conform to the field of kimberlite rather than intermediate to felsic volcanic rocks (Figure 2b). With respect to contamination, lower overall REE abundance and flattening HREE pattern exhibited by RE04-KHR-B007 may be supportive of contamination in a marine setting. If this is the case, it is important to point out that despite the potential for HREE to be influenced in a marine depositional environment, the LREE are still elevated (up to 1066 times chondrite). This illustrates the importance of using incompatible elements for the determination of kimberlitic parent material in the WCSB.

Finally, one of the most common diagrams to infer the original magmatic composition from altered volcanic rocks uses the incompatible element ratios Zr/TiO_2 versus Nb/Y (Winchester and Floyd, 1977;

Table 2. Selected geochemical data for bentonites with kimberlite compositions for comparison.

Bentonite sample	MgO (wt. %)	P_2O_5 (wt. %)	Cr_2O_3 (wt. %)	Nb (ppm)	Sr (ppm)	La (ppm)	Ce (ppm)	Pr (ppm)	Ba (ppm)	Ni (ppm)	Co (ppm)	La/Yb
RE04-KHR-B001	0.70	1.19	0.002	8.5	516.9	42.0	68.2	8.9	13325.9	77.8	12.3	14
RE04-KHR-B002	4.80	0.17	0.001	6.9	111.2	32.3	70.8	8.8	111.0	56.2	10.7	14
RE04-KHR-B003	4.28	0.12	<.0005	6.9	49.4	29.8	60.4	7.5	98.7	22.8	6.4	14
RE04-KHR-B004	2.82	0.15	0.001	5.4	137.1	11.4	24.5	2.8	329.9	23.8	6.2	16
RE04-KHR-B005	11.75	0.64	0.170	155.3	2694.9	175.2	324.6	31.4	4691.9	1008.5	78.2	250
RE04-KHR-B006	2.03	0.14	0.013	20.6	297.9	39.4	81.2	8.8	832.9	148.7	15.6	21
RE04-KHR-B007	8.60	1.65	0.542	378.6	790.0	391.1	745.8	73.5	821.6	1800.1	137.0	107
Comparative kimberlite compositions												
RE04-KHR-K001	13.11	0.72	0.228	205.2	1100.0	232.8	453.1	44.5	747.9	1634.5	94.6	119
14-01 *	34.77	0.43	0.139	133.0	624.3	141.3	283.4	27.4	308.0	1280.0	86.9	248
14B-03 *	37.18	0.41	0.133	117.1	336.8	118.4	232.6	22.8	387.0	1340.0	100.1	228
14C-06 *	29.11	0.47	0.142	158.3	737.3	163.7	312.5	31.0	535.0	1279.0	87.3	282
14C-06 *	29.34	0.51	0.153	172.5	773.7	176.4	341.8	33.7	559.0	1280.0	91.4	280
K14 surface trench *	31.26	0.49	0.156	147.2	1162.3	159.9	313.7	30.3	944.0	1206.0	80.7	250
BHH average **	29.76	0.44	0.137	134.4	645.3	127.2	237.9	22.9	926.2	993.4	78.0	214

* Geochemical results from Eccles (2004); sample numbers refer to kimberlite K14 drill hole numbers

** Average compositions of 30 whole rock kimberlite analyses from 16 pipes in the Buffalo Head Hills (Eccles, 2004)

Shading highlights kimberlite-sourced bentonite

Figure 2. Rare-earth element patterns for bentonite samples with comparative rock types.

