Kimberlite Indicator Minerals in the Fort Nelson Area, Northeastern British Columbia

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ABSTRACT

Parts of northeastern British Columbia are underlain by Precambrian basement that belongs to the North American craton. These areas have a moderate exploration potential for diamonds in terms of the traditional 'diamondiferous mantle root model'. The potential of any area to host kimberlite or lamproite-hosted diamond deposits may be assessed based on the thickness and age of basement rocks, geophysical anomalies and other data sets including the presence of kimberlite indicator minerals (KIMs) in Quaternary sediments. This study concentrates mainly on KIMs presence in Late Pleistocene glaciofluvial sands and gravels. Of the 20 samples collected and processed, 14 contain KIMs such as purple pyrope, yellowish eclogitic garnet, Cr-diopside, olivine, ilmenite or spinel. It is probable that some of these KIMs were derived from primary and secondary sources within the Fort Nelson area, however others may have been transported to the Fort Nelson area from the Northwest Territories and Alberta by Late Pleistocene glacial and/or glaciofluvial systems. Corundum and diaspore were also recovered from collected samples. At this stage, semiquantitative data do not allow for a definitive interpretation as to whether this corundum is kimberlite-related.

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INTRODUCTION

Rich deposits of high-quality diamonds have been documented within the Slave Craton of Northwest Territories (Carlson *et al.*, 1999; Lockhard *et al.*, 2004), approximately 600 km northeast of the Fort Nelson area. Several of these deposits are currently being mined or are under development. Primary diamond deposits have been discovered in the Buffalo Head Terrane in neighbouring Alberta (Eccles, 2002; Hood and McCandless, 2004), approximately 400 km southeast of the Fort Nelson area. Several alluvial diamond occurrences have been also reported in the literature (Fig. 1). Recently, indicator minerals and diamonds, in association with gem-like corundum, were reported in surficial material of the Blackwater Lake area, located in the western sector of the Northwest Territories, some 600 km north of the Fort Nelson area (Dow, 2003, 2004).

Diamond occurences have been reported in British Columbia's Alkaline province, as shown in Figure 1. (Northcote, 1983a, b; Pell 1994; Anonymous, 1994; McCallum, 1994; Allan, 1999, 2002; Roberts, 2002). The similarities between the geological settings of northern Alberta and northeastern British Columbia, and the findings in past research indicate that there is potential for primary (kimberlite, lamproite, or lamprophyres-hosted) and/or secondary (placer or paleoplacer in the Paleozoic sedimentary sequence) diamond occurrences in British Columbia. Documented diamond occurrences in British Columbia have been summarized by Simandl (2004).

The main objective of this study is to examine glaciofluvial sands and gravels for the presence of kimberlite indicator minerals (KIMs) in the Fort Nelson area. A second paper, to be released later this year will contain results of 50 additional samples collected as far as 200 km west and 350 km south of the Fort Nelson area, from Muncho Lake Park to Dawson Creek.

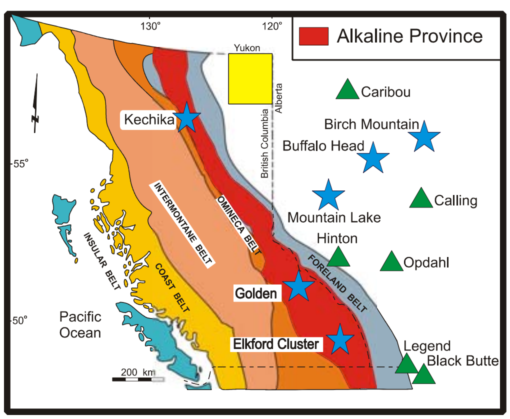

Figure 1. Location of study area (in yellow). Known primary (star) and secondary (triangle) diamond occurrences in British Columbia and Alberta are also provided. Crossing Creek diatreme, within the Elkford cluster, is the only confirmed kimberlite in British Columbia (*modified from* Simandl,2004).

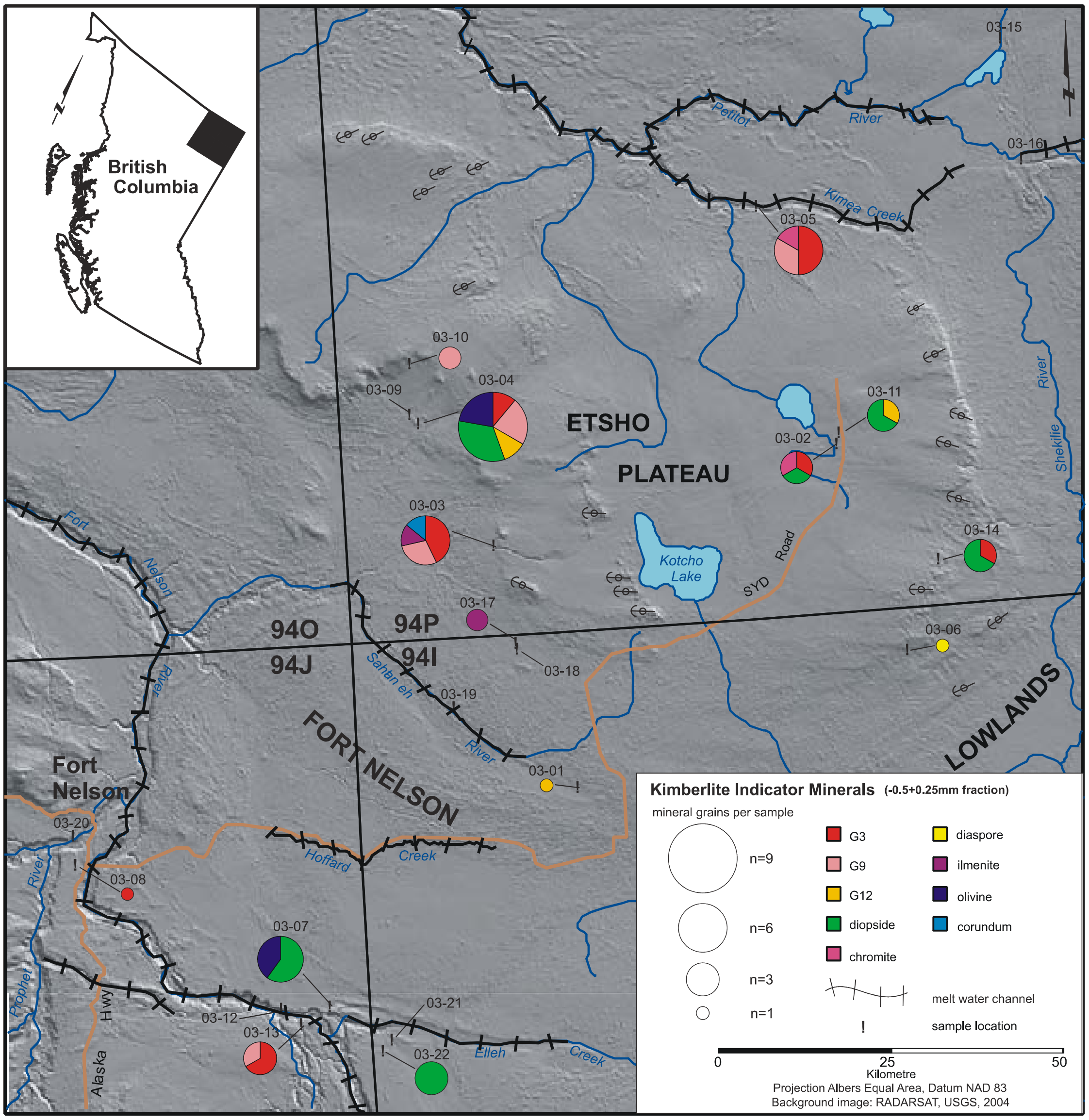

Figure 2. Location of glaciofluvial samples. Samples with kimberlite indicator minerals (KIMs) are shown; grain counts for each mineral type in brackets. Regional ice-flow directions, and orientations of major meltwater channel systems are provided.