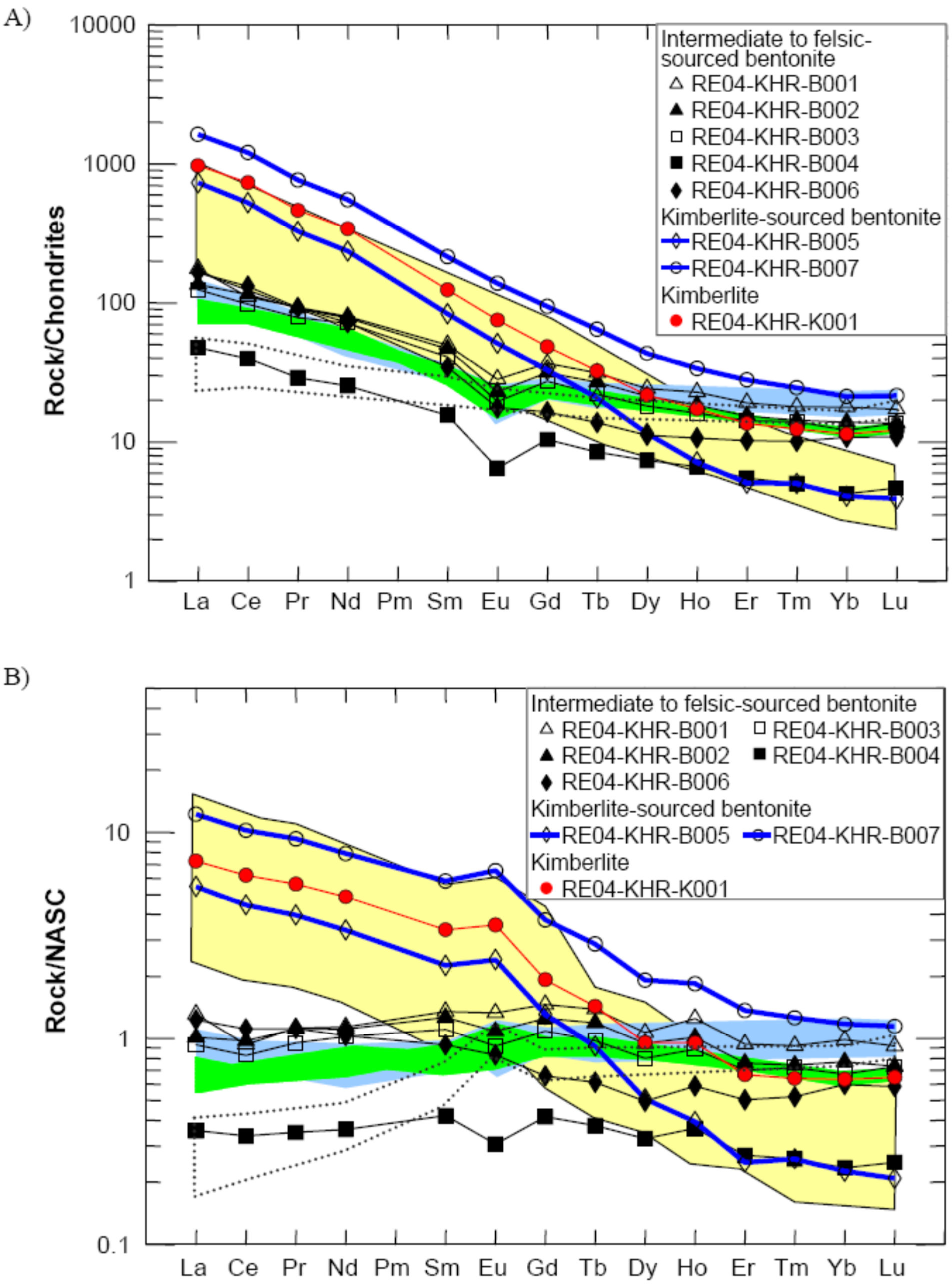

Figure 2. Rare earth element patterns for bentonite samples with comparative rock types. A) Chondrite-normalized (Sun and McDonough, 1989) rare earth element diagram. B) North American Shale Composite (NASC)-normalized (Gromet et al., 1984) rare earth element diagram. Kimberlitic bentonite samples RE04-KHR-B005 and RE04-KHR-B007 are highlighted with thicker dark blue lines. The kimberlite sample (RE04-KHR-K001) is designated with the red line and filled circles. Yellow polygon represents the northern Alberta kimberlite province field (Eccles, 2004). Dotted open, green and light blue polygons represent the fields for worldwide basalt, andesite and felsic volcanic rocks, respectively (Taylor and McLennan, 1985; Condie, 1993).

Pearce, 1996). Figure 3 shows that bentonites RE04-KHR-B005 and RE04-KHR-B007 have high Nb/Y ratios and plot within the northern Alberta kimberlite province field and adjacent to kimberlite sample RE04-KHR-K001. In contrast, the majority of the other bentonite samples plot in the field for rhyolite/dacite with samples RE04-KHR-B001 and RE04-KHR-B006 falling within the andesite/basalt and trachy-andesite/alkali basalt fields, respectively.

5 Other Observations

The geochemical data provide strong evidence for a kimberlite source for bentonites RE04-KHR-B005 and RE04-KHR-B007. Based on this deduction, other observations regarding the kimberlitic bentonites are listed in point form below.

- Given the regional distribution of over 70 Alberta intermediate to felsic volcanic-sourced bentonites (e.g., Byrne, 1955; Lerbekmo, 1968; Eccles et al., 1998; Dufresne et al., 2002) and knowledge that the kimberlitic bentonite described herein is located near kimberlite, the positive identification of future kimberlitic bentonite samples may be a good indication of a nearby kimberlite pipe and/or field.

- The nearness of intermediate to felsic volcanic-sourced bentonite to the kimberlite does not influence the geochemistry of the sample. Table 2 shows that the bentonite samples are all located vertically within 13.5 m of kimberlite. Two samples, RE04-KHR-B004 and RE04-KHR-B006 are within 1.5 and 0.7 m, respectively, yet neither sample has any kimberlite geochemical affinities.

- With respect to stratigraphic positioning, kimberlite bentonite samples RE04-KHR-B005 and RE04-KHR-B007 were located above and below volcaniclastic kimberlite, respectively. Naturally, eruptive ash clouds can be formed at the beginning and end of the volcanic event.

- Kimberlitic bentonite from the K14 complex occurs at elevations of 545 and 580 masl. This elevation should be coincident with syn-depositional kimberlite volcanism, and palynological dating of sedimentary rocks at this elevation might help to determine the emplacement age of the K14 kimberlite.

  While standard powder x-ray diffraction does record a calcite and dolomite component in the kimberlitic bentonites similar to northern Alberta kimberlite province kimberlites, there is no evidence for other common kimberlite minerals (e.g., lizardite, phlogopite). Hence, further x-ray diffraction work is recommended on the clay fraction, which may contain lizardite and other kimberlite minerals.

6 Potential Pitfalls for Future Geochemical Evaluations

The geochemical composition of any rock type may be influenced by interaction with the rock’s surrounding environment. Bentonites are no different and it is pertinent to remember that major and trace-element geochemistry of bentonite will not only depend on the mineralogical and chemical composition of the pyroclastic source, but may be affected by any number of syn- to post-depositional processes, such as

1) proximity to the vent source: soluble elements may be completely dispersed, whereas some elements such as Ti and Zr may be relatively immobile;

Figure 3. Bentonite samples plotted on the discrimination diagram of Winchester and Floyd (1977) and Pearce (1996).