LOCATION AND PHYSIOGRAPHY

The study area is located northeast of Fort Nelson, and is included in portions of NTS map areas of 094I/north, 094P and 094J/northeast (Fig. 2). The majority of the study area occurs within the Fort Nelson Lowlands physiographic region which is a subdivision of the Interior Plains (Holland, 1976).

This area is characterized by flat to subdued topography, which is an expression of the horizontally to subhorizontally bedded sedimentary rocks that underlie the region. The combination of low-relief topography and clay-rich soils results in poor drainage, and a shallow water table is present in most areas. Small shallow lakes and narrow, often meandering, low-gradient streams are common. However, larger river systems, such as the Fort Nelson, Prophet, and Petitot rivers, occur in the region.

In contrast to the lowlands, the Etsho Plateau stands approximately 700 m above sea level (Fig. 2). This feature forms a broad topographic high, 140 km long by 80 km wide, that trends roughly northwest. The plateau rises up to 300 m above the surrounding Fort Nelson Lowlands and is thought to be an outlier of the Alberta Plateau (Holland, 1976).

BEDROCK GEOLOGY

Precambrian Basement

Parts of British Columbia east of the Rocky Mountain Trench system and the alkaline province, including the Fort Nelson area, are underlain by a Precambrian basement that belongs to the North American craton (Hoffman, 1988, 1989, 1991; Ross *et al.*, 1991, 1995; Villeneuve *et al.*, 1993). This basement may contain kimberlite or lamproite-hosted diamond occurrences (Simandl, 2004). The boundaries of individual basement terranes are based largely on geophysical interpretation, geological extrapolation and isolated radiometric ages (Pilkington *et al.*, 2000). One of these basement terranes, commonly referred to as Archean Nova Terrane, is located south and southeast of the Fort Nelson study area and is believed to be of Archean age.

There are not enough isotopic dates to confirm the prevailing hypothesis that the Nova Terrane is a slice of Archean Slave craton. Zircons recovered from Penn West's borehole Numac Septimus 7-27-81-18 suggest that the Nova Terrane may be related to Buffalo Head Hill Terrane (Simandl and Davis, 2005), indicating that the current basement subdivision is unreliable at best. It is possible that some of the basement terranes currently located in northeastern British Columbia were previously associated with a deep crustal keel (Simandl, 2004). Such keels are characterized by old, thick and stable cratons, as illustrated by the 'Diamondiferous Mantle Root' model, described by Haggerty (1986), Mitchell (1991), Kirkley *et al.* (1991), and Helmstaedt and Gurney (1995), and commonly used to explain Clifford's rule (Janse, 1994). Such roots however, may have since been destroyed.

Most kimberlite pipes in the Northwest Territories were emplaced between 45 and 75 Ma (Lockhart *et al.*, 2004). Within the Lac de Gras area, pipes with the highest diamond potential seem to be restricted to periods of emplacement of 51 to 53 Ma and 55 to 56 Ma (Creaser *et al.*, 2004). In northern Alberta, radiometric ages of kimberlite emplacement range from 70.3 ± 1.6 Ma to 88 ± 5 Ma (Eccles *et al.* 2004). The radiometric ages of lamprophyres, lamproites and kimberlites within the British Columbia alkaline province vary from 391 ± 12 Ma for HP pipe to approximately 240 Ma (Smith *et al.*, 1988; Pell, 1994). It is possible that pipes of similar age to those listed above cut comparable or older stratigraphic levels in northeastern British Columbia.

Mesozoic Rocks

Bedrock outcrops in the study area are rare except along stream cuts and in some excavations on the Etsho Plateau. The Fort Nelson Lowlands are predominantly underlain by marine shales of the Shaftsbury Formation, part of the Lower Cretaceous Fort St. John Group. These shales are dark grey and flaky to fissile, and are interpreted to have been deposited in a prodelta or shelf environment during a transgression of an embayment in Early Cretaceous time (Thompson, 1977). These rocks are part of the Blaimore foredeep clastic wedge tectonic assemblage (Journeay et al., 2000).

Directly overlying the Fort St. John Group, and forming the resistive cap of the Etsho Plateau, are sandstones of the Duvegan Formation, of the Upper Cretaceous Smoky Group. On the Etsho Plateau these sandstones are mainly fine grained; however elsewhere in northeastern British Columbia, the Duvegan Formation ranges from clay-rich shales and mudstones to boulder conglomerates. This variability is attributable to the contrasting deltaic and prodeltaic depositional environments in which these rocks are interpreted to have been deposited during a regressive cycle. The contact between the Dunvegan and Shaftsbury formations is gradational and consists of sandy siltstones and fine-grained sandstones interbedded with silty shales (Thompson, 1977; Stott, 1982). The stratigraphy and sedimentology of the Dunvegan Formation have recently been discussed in detail by Plint *et al.* (2001), Plint (2002), and Plint and Wadsworth (2003). These rocks are part of the Trevor wedge tectonic assemblage (Journeay et al., 2000).

SURFICIAL GEOLOGY

The dominant surficial materials in the study area are silt and clay-rich morainal deposits. They typically occur at the surface in better-drained forested areas, and are overlain by organic materials and/or glaciolacustrine sediments in poorly drained areas. Moraine landforms include low-relief plains, crevasse-squeeze ridges, flutes and rolling, recessional and interlobate moraines (Levson *et al.*, 2004). Quaternary studies on the Alberta side of the border have described similar surficial materials and glacial features (e.g., Plouffe *et al.*, 2004; Paulen *et al.*, in press; Smith *et al.*, in press).

Glaciofluvial landforms are relatively uncommon in the region, although eskers, kames, fans, deltas and terraces can occasionally be observed. Most of the larger terrace features occur within the Kimea Creek – Petitot River meltwater channel system (Fig. 2). Other large meltwater channel systems occur in the study area (e.g., Fort Nelson River, Elleh Creek) and contain elevated glaciofluvial landforms that are thought to be ice proximal and/or subglacial in origin. Glaciofluvial sands and gravels were locally deposited in smaller meltwater channel systems (e.g., Hoffard Creek), although many of these systems appear to be almost entirely erosional and may have formed subglacially (Levson *et al.*, 2004). Irrespective of type and size of glaciofluvial landform, the presence of clast rock types from the Precambrian Shield (red and pink granites and gneisses) indicate that these glaciofluvial sands and gravels have an eastern provenance, or are derived from tills with an eastern provenance.

Quaternary History

During the Late Pleistocene (after 25 000 years BP), the Laurentide ice sheet advanced westward up the regional slope into northeastern British Columbia. The region was covered by ice during the glacial maximum. The configuration of advancing and retreating ice fronts was complex, as indicated by crosscutting relationships observed in large-scale landforms (e.g., flutes, crag and tail landforms and recessional moraines).

The regional ice-flow record is preserved almost exclusively in flutes and crag-and-tail ridges that occur on, and along, the periphery of the Etsho Plateau (Fig. 2). Although, in general terms, the Laurentide ice sheet moved into the region from the east and northeast, there is variability in the details of this glacial advance. As seen in Figure 2, differing orientations of large-scale landforms suggest that multiple ice-flow events occurred in the region during the Late Wisconsinan and that ice lobes were active during the later stages of glaciation. While the orientations of some features likely indicate divergent flow around topographic barriers (e.g., southeast portions of the Etsho Escarpment), the orientations of other features located in the northeastern and east-central portions of the Etsho Escarpment suggest that topography had less influence in these areas.

During retreat of the Laurentide ice sheet, numerous meltwater channels were incised by streams generally flowing west, away from the retreating ice sheet. Glacial lakes commonly developed along the ice margin as drainage down the regional slope to the east was blocked by the ice (Mathews, 1980). For example, Glacial Lake Hay formed in the lowlands southeast of Kotcho Lake and extended east into Alberta, as a result of damming by the eastward retreating Laurentide ice sheet. This resulted in the widespread deposition of clay-rich glaciolacustrine sediments over pre-existing Quaternary deposits. These fine-grained deposits are common and are one reason why glaciofluvial deposits occur only rarely at surface in the region.

SAMPLE COLLECTION, PROCESSING AND ANALYSIS

During the 2003 field season, 20 samples of glaciofluvial sands and gravels were collected (Fig. 2). Sample weights typically ranged from 20 to 30 kg but were occasionally up to 40 kg. Although not sieved in the field, an effort was made while collecting samples to exclude clasts >4 mm in size and to include as much sand-sized material as possible. Vertical exposures in operating gravel pits or roadcuts and rare test pits dug by a tracked excavator were sampled. The spatial coverage of samples was limited by the scarcity of glaciofluvial surface material and poor access. Sample depth was typically 1 to 4 m below surface in undisturbed material.

Descriptions were made for each sample collected, and included sedimentological data such as clast sizes, matrix texture, degree of sorting and rounding, petrological data, primary structures, within-unit variability, and type and orientation of contacts. Also at each sample site, notes were made on type of exposure, terrain map unit, geomorphology (e.g., topographic position, aspect, slope, drainage), and local stratigraphy.

Heavy mineral concentrates were produced by Vancouver Indicator Processors Inc. A +4.75 mm fraction was produced first by dry screening deslimed samples, with the undersize from this fraction screened on two single-deck, 30-inch, vibrating, self-cleaning wet screens. These screens were operated in tandem with the underflow from the coarser screen cascading onto the finer screen. The -4.75+2 mm, -0.0+1.11 mm, -1.11+0.5 mm and -0.5+0.25 mm fractions were produced using this wet method.

The -0.5+0.25 mm fraction was dried and a magnetic concentrate produced from it using a permanent-type, dry magnetic separator operating at 2.1 T. Heavy liquid processing on up to 1.0 kg of the strong and weakly magnetic fractions was carried out at the Global Discovery Laboratories of TeckCominco Ltd., a partner of

Sample ID	Glaciofluvial System	Glaciofluvial Feature Sampled	Depositional Environment
03-01	Sahtenah River	meltwater channel terrace	subaerial
03-02	unnamed	esker	subglacial
03-03	Courvoisier Creek	meltwater channel terrace	subaerial
03-04	unnamed	delta	subaerial
03-05	Kimea Creek - Petitot River	meltwater channel terrace	subaerial
03-06	unnamed	buried sands and gravels	?
03-07	Elleh Creek	kame?	subglacial, ice-proximal
03-08	Fort Nelson River	meltwater channel	subaerial
03-10	unnamed	outwash	subaerial
03-11	unnamed	esker	subglacial
03-13	Klua Creek	fan-delta	subaerial
03-14	unnamed	buried sands and gravels	?
03-17	unnamed	esker	subglacial
03-22	Elleh Creek?	buried channel	subglacial?

Table 1. Details of glaciofluvial systems, features, and depositional environments sampled.

Vancouver Indicator Processors Inc. Here, a two-stage process was used in which the heavy sink from tetrabromoethane (2.96 g/cm^3) was further concentrated in methylene iodide to produce a heavy mineral concentrate of >3.33 g/cm^3.

The -0.5+0.25 mm heavy mineral concentrates were sent to I. & M. Morrison Geological Services Ltd., Delta, BC, for visual picking and characterization of minerals that are thought to have a kimberlitic source or mantle source. A representative sample-split was produced from the concentrate, and kimberlite indicator minerals (KIMs) were picked and described in terms of their size, shape, surface morphology, colour, and where applicable, alteration.

One hundred ninety-seven hand-picked mineral grains were sent to SGS Lakefield Research Ltd., Lakefield, ON, to be set in a circular epoxy mount for microprobe analysis. This analysis was conducted by I. Kjarsgaard (Consulting Mineralogist) at Carleton University's microprobe facility.

Out of 197 analyzed mineral grains, 46 grains were confirmed as KIMs using discriminative data analysis. The locations of the samples containing these grains are provided in Figure 2.

DEPOSITIONAL SETTINGS OF SELECTED SAMPLES

Glaciofluvial environments vary in terms of flow regimes, depositional settings, the length of time a system is active and sediment transport distances. Table 1. summarizes the glaciofluvial systems and features sampled. Larger meltwater channel systems (i.e., widths from 1 to >2.5 km, 10 to 30 m deep and >40 km long), such as Kimea Creek, Petitot River and Elleh Creek with westerly paleoflows; and Fort Nelson River and possibly Sahtaneh River with northerly paleoflows, were high-energy systems that would have transported some sediment particles long distances (tens to hundreds of kilometres). The size of these systems, their orientation and the presence of red and pink granitic and gneissic clasts (i.e., Precambrian Shield rock types) suggest that sediments occurring in these meltwater channel systems (i.e., samples 03-01, 03-05, 03-07, 03-08) have sources as far east and northeast as Alberta and the Northwest Territories. However, some sedimentary clasts in these systems are also locally derived (less than 10 km from the source). Subaerial depositional settings dominate in these systems however, some sediments in the region were deposited in an ice-proximal and/or subglacial environment.

Sample 03-13 was collected from boulder-size gravels deposited in a fan delta on the Klua Creek meltwater channel system. These gravels occur near the confluence of the Elleh Creek and Fort Nelson River systems, with a northward paleoflow. The difference between the Klua Creek gravels compared to the Elleh Creek and Fort Nelson River gravels, is an abundance of local cobble to boulder-size shale clasts. The Klua Creek gravels probably were deposited in an aggradational and less mature system. The relative abundance of soft local bedrock types suggests shorter transport distances for a greater proportion of sedimentary clasts.

In contrast to the large glaciofluvial systems, there are smaller scale systems situated along the periphery of the Etsho Plateau. These meltwater channel systems (e.g., in the vicinity of samples 03-03, 03-04, and 03-10), are typically 10 to 30 m wide, 5 to 10 m deep and up to 10 km long. These systems head on the top of the plateau and paleoflow data indicate westerly flow. Transport distances, relative to the systems discussed above, are probably much shorter. These systems probably also had a lower energy flow regime, as suggested by the dominance of sand-size material. Sources for these sediments, including KIMs could be on the plateau itself, and could be primary (kimberlitic), secondary (paleoplacer), or tertiary (eroded from till, transported and redeposited in a glaciofluvial system). Although likely deposited in a different environment, sediments collected in samples 03-06 and 03-14 could also have a source on the plateau. As these sediments are buried, it is difficult to assess the length of the transport and characteristics of these depositional systems. The cobble to boulder-size gravels that occur at sample site 03-06 suggest deposition in a higher energy system. Conversely, the finer-textured sands and gravels occurring at sample site 03-14 suggest deposition in a lower energy system. Sample 03-22 was also collected from buried sands and gravels, and similarly, little is known about the system of transport and deposition.

Two esker systems with southwesterly paleoflow directions, located in the vicinity of the Etsho Plateau, were sampled (samples 03-02, 03-11, and 03-17). These features are also relatively small in scale (5 to 10 m wide, up to 5 m high and >1 km long), and dominated by sand-size material that was deposited subglacially. Esker systems are typically fed by a complex network of meltwater channels within the ice sheet and could have long transport distances. This is particularly true of the esker system that occurs northeast of Kotcho Lake. The esker segment sampled (samples 03-02 and 03-11) is part of a larger segmented esker system that trends northeast and continues for >20 km. The dominance of sand-size material in these eskers suggests that they were relatively low-energy systems.

INTERPRETATION OF INDICATOR MINERALS

Of the 22 samples collected for this study, 14 contain KIMs. Of these, eight contain more than one indicator mineral and often more than one grain of each (Fig. 2). This section presents identification and interpretation of KIMs based largely on microprobe analysis.

Garnet

Mantle-derived garnets are considered the most important kimberlite and diamond indicator minerals. The pioneering work of Dawson and Stephens (1975) and Gurney (1984) formed the base for the use of garnet as an indicator mineral, and many researchers have followed and refined these original studies. The two most current studies on garnet classification and interpretation are those of Schulze (2003) and Grütter *et al.* (2004). Both of these classifications are very effective in distinguishing pyropes, eclogitic and crustal garnets. The main elements used to identify and interpret mantle-derived garnets, and to estimate a diamond potential of an area or individual pipe, are Cr, Ca, Mg, Fe, Ti and Na.