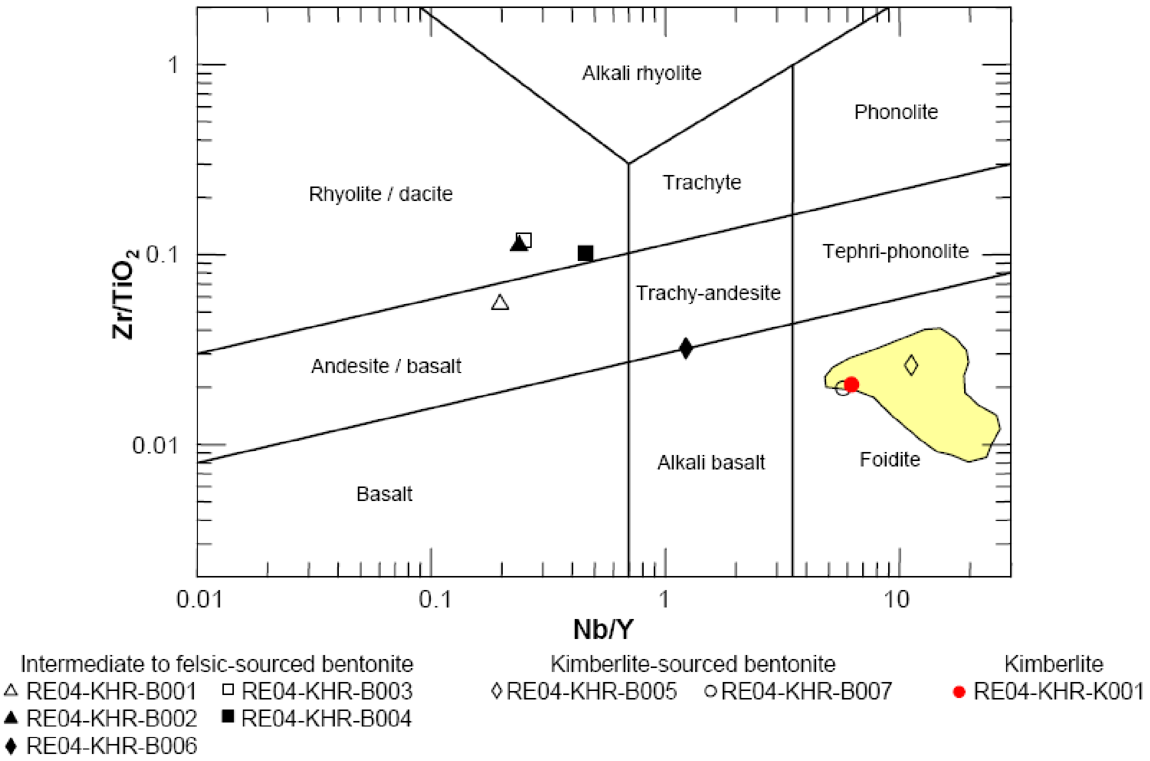

Figure 3. Bentonite samples plotted on the discrimination diagram of Winchester and Floyd (1977) and Pearce (1996). The kimberlite sample (RE04-KHR-K001) is designated with the red circle. The yellow polygon represents a field for kimberlite samples from the northern Alberta kimberlite province (Eccles, 2004).

2) winnowing of the pyroclastic cloud (e.g., by wind and water);
3) postdepositional modification by bioturbation;
4) physicochemical conditions present during alteration of glass to clay minerals and/or weathering;
5) ash deposition in a marine environment may be subjected to prolonged interaction with sea water, thereby altering its original signature; for example, authigenic clays take up REEs from seawater and may display an REE pattern similar to that of seawater (Chamley, 1989);
6) diagenetic modification of REE signatures may occur under highly reducing conditions where Eu is reduced from Eu^{3+} to Eu^{2+} and becomes mobile (MacRae et al., 1992); and
7) coexistence of foreign materials in the magma (e.g., crustal or mantle xenoliths in kimberlite) may influence the trace-element pattern of the ash.

7 Conclusions

Two bentonite samples collected during the investigation of sedimentary cores in the vicinity of the Buffalo Head Hills kimberlite field have been sourced from kimberlite. The presence of micaceous flakes and carbonate-enrichment in the form of calcite and dolomite help to characterize kimberlitic bentonite in hand samples.

Geochemical data, particularly immobile elements, provide strong evidence for the source magma, and clearly separate the kimberlitic bentonite from intermediate to felsic volcanic parental material typical of bentonite in the Alberta basin. The two bentonites have similar geochemical compositions to whole-rock kimberlite from the northern Alberta kimberlite province. The kimberlitic bentonites have

- elevated ultramafic (Mg, Co, Ni, Cr, Cu) and incompatible element (LREE, Ba, Sr, Rb, P, Nb) compositions;
- simple, steep linear REE distribution patterns that display strong LREE enrichment (La enriched 480 to 1,066 times chondrite) and HREE depletion; and
- high ratios of La/Yb (107 and 250) and Nb/Y (6 and 11).

While there is evidence that contamination of the bentonite in the marine environment can influence the HREE, the LREE and MREE are still such that kimberlitic affinities can be determined. This illustrates the importance of using incompatible elements for the determination of kimberlitic parent material in the WCSB.

Based on the conclusion that bentonites have kimberlite affinities, bentonite should not be ignored in field investigations in the Western Canada Sedimentary Basin. Bentonite characterization and geochemistry can provide a quick and cost effective means of testing kimberlite potential of an area. Once a potentially kimberlitic bentonite has been identified, an extensive vertical and lateral sampling program should be performed to test whether the bentonite has been influenced by the environmental setting. In addition, the locale should be further investigated through a variety of exploration methods, including other geochemical techniques, such as stream, till and bedrock heavy mineral concentrate sampling, which will hopefully lead to the implementation of a drill program and a new kimberlite discovery.

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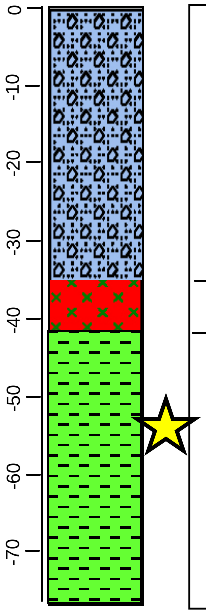
Appendix 1

Target:	K1A	Company:	Ashton Mining of Canada Inc.
Drill hole:	DDH1A-03	Azimuth:	180 º
Location:	569563, 62847512	Incline:	-58º
Zone, Datum:	11, NAD 27	Core diameter:	HQ
Elevation:	733 masl	Geologist:	D. Stickland
Start-End Date:	12-07-97 – 14-07-97	End of hole:	78.3 m