In this paper, the scheme described by Grütter *et al.* (2004) is used to classify different garnet species. Although this approach introduces concepts that may not be familiar to some geologists, such as Ca-intercepts, it is a comprehensive, straightforward and well suited for diamond exploration. In this classification scheme, garnets are divided into 12 categories (G1 to G12). Of these, harzburgitic (G10), pyroxenitic, websteritic and eclogitic garnets (G4, G5 and G3) are commonly associated with diamonds. Wehrlitic garnets are referred to as G12, low-Cr megacrysts as G1, and Ti-rich peridotitic varieties as G11. The garnets that do not fit into any of the twelve categories, including crustal garnets, are referred to as G0. The scheme is at least in part empirical; it was tested on a large data set and appears quite robust.

Of the 46 garnets that were visually picked and analyzed, at least 23 can be considered as KIMs. Microprobe analyses of selected garnets, and results of classification using the method outlined by Grütter *et al.* (2004), are provided in (Table 2.) and G9, G12 and G3 garnets are shown on Figure 3. Although there are no G10 garnets present, one of the G9 garnets plots very close to the G9-G10 boundary (Fig. 3). Eight of the mantle-derived garnets are lherzolitic (G9), three are wehrilitic (G12) and twelve can be considered as eclogitic (G3). The remaining garnets are classified as G0. The garnets with significant chrome content (G9) follow a well-defined trend from the G10-G9 to G9-G12 boundaries, forming an acute angle with the lherzolite field (Fig. 3). High Na_2O content (>0.07 wt %) in eclogitic garnets is considered as a positive indication of diamond potential (Gurney, 1984; Grütter *et al.*, 2004). However, no G3 grains recovered in this study have sufficiently high Na_2O content to merit the suffix 'D'.

With one possible exception, kelyphitic rims were not observed on any of the visually picked garnets. In this specific case, the dark substance covering less than 1% of the grain's surface was tentatively identified as a kelyphitic rim. Several of the garnets have orange-peel texture. The overall absence of kelyphitic rims and presence of orange-peel textures suggest that these garnets were probably subjected at least to limited transport or local reworking after being liberated from their host rock. The spatial distribution of G3, G9 and G12 garnets is presented in Figure 2.

Clinopyroxene

Chrome-bearing, green to bright green clinopyroxenes are easily identifiable in heavy mineral concentrates. For these reasons, clinopyroxenes are considered effective KIMs. Unfortunately, clinopyroxenes with characteristics similar to those present in kimberlitic rocks are also found in a variety of other rock types. Consequently, microprobe analyses are required to differentiate kimberlite-related clinopyroxeness from those associated with other rock types. Twenty clinopyroxene grains were visually picked from concentrates. Their chemical composition is provided in Table 3.

As seen in Table 3, the Mg numbers (100Mg/[Mg+Fe]) of these clinopyroxenes vary from 77.52 to 93.52. Chrome diopside grains with an Mg number >88 are likely to be from mantle peridotite, particularly if they have elevated Cr_2O_3 (>0.5 wt.%). Based on Mg number, there appear to be 10 clinopyroxenes that could be considered as kimberlitic indicators.

The discrimination plot Cr_2O_3-Al_2O_3 of Ramsey and Tompkins (1994) was used to further refine this interpretation. Worldwide, most of the clinopyroxenes found as solid inclusions or intergrowths, in and/or with diamonds, plot in the 'on craton' garnet-peridotite field (Fig. 4). Of the 20 clinopyroxenes analyzed, 8 plot in this field. Of the 10 clinopyroxenes identified as being peridotitic or kimberlite indicators, based simply on the Mg number, 4 plot in the 'on craton' and 3 within the "off craton" fields (Fig. 4). Four additional clinopyroxenes plot within this field, although they have Mg numbers <88. Of the 20 clinopyroxenes identified during this study, 14 are considered to be KIMs (other considerations are involved as well). The spatial distribution of clinopyroxene is presented in Figure 2.

Spinel

Based on microprobe analyses, only one visually picked mineral grain is chromite (sample 03-05; Fig. 2). This black chromite grain consists mainly of Al_2O_3 (30.56%), Cr_2O_3 (33.22%), FeO (21.01%), MgO (12.67%) and smaller concentrations of TiO_2 (0.43%), ZnO (0.27%), MnO (0.21%), NiO (0.14%), SiO_2 (0.09 %); V_2O_3 and CaO were not detected. The grain has an MgO value comparable to chromites reported as inclusions or intergrowths in and/or with diamonds. Its Cr_2O_3 content (33.22%), however, is too low relative to compositional fields of diamond-associated chromites, which commonly contain >60% Cr_2O_3.

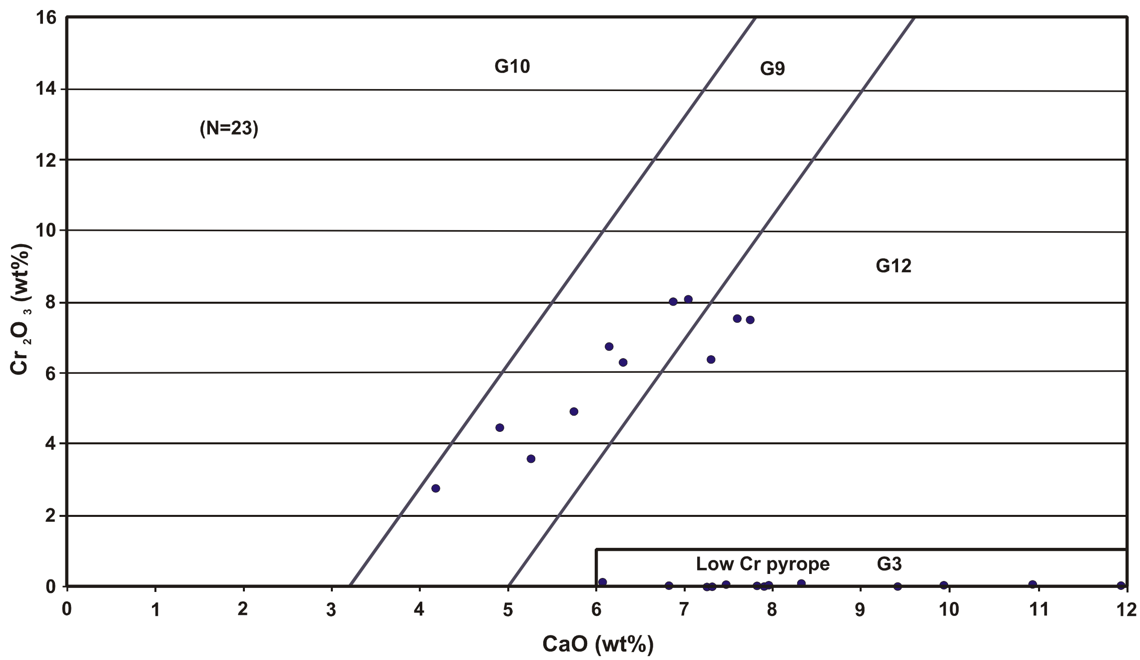

Figure 3. Garnet Cr_2O_3-CaO diagram showing composition of G9, G6 and G3 garnets. G0 garnets are not shown. Compositional fields from (Grütter et al., 2004).

This chromite grain may fit into the compositional fields of the spinels observed at the Prairie Creek, Kirkland Lake, Joff, Ile Bizard, Mountain and Blackfoot-type diatremes (Fipke *et al.*, 1995), but may also fit into compositional fields of spinels from a wide variety of other ultramafic rocks. Due to its association with other indicator minerals, however, this grain was retained as a potential KIM.

Ilmenite

Ilmenite is one of the most widely used kimberlite indicator minerals. It is a common member of the megacryst suite, and the major elements TiO_2, MgO, CrO_2, MnO_2 and Fe_2O_3 are used to distinguish kimberlitic ilmenites from those that are non-kimberlitic (Wyatt *et al.*, 2004). Microprobe analyses of ilmenite grains from the Fort Nelson area are given in Table 4. Based on the TiO_2 and MgO plot (Fig. 5), there are three analyses that plot in the kimberlite field (i.e., on the right of the curve marked 'A').

As shown in Figure 6, the Cr_2O_3 and MgO plot also suggests that the same three grains identified in Figure 5 are kimberlite related. They have higher MgO values, and two of them have higher Cr_2O_3 content than their non-kimberlitic counterparts. The fields of typicalNorth American, South African (on and off craton) and Australian kimberlitic ilmenites are provided in Figure 6 for reference (based on data from Wyatt *et al*., 2004).

Most of the non-kimberlitic (crustal) ilmenites have low MgO values and probably originated from the same, non-kimberlitic, crustal protolith (Fig. 5, 6). One of these grains plots above the 0% Fe_2O_3 contour. That analysis is either incorrect and the mineral is not ilmenite, or the probe encountered a rutile inclusion. It is worth noting that the crustal ilmenite cluster shown in Figure 6 coincides with the crustal ilmenite clusters seen from the Slave Craton. Three kimberlitic ilmenites with low Fe^{3+}/Fe^{2+} ratio were identified during this study. Two of them come from samples collected in the Etsho Plateau area and one of them occurs with G3 and G9 garnets and corundum (Fig. 2). Ilmenites with low Fe^{3+}/Fe^{2+} ratios indicate favourable oxidation-reduction conditions for diamond preservation and therefore provide additional information for evaluation of individual pipes (Gurney and Moore, 1994). Such an exercise, however, is beyond the scope of this reconnaissance study.

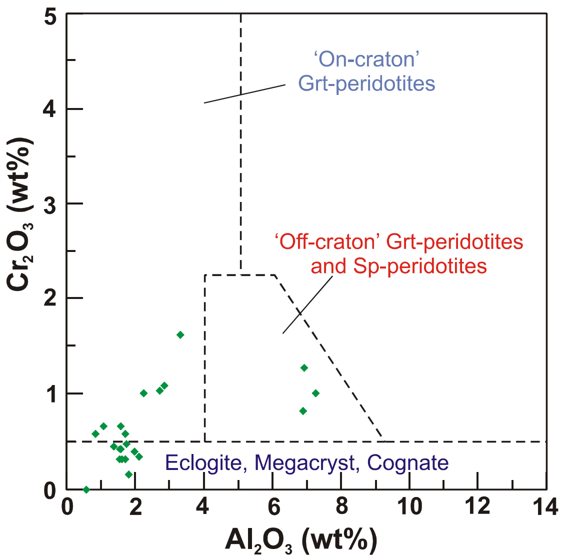

Figure 4. Clinopyroxenes Cr_20_3-Al_20_3 discrimination plot (after Ramsey and omkins, 1994). Eight of the clinopyroxenes plot within the 'On-craton' garnet peridotite field and three plot within 'Off-craton' garnet peridotite and spinel peridotites field. Clinopyroxenes plot within the 'On-craton' garnet peridotite field.

Olivine

In cold climates, such as in northeastern British Columbia, olivine is more resistant to serpentinization and is considered a useful KIM. Although olivine is a common rock-forming mineral in kimberlites, it is also present in a variety of other ultramafic rocks in British Columbia (Voormeij and Simandl, 2004a, b) and therefore does not provide as much diamond potential information as garnet, clinopyroxene, chromite or ilmenite.

The Mg-rich variety of olivine identified in samples from Fort Nelson area is commonly pale yellow-green, equidimensional and subrounded to rounded, and has a fresh appearance. Olivine provenance cannot be established solely by visual examination, so microprobe analyses are required. . Microprobe data on 28 olivine grains recovered from collected samples are presented in Table 5, while a NiO-Fo diagram using the same data is presented in Figure 7.

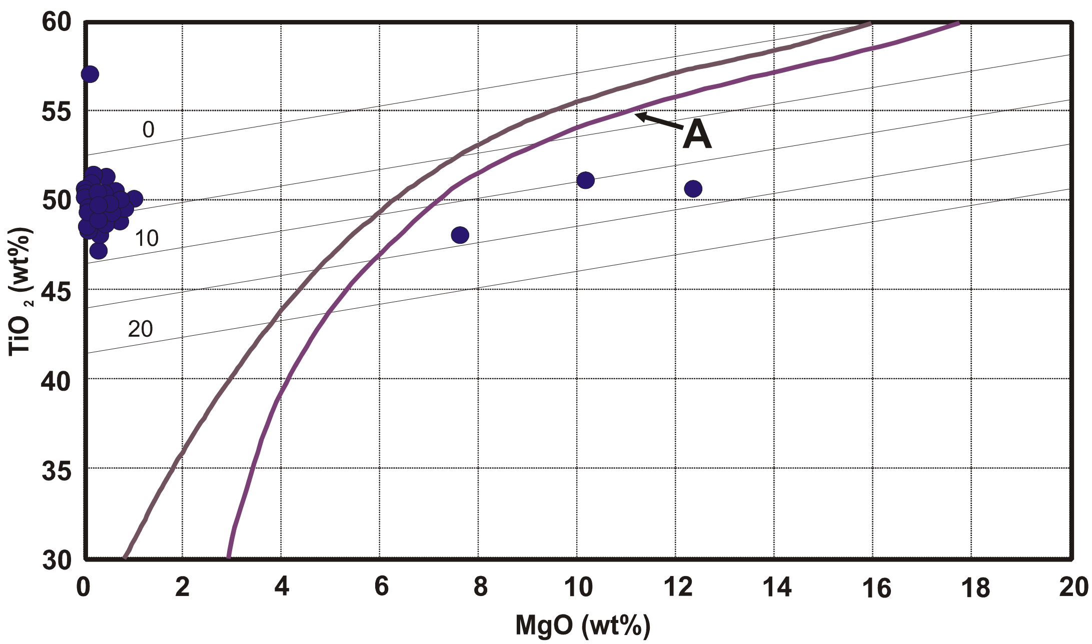

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Figure 5. Ilmenite- $Ti0_2$ and Mg0 discrimination plot (after Wyatt *et al*., 2004). Three grains plot within the kimberlite field, which is located to the right of the curve marked 'A'.