Description



Overburden: 0 to 35.1 m

Macrocrystic volcaniclastic kimberlite: 35.1 to 41.8 m

Mudstone: 41.8 to 78.3 m

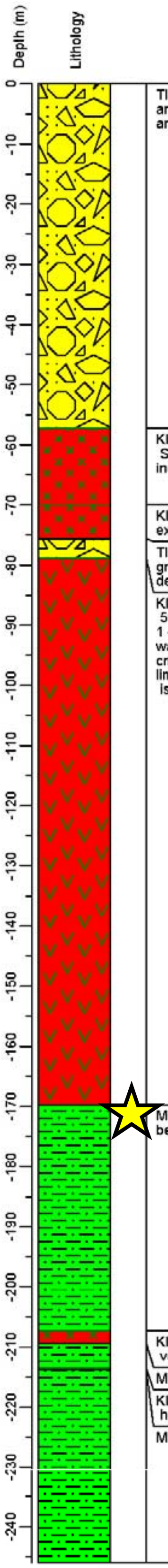
EOH: 78.3 m

★ Location of bentonite samples RE04-KHR-B001, RE04-KHR-B002 and RE04-KHR-B003

Appendix 1. Drill log DDH1A-03 (compliments of the northern Alberta diamond joint venture)

Appendix 1

Target:	**K14**	**Company:**	**Ashton Mining of Canada Inc.**
Drill Hole:	DDH14-07	Collar Azimuth:	°
Location:	583162E, 6315101N	Collar Incline:	-60 °
Zone & Datum:	Z11, NAD 27	Core Diameter:	63.5 mm (HQ)
Elevation:	605 m asl	Geologist Logging:	J. Ward/D. Skelton
Start - End Date:	25/10/1997 - 28/10/1997	End of hole (EOH):	245.96 m



Description

TILL: 0.00 - 57.23 m: Grey glacial till with subangular to subrounded clasts, 0.5 cm to 10 cm in size - large clasts are rare, sedimentary clasts are always small. Clasts mainly granitic or gneissic composition and are rounded. Sedimentary clasts such as limestone and siltstone are rare and more angular . Clasts <5% of unit, matrix is generally sandy in composition however some finer grained clay rich sections are present.

KIMBERLITE: 57.23 - 70.00 m: Kimberlite sand with minor gravel. Dark green-black granular unit with moderately sharp upper contact. Semi-consolidated but crumbles easily to a mica/serpentine olivine/carbonate sandy clay that reacts readily with HCl. Sand becomes increasingly coarse down the section. Grades into kimberlite gravel/boulder section below.

KIMBERLITE: 70.00 - 75.65 m: Kimberlite gravel and cobbles in a cb clayey sand matrix. Kimberlite clasts greenish to beige green when extremely carbonate and serpentine altered, up to 30 cm in size. Clasts are of an olivine lapilli tuff. Altered olivine macrocrysts

TILL: 75.65 - 78.81 m: Glacial till with some fining of grain size at depth and contains kimberlite clasts. Clasts of mainly subrounded granite/gneiss make up 1 - 2% of till, up to 5 cm. Kimberlite clasts are common, <5 cm in size and very altered. Matrix is sandy to silty clay at depth. No bedding is apparent.

KIMBERLITE TUFF: 78.81 - 169.77 m: Black green to light green fine grained macrocrystal tuff. 50% olivine, 45% carbonate/serpentine matrix, 5% xenoliths. The matrix is aphanitic carbonate/serpentine containing <1 mm altered olivine and trace ~1% brown mica. Olivine measure from 1 - 5 mm (rarely up to 1 cm), are fractured and replaced by carbonate, serpentine and black serpentine? -In some sections brown mica <1 mm was observed constituting up to 5%. Olivine-cored lapilli are sparse (2% max locally) and generally <5 mm, with only a few exceptions (up to 2 cm - 86.3 m). Lapilli are rounded and contain fine grained-olivine <1 mm in an aphanitic serpentine matrix. Xenoliths comprise granite and limestone with the occasional gneissic clast. Shale is relatively rare. Upper section is fragmented kimberlite with sand and shale. Lower contact is sharp at 64° to core axis.

MUDSTONE: 169.77 - 207.33 m: Dark grey brown to black brown colour . Fine grained, poorly consolidated beds of mud and silt. Individual beds <2 cm in width. Laminated beds 60 - 62° TCA. Occasional buff coloured ash beds, <~5 cm in width

KIMBERLITE: 207/33 - 209.39 m: Grey green, carbonate-olivine macrocrysts <5 mm. Contact at 28° to core axis. Some turbation and carbonate veining on lower contact.

MUDSTONE: 209.39 - 213.52 m: As described for intersection 169.77 - 207.33 m.

KIMBERLITE TUFF: 213.52 - 213.81 m: Graded tuff. Completely replaced to brown carbonate(?). Fine grained grading to coarse grained down hole. Relict macrocrysts and xenoliths. Contact is sharp at 58° to core axis.

MUDSTONE: 213.82 - 245.96 m: As described for intersection 169.77 - 207.33 m.

☆ Location of bentonite sample RE04-KHR-B004

Appendix 1. Drill log DDH14-07 (from Skelton and Bursey, 1999)

Appendix 1

Target:	**K14C**	**Company:**	**Ashton Mining of Canada Inc.**
Drill Hole:	DDH14C-07	Collar Azimuth:	°
Location:	583029E, 6315357N	Collar Incline:	-70 °
Zone & Datum:	Z11, NAD 27	Core Diameter:	85.0 mm
Elevation:	609 m asl	Geologist Logging:	Dave Skelton
Start - End Date:	20/10/1997 - 21/10/1997	End of hole (EOH):	76.80 m

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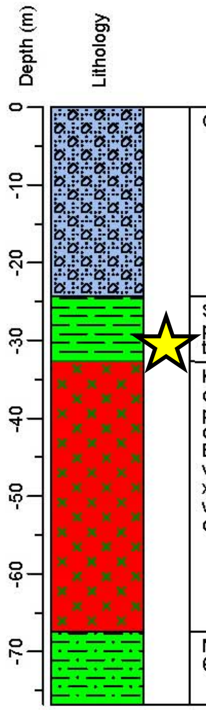

Description

OVERBURDEN: 0.00 - 24.38 m:

SHALE: 24.38 - 32.61 m: Dark grey to black shale. Unit is comprised of two alternating shale horizons: continuous shale and shale pebbles/fragments in a clay matrix. Talc alteration of the shale is prevalent throughout the unit (greasy shale). Shale fragments in the clay are typically pebble to cobble sized. Clay is not kimberlitic. Bedding is not well developed in competent sections.