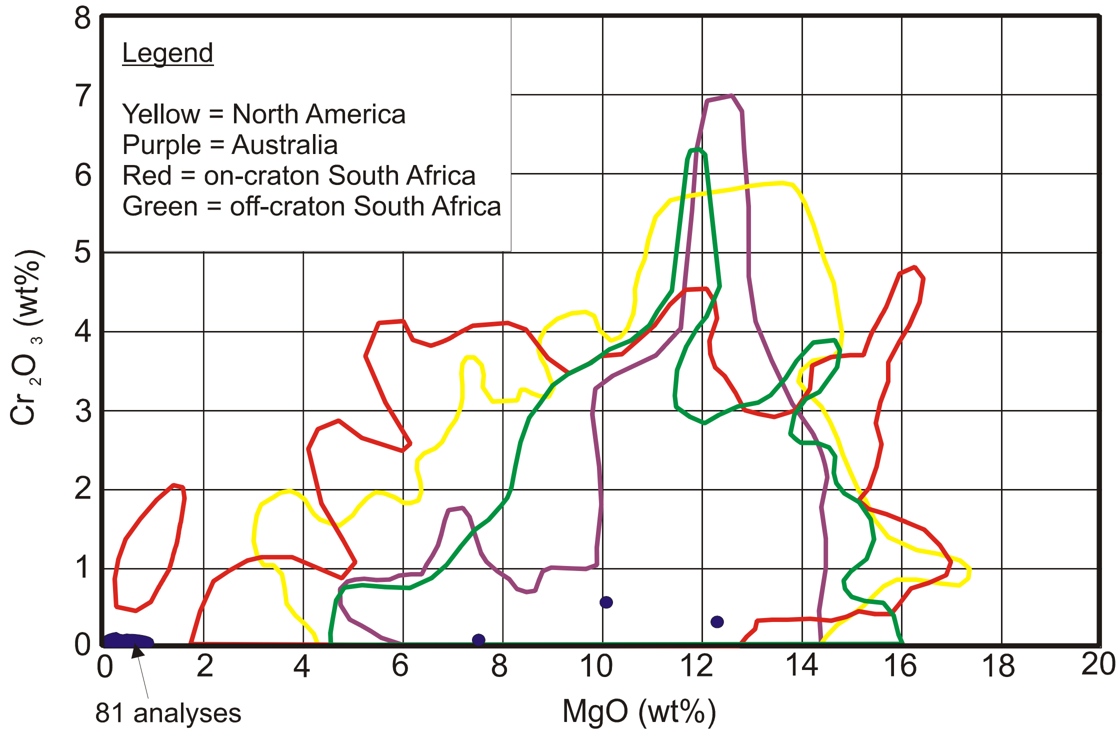

Figure 6. Ilmenite $Cr_2 0_3$ and MgO discrimination plot (*after* Haggerty, 1991). Simplified fields representing North American, Austrailian and South African (on and off-craton) kimberlitic ilmenites are derived from plots by Wyatt *et al*., (2004). Three out of 84 grains from the Fort Nelson area can be considered as KIMs.

The MgO content of these olivine grains ranges from ~41 to 50 wt % and that of FeO from ~8 to 19 wt %. Olivines derived from kimberlite rocks typically plot within the green field delineated by a curve (Fig. 7; Eccles *et al.*, 2004). Six olivine grains from the Fort Nelson area fall within this compositional field and three other grains are located on the periphery of the kimberlite field. Based on data from Eccles *et al.* (2004), orange field (Fig. 7) delineates a more restricted field, which represents the most common composition of olivine grains from the northern Alberta kimberlite province. Four of the most Mg-rich grains from this study fall within this field.

Of these four of the grains are KIMs and may have been derived from kimberlites in northern Alberta, from the local Mesozoic to Paleozoic sedimentary cover, or from undiscovered kimberlites within northeastern British Columbia. Locations of identified olivine grains are presented in Figure 2.

Corundum

Corundum and in rare circumstances, its gem quality equivalents; sapphire and ruby, are found in silica-under-saturated rocks such as high-grade alumina-rich gneisses. They are also found in a variety of alkali basalts, lamprophyres, and other alkaline rocks from contact metamorphic settings (Simandl and Paradis, 1999a, b, c). It is also reported in association with placer diamond deposits in New South Wales (Coenraads, 1990). A direct but not exclusive corundum-diamond link was established through study of corundum inclusions in diamonds (Hutchinson *et al.*, 2001; Hutchinson *et al.*, 2004). Preliminary data indicate that these inclusions, interpreted as being syngenetic with the growth of diamond, have a higher Ni content and higher Mg/Fe ratio than corundum from any other temperature-pressure settings (Hutchison *et al.*, 2004). Corundum with 1.1–1.7 wt % Cr_2O_3 was also described in garnetite within the ultrahigh-pressure zone of Sulu Terrane, China (Zhang *et al.*, 2004), and in variety of eclogite-grade rocks (Morishita and Arrai, 2001; Qi *et al.*, 1997).

A single purple corundum grain was recovered during this study. Both its colour and high Cr content indicate that it is very similar to ruby. This grain is composed almost entirely of Al_2O_3, with minor components of Cr_2O_3 (0.54%)

and FeO (0.19%), and even less NiO (0.03%) and MnO (0.01%). Laser-ablation ICP-MS, or energy dispersive spectrometry, would be necessary if further interpretation of the data based on chemical composition is required.

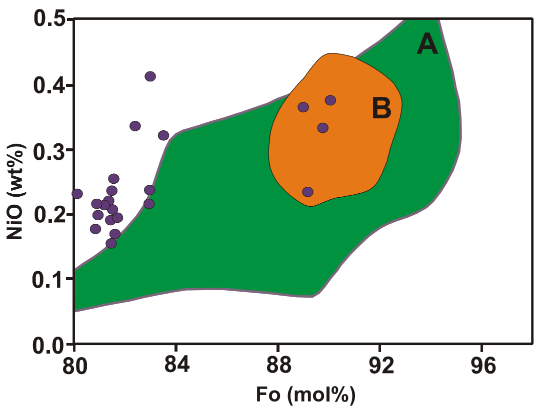

Figure 7. Olivine NiO-Fo discrimination plot. Olivines derived from kimberlite rocks plot in field A (Eccles *et al.*, 2004). Six olivine grains from the Fort Nelson area fall within this compositional field; three additional grains plot on the periphery. Field B, a more restricted field that represents typical compositions of olivine indicator grains from the northern Alberta kimberlite province, is based from Eccles *et al.*, (2004).

Chromium-bearing corundum similar in colour to the one described above is reported in association with spinel in barren and diamondiferous pipes in the Buffalo Head Hills, Alberta (Hood and McCandless, 2004), in the Fort-à-la-Corne area, Saskatchewan (Hutchison *et al.* 2004), and in the Northwest Territories. Although corundum (sapphire) grains are also reported in small quantities in some pipes and alkaline complexes within the British Columbia alkaline province, west to east transport in the study area is unlikely.

Corundum came from sample 03-03, which also contained several kimberlite indicators, including mantle-derived garnets and ilmenite. The sample, located in Figure 2, may be worth following-up both from diamond and gem corundum perspectives.

Diaspore

Diaspore, a hydrated alumina (AlOOH), is not typically considered a KIM. It is known to coexist with corundum in altered silica-undersaturated rock types, especially as a retrograde product in regionally metamorphosed corundum-bearing alumina-rich sedimentary rocks (Simandl and Paradis, 1999a). Although it is not commonly reported as an accessory mineral in ultramafic rocks, it could be present in ultramafic-related corundum-bearing contact metamorphic rocks, such as those described by Simandl and Paradis (1999b), and in most corundum-bearing alkaline volcanics such as alkali basalts, kimberlites, and lamrophyres described by Simandl and Paradis (1999c). In its fine-grained and massive form, diaspore is also found as an important constituent in aluminous clay and bauxite deposits (Hill, 1994).

Two yellow grains from samples 03-06 and 03-02 were identified, based on their Al_2O_3 content, as diaspore. These grains have similar NiO values to those of the previously described corundum grains. The diaspore grains differ from the corundum grains in that they have lower Cr_2O_3 values, higher FeO values and detectable TiO_2 (Table 6). Little is known about the mobility of Cr, Ti and Fe during corundum-diaspore transition. Based strictly on the microprobe analyses, these diaspore grains do not appear to be genetically related to the Cr-rich corundum grain described above. The shape of diaspore grains does not provide clues to distance traveled, and their geographic distribution and chemical composition does not suggest strong association with kimberlite indicators or with the purple corundum grain.

DISCUSSION AND HIGHLIGHTS

The KIMs recovered in the Fort Nelson area likely originated from more than one source. Possible sources are known diatremes located east of the study area in the Buffalo Head Terrane and in the Slave Craton, undiscovered pipes cutting Mesozoic to Paleozoic sedimentary rocks in the Fort Nelson area, British Columbia's alkaline province, high-pressure zones such as those described by Canil *et al.* (2003) and, in the case of olivine, a variety of accreted terranes. The geology of the Precambrian basement in northeastern British Columbia is poorly understood, but there are indications that it could be more favourable for diamond exploration than previously reported (Simandl, 2004; Simandl and Davis, 2005). Therefore, the results of this study are important, particularly given alternative interpretations of the character of the Precambrian basement terranes.