KIMBERLITE: 32.61 - 67.50 m: Predominantly medium grey-green to pale beige-green. Variably altered olivine macrocrysts, 1 - 7.5 mm, comprise 40 - 60% of constituents. Olivines are rounded and internally fractured. Second population of fine grained, green, rounded olivine phenocrysts? Usually <1 mm locally altered, comprise 25 - 40% of fabric in anaphanitic light green serpentine + carbonate + clay matrix. Three distinct phases based on textural variations were observed: coarse olivine, fine olivine and a lapilli-rich section, transitions are gradual. Embayed olivine grains in shale were observed. Texture is relatively homogeneous over a given section of core (changes occur gradually) but is variable throughout the section. 5% rounded lapilli up to 2.0 cm (large lapilli are uncommon). <5% angular to predominantly rounded black shale xenoliths up to 3 cm -these are generally smaller and not common. Discontinuous weak to strong interstitial carbonate alteration in matrix and weak carbonate fracture network. No obvious preferred orientation to unit. Strong oxidation and large black shale xenoliths towards lower contact.

MUDSTONE: 67.50 - 76.80 m: Light grey, fine grained, weakly consolidated interbedded muds, silts, and sand. Locally well defined bedding at 60° TCA.

☆ Location of bentonite sample RE04-KHR-B005

Appendix 1. Drill log DDH14C-07 (from Skelton and Bursey, 1999)

Appendix 1

Target:	**K14B**	**Company:**	**Ashton Mining of Canada Inc.**
Drill Hole:	DDH14B-03	Collar Azimuth:	°
Location:	582820 , 6315277	Collar Incline:	0.00°
Zone & Datum:	Z11, NAD 27	Core Diameter:	85.0 mm
Elevation:	620 m asl	Geologist Logging:	Jeff Ward
Start - End Date:	26/10/1997 - 27/10/1997	End of hole (EOH):	92.05 m

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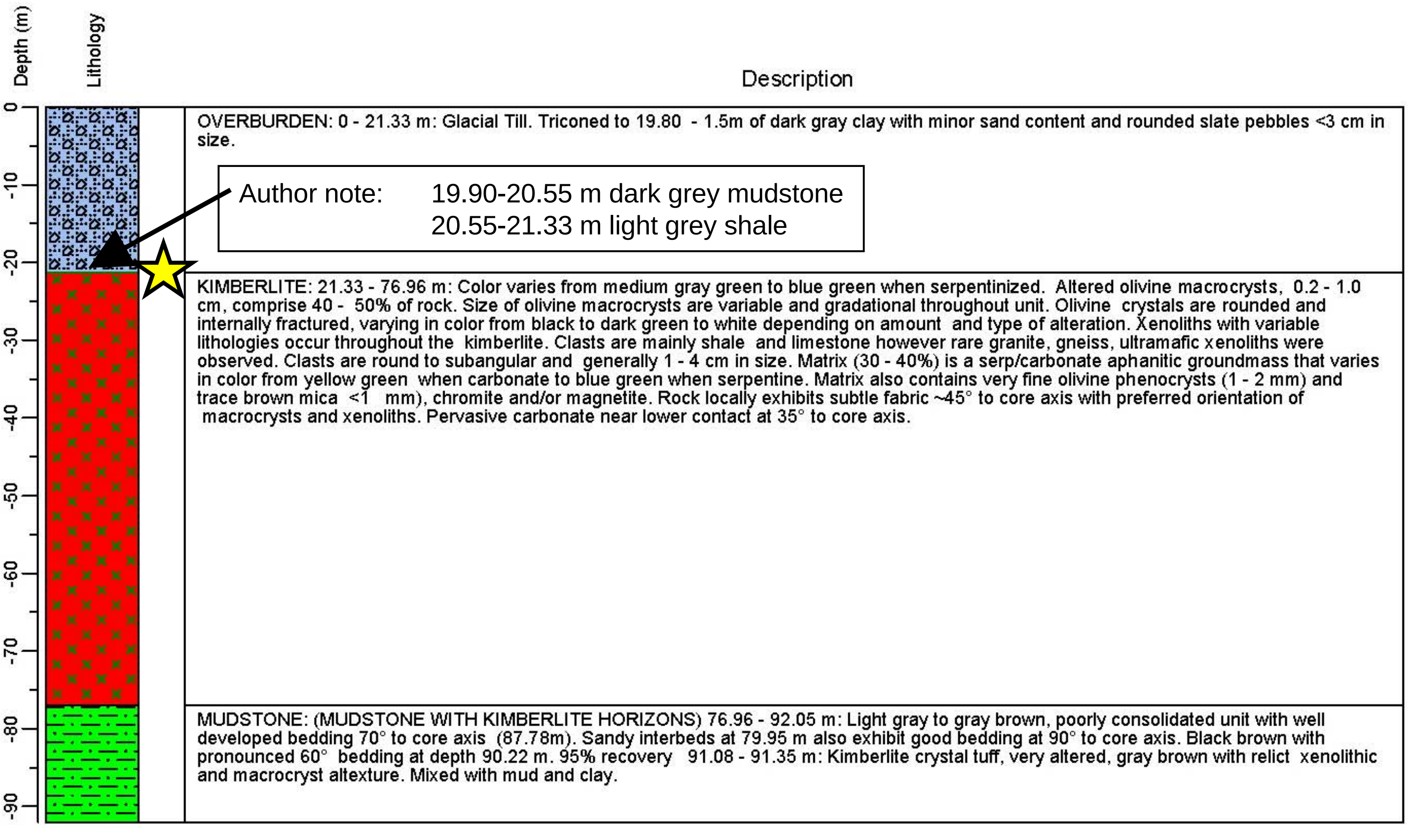

OVERBURDEN: 0 - 21.33 m: Glacial Till. Triconed to 19.80 - 1.5m of dark gray clay with minor sand content and rounded slate pebbles <3 cm in size.

Author note: 19.90-20.55 m dark grey mudstone
20.55-21.33 m light grey shale

KIMBERLITE: 21.33 - 76.96 m: Color varies from medium gray green to blue green when serpentinized. Altered olivine macrocrysts, 0.2 - 1.0 cm, comprise 40 - 50% of rock. Size of olivine macrocrysts are variable and gradational throughout unit. Olivine crystals are rounded and internally fractured, varying in color from black to dark green to white depending on amount and type of alteration. Xenoliths with variable lithologies occur throughout the kimberlite. Clasts are mainly shale and limestone however rare granite, gneiss, ultramafic xenoliths were observed. Clasts are round to subangular and generally 1 - 4 cm in size. Matrix (30 - 40%) is a serp/carbonate aphanitic groundmass that varies in color from yellow green when carbonate to blue green when serpentine. Matrix also contains very fine olivine phenocrysts (1 - 2 mm) and trace brown mica <1 mm), chromite and/or magnetite. Rock locally exhibits subtle fabric ~45° to core axis with preferred orientation of macrocrysts and xenoliths. Pervasive carbonate near lower contact at 35° to core axis.

MUDSTONE: (MUDSTONE WITH KIMBERLITE HORIZONS) 76.96 - 92.05 m: Light gray to gray brown, poorly consolidated unit with well developed bedding 70° to core axis (87.78m). Sandy interbeds at 79.95 m also exhibit good bedding at 90° to core axis. Black brown with pronounced 60° bedding at depth 90.22 m. 95% recovery 91.08 - 91.35 m: Kimberlite crystal tuff, very altered, gray brown with relict xenolithic and macrocryst altexture. Mixed with mud and clay.

★ Location of bentonite sample RE04-KHR-B006

Appendix 1. Drill log DDH14B-03 (from Skelton and Bursey, 1999)

Appendix 1

Target:	**14C**	**Company:**	**Ashton Mining of Canada Inc.**
Drill Hole:	DDH14C-01	Collar Azimuth:	°
Location:	583029E, 6315357N	Collar Incline:	-90 °
Zone & Datum:	Z11, NAD 27	Core Diameter:	85.0 mm
Elevation:	610 m asl	Geologist Logging:	Derrick Strickland
Start - End Date:	09/10/1997 - 11/10/1997	End of hole (EOH):	81.83 m

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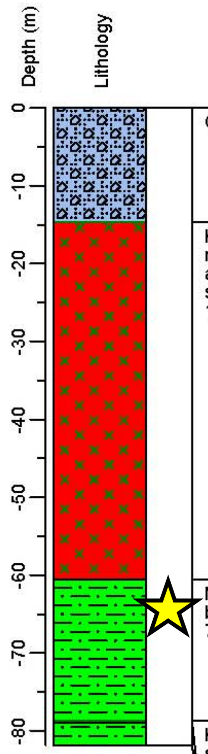

Description

OVERBURDEN: 0.00 - 14.70 m: Brown-green, silty till, variably clast-rich and poor.

KIMBERLITE: 14.70 - 60.60 m: Green, medium to coarse grained, equigranular volcaniclastic kimberlite, consisting of rounded olivine macrocrysts, light green-brown in colour 3 x 3 mm, (35 - 40% of the rock) and a microcryst population of <1 mm olivine which constitutes another 30%, all in a serpentine matrix. Much of the olivine has been serpentinized as well. Xenoliths of fine black shale up to 3.0 x 7.5 cm in size comprise 5 - 10% of the rock. Xenoliths of carbonate, <3 x 2 cm are also present, 3 - 5%. Lapilli and/or autoliths are present in amounts of 15-20%.

MUDSTONE: (MUDSTONE AND SANDSTONE) 60.60 - 66.14m: Grey in colour, fine grained, not yet fully consolidated, has a muddy feel with bedding 30°- 40° TCA. 66.14-70.10 m: Sandstone: Grey-brown, fine-grained, unconsolidated. 70.10 - 75.28 m: Mudstone, as above. 75.28 - 75.79 m: Sandstone, as above. 75.79 - 78.72 m: Mudstone, as above.

KIMBERLITE TUFF: 78.72 - 78.93 m: Grey in colour, medium to coarse grained, silica rich, 30 - 40% looks like the olivine has been altered to silica. Lapilli 5 - 10%, with largest being 1.2 x 1.2 cm altered to light green with a kernel of silicified olivine. Carbonate crystals are up to 1x1 mm, <1% of the rock. Shale xenoliths 10 - 15%, up to 0.5 x 0.5 cm, black. Contacts above and below are sharp, 70° TCA and show minor amounts of contact alteration. Upper contact fine grained for 1 cm and is darker gray than the rest of section.

MUDSTONE: 78.93 - 81.83 m: Grey, fine grained, muddy, not fully consolidated, bedding at 30 - 40° TCA.