Interpretations of the local surficial geology (material types sampled as part of this study) and Late Pleistocene glacial history help constrain some of these options and suggest that some indicators may have been locally derived, while others may have been transported west and southwest from Northwest Territories or Alberta. Based on a combination of parameters such as indicator mineral grain count, coexistence of more than one KIM in the same sample, results of microprobe analyses and interpretation of transport distances based on surficial geology, it is possible that samples 03-03, 03-09, 03-10 and 03-17, and potentially samples 03-02 and 03-11, may contain indicators derived from proximal sources, possibly within the Etsho Plateau. Sample 03-04 is particularly encouraging as it contains a relatively high mineral indicator count and a combination of G3, G9 and G12 garnets, olivine and Cr-diopside (Figure 2).

The provenance of KIMs in samples collected within large-scale, high energy meltwater channels, such as the Kimea Creek – Petitot River, Elleh, and Fort Nelson River systems (Fig. 2), is more difficult to establish. Analysis of coarse fractions from selected samples and follow-up sampling may provide additional information that could be used to better constrain the sources of the indicator minerals and provide an estimate of transportation distance.

Existing geophysical surveys carried out by the oil and gas industry may help to further focus diamond exploration in this area, as diatremes may have an electromagnetic, magnetic, gravity or seismic expression.

SUMMARY

Kimberlite indicator minerals, including peridotitic and eclogitic garnets, ilmenite, Cr-diopside, olivine and corundum, were recovered from -0.5+0.25 mm heavy mineral concentrates from the Fort Nelson area. These concentrates were produced from glaciofluvial sands and gravels. Fourteen of the 20 samples collected contained KIMs, many with more than one mineral type. Most of the indicator grains appear fresh and subrounded to subangular, but several have sharp edges. Garnets do not appear to have kelyphitic rims, but a few do have an orange-peel texture, suggesting that they were subject to small degree of transportation or local reworking.

Indicator minerals present in samples proximal to or on the Etsho Plateau occur in small-scale, low-energy glaciofluvial systems and may have a local source, perhaps somewhere on the plateau itself. Others, particularly those occurring in large-scale, high-energy glaciofluvial systems, were more likely transported into the area by glaciofluvial processes from Alberta (Buffalo Head Terrane), the Northwest Territories (Slave Craton) and undiscovered pipes cutting sedimentary rocks of Mesozoic to Paleozoic age in other parts of northeastern British Columbia. The geology of the Precambrian basement in northeastern British Columbia is poorly understood, and this part of the province should not be ignored in diamond exploration.

During the 2004 field season, 50 additional samples were collected over an area extending 200 km west and 300 km south of Fort Nelson. These samples are currently being processed and may provide additional information on possible sources of KIMs identified here, and help to establish what is the background concentration of KIMs in the region.

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REFERENCES

Allan, R.J. (1999): Micro-diamond results from Ice Claim project, BC; *Skeena Resources Limited*, news release, August 20, 1999.

Allan, R.J. (2002): Diamond exploration corporate up-date; *Skeena Resources Limited*, news release, March 22, 2002.

Anonymous (1994): BC diamonds discovered; *in* George Cross News Letter, *Consolidated Ramrod Gold Corporation*, No. 225.

Canil, D., Schulze, D.J., Hall, D., Hearn, B.C. Jr., and Milliken, S.M. (2003): Lithospheric roots beneath western Laurentia: the geochemical signal in mantle garnets; *Canadian Journal of Earth Sciences*, Volume 40, pages 1027–1051

Carlson, S.M., Hillier, W.D., Hood, C.T., Pryde, R.P. and Skelton, D.N. (1999): The Buffalo Hills kimberlites: a newly-discovered diamondiferous kimberlite province in north-central Alberta, Canada; *in* Proceedings of the VIIth International Kimberlite Conference, Gurney, J.J., Gurney J.L., Pascoe, M.D. and Richardson, S.H., Editors, Volume 1, pages 109–116.

Coenraads, R.R. (1990): Key areas for alluvial diamond, sapphire exploration in the New England gem fields, New South Wales, Australia; *Economic Geology*, Volume 85, pages 1186–1207.

Creaser, R.A. Grüter, H., Carlson, J. and Crawford, B. (2004): Macrocrystal phlogopite Rb-Sr dates for the Ekati property kimberlites, Slave Province, Canada: evidence for multiple intrusive episodes in the Paleocene and Eocene; *Lithos*, Volume 76, pages 399–414.

Dawson, J.B. and Stephens, W.E. (1975): Statistical classification of garnets from kimberlite and associated xenoliths; *Journal of Geology*, Volume 83, pages 589–607.

Dow, R.B. (2004): Patrician recovers another diamond; *Patrician Diamonds Inc.*, press release 04-04, February 11, 2003.

Dow, R.B. (2003): Patrician recovers diamonds, sapphires and kimberlitic indicators in the Yukon; *Patrician Diamonds Inc.*, press release 03-08, November 10, 2003.

Eccles, D.R. (2002): Enzyme leach-based soil geochemistry of the Mountain Lake diatreme, Alberta; *in* Industrial Minerals in Canada, Dunlop, S.and Simandl, G.J., Editors, *Canadian Institute of Mining and Metallurgy and Petroleum*, Volume 53, pages 355–360.

Eccles, D.R., Heaman, L.M., Luth, R.W. and Creaser, R.A. (2004): Petrogenesis of the Late Cretaceous northern Alberta kimberlite province; *Lithos*, Volume 76, pages 435–459.

Fipke, C.E., Gurney, J.J. and Moore, K.O. (1995): Diamond exploration techniques emphasizing indicator mineral geochemistry and Canadian examples; *Geological Survey of Canada*, Bulletin 423, 85 pages.

Grütter, H.S., Gurney, J.J., Menzies, A.H. and Winter, F. (2004): An updated classification scheme for mantle-derived garnet, for use by diamond explorers; *Lithos*, Volume 77, pages 841–857.

Gurney, J. J. (1984): A correlation between garnets and diamonds in kimberlites; *in* Kimberlite Occurrence and Origin: A Basis for Conceptual Models in Exploration, J.E. Glover and P.G. Harris, Editors, *University of Western Australia*, Geology Department and University Extension, Publication 8, pages 143–166.

Gurney, J.J and Moore R.O. (1994): Geochemical correlation between kimberlitic indicator minerals and diamonds as applied to exploration; *in* Kimberlites, Related Rocks and Mantle Xenoliths, 5th International Kimberlite Conference, Araxa, Brazil, *Companhia de Pesquisa de Recursos Minerais (CPRM)*, Volume 1, page 125.

Haggerty, S.E. (1986): Diamond genesis in a multiply constrained model; *Nature*, Volume 320, pages 34–38.

Helmstaedt, H.H. and Gurney, J.J. (1995): Geotectonic controls of primary diamond deposits: implications for area selection; *Journal of Geochemical Exploration*, Volume 53, pages 125–144.

Hill, V.G. (1994): Bauxite*; in* Industrial Minerals and Rocks (6th Edition), Carr, D.D., Editor, *Society for Mining, Metallurgy, and Exploration Inc.*, pages 135–147.

Hoffman, P.F. (1988): United plates of America: the birth of a craton; *Annual Reviews in Earth and Planetary Sciences*, Volume 16, pages 543–603.

Hoffman, P.F. (1989): Speculations on Laurentia's first gigayear (2.0–1.0 Ga); *Geology*, Volume 17, pages 135–138.

Hoffman, P.F. (1991): Did the breakout of Laurentia turn Gondwanaland inside-out? *Science*, Volume 252, pages 1409–1412.

Holland, S.S. (1976): Landforms of British Columbia: a physiographic outline; *BC Ministry of Energy, Mines and Petroleum Resources*, Bulletin 48, 138 pages.

Hood, C.T.S. and McCandless, T.E. (2004): Systematic variations in xenocryst mineral composition at the province scale, Buffalo Hills kimberlites, Alberta, Canada; *Lithos*, Volume 77, pages 733–747.

Hutchinson, M.T, Husthouse, M.B. and Light, M.E. (2001): Mineral inclusions in diamonds: associations and chemical distinctions around the 670 km discontinuity; *Contributions to Mineralogy and Petrology*, Volume 142, pages 119–126.

Hutchinson, M.T., Nixon, P.H. and Harley, S.L. (2004): Corundum inclusions in diamonds – discriminatory criteria and corundum compositional dataset; *Lithos*, Volume 77, pages 273–286.