★ Location of bentonite sample RE04-KHR-B007

Appendix 1. Drill log DDH14C-01 (from Skelton and Bursey, 1999)

Target:	**K14C**	**Company:**	**Ashton Mining of Canada Inc.**
Drill Hole:	DDH14C-03	Collar Azimuth:	°
Location:	583029E, 6315357N	Collar Incline:	-70 °
Zone & Datum:	Z11, NAD 27	Core Diameter:	85.0 mm
Elevation:	609 m asl	Geologist Logging:	Derrick Strickland
Start - End Date:	13/10/1997 - 15/10/1997	End of hole (EOH):	82.90 m

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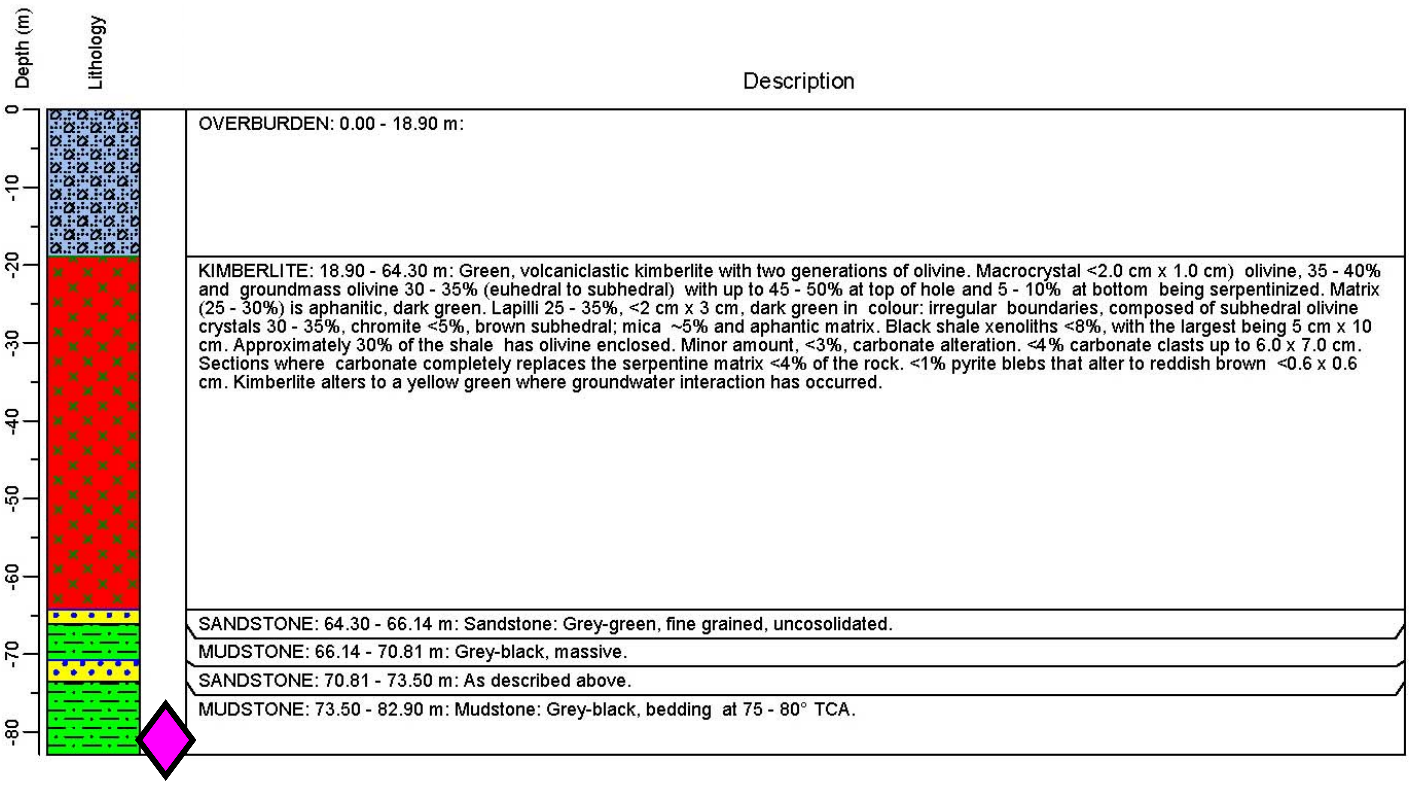

OVERBURDEN: 0.00 - 18.90 m:

KIMBERLITE: 18.90 - 64.30 m: Green, volcaniclastic kimberlite with two generations of olivine. Macrocrystal <2.0 cm x 1.0 cm) olivine, 35 - 40% and groundmass olivine 30 - 35% (euhedral to subhedral) with up to 45 - 50% at top of hole and 5 - 10% at bottom being serpentinized. Matrix (25 - 30%) is aphanitic, dark green. Lapilli 25 - 35%, <2 cm x 3 cm, dark green in colour: irregular boundaries, composed of subhedral olivine crystals 30 - 35%, chromite <5%, brown subhedral; mica ~5% and aphantic matrix. Black shale xenoliths <8%, with the largest being 5 cm x 10 cm. Approximately 30% of the shale has olivine enclosed. Minor amount, <3%, carbonate alteration. <4% carbonate clasts up to 6.0 x 7.0 cm. Sections where carbonate completely replaces the serpentine matrix <4% of the rock. <1% pyrite blebs that alter to reddish brown <0.6 x 0.6 cm. Kimberlite alters to a yellow green where groundwater interaction has occurred.

SANDSTONE: 64.30 - 66.14 m: Sandstone: Grey-green, fine grained, uncosolidated.

MUDSTONE: 66.14 - 70.81 m: Grey-black, massive.

SANDSTONE: 70.81 - 73.50 m: As described above.

MUDSTONE: 73.50 - 82.90 m: Mudstone: Grey-black, bedding at 75 - 80° TCA.

◆ Location of kimberlite sample RE04-KHR-K001

Appendix 1. Drill log DDH14C-03 (from Skelton and Bursey, 1999)

Appendix 2. Geochemical data

	Element	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3	Sc	LOI	TOT/C	TOT/S	SUM	Be	Co	Cs	Ga	Hf	Nb	Rb
	Unit	%	%	%	%	%	%	%	%	%	%	%	ppm	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Sample	Analysis *	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4A	G4B	G4B	G4B	G4B	G4B	G4B	G4B
RE04-KHR-B001		25.11	7.13	16.74	0.7	7.83	0.58	1.37	0.24	1.19	0.03	0.002	8	37.5	1.06	9.47	98.43	1	12.3	0.7	6.3	2.9	8.5	42.9
RE04-KHR-B002		47.8	15.52	3.8	4.8	1.27	0.2	0.23	0.22	0.17	0.03	0.0013	6	25.7	0.07	1.79	99.76	1	10.7	0.1	18.4	5.8	6.9	5.9
RE04-KHR-B003		50.62	16.66	2.89	4.28	0.71	0.22	0.24	0.28	0.12	0.02	<.0005	7	23.8	0.08	0.66	99.84	1	6.4	0.2	20.1	7.3	6.9	5.4
RE04-KHR-B004		54.64	17.44	2.46	2.82	1.45	0.36	0.44	0.13	0.15	0.02	0.0008	3	20.1	0.16	0.17	100.02	1	6.2	1	24	5.7	5.4	18.6
RE04-KHR-B005		20.84	1.92	3.68	11.75	28.86	0.2	0.14	0.92	0.64	0.32	0.17	11	29.3	6.31	0.03	98.88	1	78.2	0.3	5.1	4.7	155.3	7.4
RE04-KHR-B006		64.35	13.33	5.54	2.03	0.14	0.83	2.97	0.72	0.14	0.01	0.0129	15	9.8	0.56	0.76	99.89	2	15.6	8.3	17.7	4.5	20.6	140.8
RE04-KHR-B007		24.25	8.89	20.3	8.6	4.86	0.32	1.1	2.33	1.65	0.31	0.542	31	26	5.01	0.74	99.36	2	137	1.9	16.2	9.8	378.6	50.7
RE04-KHR-K001		8.63	2.87	9.49	13.11	26	0.22	0.52	1.21	0.72	0.27	0.2281	21	36.1	10.56	0.46	99.55	2	94.6	0.3	4.1	3.3	205.2	21

	Element	Sn	Sr	Ta	Th	U	V	W	Zr	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
	Unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Sample	Analysis *	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B	G4B
RE04-KHR-B001		1	516.9	0.3	10.7	25.3	236	1.2	78.6	43.1	42	68.2	8.89	37.6	7.7	1.65	7.6	1.18	6.18	1.3	3.19	0.46	3.05	0.44
RE04-KHR-B002		2	111.2	0.9	15.4	9.3	26	0.2	146.2	29	32.3	70.8	8.77	36.6	7.2	1.34	6.51	1.01	5.47	1.05	2.57	0.37	2.38	0.35
RE04-KHR-B003		1	49.4	1	5.1	3.1	65	0.2	200	27.6	29.8	60.4	7.52	33.7	6.3	1.14	5.65	0.83	4.65	0.92	2.38	0.36	2.08	0.35
RE04-KHR-B004		4	137.1	3.8	31.9	12.1	25	0.3	79.1	11.8	11.4	24.5	2.76	11.9	2.4	0.38	2.16	0.32	1.89	0.38	0.92	0.13	0.73	0.12
RE04-KHR-B005		<1	2695	6.4	23.6	3.6	55	0.4	143.6	13.8	175	324.6	31.4	111	12.9	2.99	6.81	0.78	2.95	0.41	0.85	0.13	0.7	0.1
RE04-KHR-B006		2	297.9	1	9.2	2.8	278	1.6	138.4	16.8	39.4	81.2	8.83	34	5.3	1.03	3.41	0.52	2.87	0.61	1.71	0.26	1.85	0.28
RE04-KHR-B007		2	790	20.9	55.9	9	174	2.5	276.3	65.7	391	745.8	73.5	261	33.2	8.11	19.58	2.44	11.1	1.92	4.65	0.63	3.64	0.55
RE04-KHR-K001		<1	1100	12.5	32.1	5.5	62	1.3	149.7	32.8	233	453.1	44.5	161	19.2	4.41	10.04	1.22	5.54	0.99	2.27	0.32	1.96	0.31

	Element	Ba	Mo	Cu	Pb	Zn	Ag	Ni	Mn	Fe	As	Au	Cd	Sb	Bi	Cr	Mg	Ti	Li	Tl	Hg	Se	Pd	Pt
	Unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	%	%	ppm	ppm	ppb	ppm	ppb	ppb
Sample	Analysis *	G4B	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1EX	G1F15	G1F15	G1F15	G1F15	G1F15
RE04-KHR-B001		13325.9	117.9	73	13.8	198	0.1	77.8	221	10.68	185	<.1	3.6	9.5	0.2	11.8	0.37	0.15	12.1	0.88	97	32.5	<10	2
RE04-KHR-B002		111	5.8	21.8	23.9	169	0.1	56.2	251	2.75	34	<.1	2.2	1.9	0.3	1.9	2.59	0.14	96.9	0.4	15	1.4	<10	<2
RE04-KHR-B003		98.7	14.4	15.8	26.1	74	0.1	22.8	177	2.15	28	<.1	0.8	2.7	0.3	2	2.43	0.19	122	0.52	8	2	<10	<2
RE04-KHR-B004		329.9	1	4.9	20.3	161	0.1	23.8	183	1.82	4	<.1	0.4	0.4	0.7	4	1.56	0.09	24.9	0.09	16	0.1	<10	<2
RE04-KHR-B005		4691.9	0.6	34.2	8.3	68	0.1	1009	3168	2.92	20	<.1	0.3	0.6	0.1	402.4	6.66	0.63	67.3	0.25	94	0.1	<10	<2
RE04-KHR-B006		832.9	1.6	35.8	19.6	72	<.1	148.7	71	4.17	17	<.1	0.1	1.3	0.3	102.1	1.22	0.44	81.9	0.32	118	0.8	<10	<2
RE04-KHR-B007		821.6	7.4	110.8	25.8	202	0.2	1800	2804	14.3	89	<.1	0.6	6.7	0.2	3241.1	4.9	1.52	28.4	0.2	250	0.8	<10	7
RE04-KHR-K001		747.9	5	47.4	16.5	89	<.1	1635	2443	6.96	136	<.1	0.5	2.5	0.1	805.5	7.07	0.77	10	0.67	178	1.2	<10	3

* G4A - Group 4A whole rock; G4B - Group 4B trace element; G1EX - 4-acid digestion/ICP-MS; G1F15 - aqua regia/ECP-MS (see text for further explanation)