Janse, A.J.A. (1994): Is Clifford's Rule still valid? *in*

Kimberlites, Related Rocks and Mantle Xenoliths, Proceedings of the 5th International Kimberlite Conference, Araxa, Brazil, *Companhia de Pesquisa de Recursos Minerais (CPRM)*, Volume 2, pages 215–235.

Journeay, J.M., Williams, S.P. and Wheeler, J.O (2000): Tectonic assemblage map, Fort Nelson, British Columbia; *Geological Survey of Canada*, Open File 2948, scale 1:1 000 000.

Kirkley, M.B., Gurney, J.J. and Levinson, A.A. (1991): Age, origin and emplacement of diamonds: scientific advances in the last decade; *Gems and Gemology*, Spring 1991, pages 2–25.

Levson, V.M., Ferbey, T., Kerr, B., Johnsen, T., Bednarski, J., Smith, I.R., Blackwell, J. and Jonnes, S. (2004): Quaternary geology and aggregate mapping in northeast British Columbia: applications for oil and gas exploration and development; *in* Geological Fieldwork 2004, *BC Ministry of Energy and Mines*, Paper 2004-1, pages 29–40.

Lockhart, G., Grütter, H. and Carlson, J. (2004): Temporal, geomagnetic and related attributes of kimberlite magmatism at Ekati, Northwest Territories, Canada; *Lithos*, Volume 77, pages 665–682.

McCallum, M.E. (1994): Lamproitic (?) diatremes in the Golden area of the Rocky Mountain Fold and Thrust Belt, British Columbia, Canada; *in* Kimberlites, Related Rocks and Mantle Xenoliths, Proceedings of the 5th International Kimberlite Conference, Araxa, Brazil, *Companhia de Pesquisa de Recursos Minerais (CPRM)*, Volume 1, pages 195–209.

Mathews, W.H. (1980): Retreat of the last ice sheets in northeastern British Columbia and adjacent Alberta; *Geological Survey*, Bulletin 331, 22 pages.

Mitchell, R.H. (1991): Kimberlites and lamproites: primary sources of diamonds; *Geoscience Canada*, Volume 18, pages 1–16.

Morishita, T. and Arrai, S. (2001): Petrogenesis of corundum-bearing mafic rock in the Horoman Peridotite Complex, Japan; *Journal of Petrology*, Volume 42, pages 1279–1299.

Northcote, K.E., (1983a): Report on Mark property, Pangman Peek (82N/15W); *BC Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 13 596.

Northcote, K.E. (1983b): Report on Jack Claims Lens Mountain (82N/14E); *BC Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 13 597.

Okulitch, A.V., MacIntyre, D.G., Taylor, G.C., Gabrielse, H., Cullen, B., Massey, N. and Bellefontaine, K., Compilers (2002): Bedrock geology, central Foreland, British Columbia, Yukon Territory, Northwest Territories: maps NO-10, NP 9-10; *Geological Survey of Canada*, Open File 3604 (revised), scale 1:500 000.

Paulen, R.C., Fenton, M.M., Pawlowicz, J.G., Smith, I.R. and Plouffe, A. (in press): Surficial geology of the Zama Lake area (NTS 84L/NW); *Alberta Energy and Utilities Board*, EUB/AGS Map 315, scale 1:100 000.

Pell, J., (1994): Carbonatites, nepheline syenites, kimberlites and related rocks in British Columbia; *BC Ministry of Energy and Mines*, Bulletin 88, 136 pages.

Plint, A.G., McCarthy, P.J. and Faccini, U.F. (2001): Nonmarine sequence stratigraphy: updip expression of sequence boundaries and systems tracts in a high-resolution framework, Cenomanian Dunvegan Formation, Alberta foreland basin, Canada; *AAPG Bulletin*, Volume 85, pages 1967–2001.

Plint, A.G. (2002): Paleovalley systems in the Upper Cretaceous Dunvegan Formation, Alberta and British Columbia; *Bulletin of Canadian Petroleum Geology*, Volume 50, pages 277–296.

Plint, A.G. and Wadsworth, J.A. (2003): Sedimentology and palaeogeomorphology of four large valley systems incising delta plains, Western Canada foreland basin; implications for Mid-Cretaceous sea-level changes; *Sedimentology*, Volume 50, pages 1147–1186.

Plouffe, A., Smith, I.R., Paulen, R.C., Fenton, M.M. and Pawlowicz, J.G. (2004): Surficial geology, Bassett Lake, Alberta (NTS 84L/SE); *Geological Survey of Canada*, Open File 4637, scale 1:100 000.

Pilkington, M., Milles. W.F, Ross, G.M. and Roest, W.R. (2000): Potential-field signatures of buried Precambrian basement in Western Canada Sedimentary Basin; *Canadian Journal of Earth Sciences*, Volume 37, pages 1453–1471.

Qi, Q., Taylor, L.A., Snyder, G.A, Clayton, R.N., Mayeda, T.K. and Sobolev, N.V. (1997): Detailed petrology and geochemistry of a rare corundum eclogite xenolith from Obhazhennaya, Yakutia; *Russian Geology and Geophysics*, Volume 38, pages 247–260.

Ramsey, R.R. and Tompkins, L.A. (1994): The geology, heavy mineral concentrate mineralogy, and diamond prospectivity of Boa Esperanca and Cana Verde pipes, Corrego D'anta, Minas Gerais, Brazil; *in* Kimberlites, Related Rocks and Mantle Xenoliths, Proceedings of the 5th International Kimberlite Conference, *Companhia de Pesquisa de Recursos Minerais (CPRM)*, Volume 2, pages 329–345.

Roberts, W.J. (2002): Diamond discovery at Xeno; *Pacific Ridge Exploration Limited.*, news Release, March 13, 2002.

Ross, G.M., Parish, R.R., Villeneuve, M.E. and Bowring, S.A. (1991): Geophysics and geochronology of the crystalline basement of the Alberta Basin, Western Canada; *Canadian Journal of Earth Sciences*, Volume 28, pages 512–522.

Ross, G.M., Milkerreit, B., Eaton, D., White, D. Kanasewich, E.R. and Buryanyk, M.J.A. (1995): Paleoproterozoic collisional orogen beneath Western Canada Sedimentary Basin imaged by Lithoprobe crustal seismic reflection data; *Geology*, Volume 23, pages 195–199.

Schulze, D.J. (2003): A classification scheme for mantle-derived garnets in kimberlite: a tool for investigating the mantle and exploring for diamonds; *Lithos*, Volume 71, pages 195–213.

Simandl, G.J. (2004): Concepts for diamond exploration in "on/off craton" areas - British Columbia, Canada; *Lithos*, Volume 77, pages 749–764.

Simandl, G.J. and Paradis, S. (1999a): Ultramafic-related corundum; *in* Selected British Columbia Mineral Deposit Profiles, Volume 3, Industrial Minerals and Gemstones, Simandl, G.J., Hora, Z.D. and Lefebure, D.V., Editors, *BC Ministry of Energy and Mines*, pages 123–127.

Simandl, G.J and Paradis, S. (1999b): Corundum in alumina-rich metasediments; *in* Selected British Columbia Mineral Deposit Profiles, Volume 3, Industrial Minerals and Gemstones, Simandl, G.J., Hora, Z.D. and Lefebure, D.V., Editors, *BC Ministry of Energy and Mines*, pages 105–108.

Simandl, G.J. and Paradis, S. (1999c): Alkali basalt and lamprophyre-hosted sapphire and ruby; *in* Selected British Columbia Mineral Deposit Profiles, Volume 3, Industrial Minerals and Gemstones, G.J., Hora, Z.D. and Lefebure, D.V., Editors, *BC Ministry of Energy and Mines*, pages 129–132.

Smith, C.B., Colgan, E.A., Hawthorne, J.B. and Hutchinson G. (1988): Emplacement age of the Cross kimberlite, southeastern British Columbia, by Rb-Sr phlogopite method; *Canadian Journal of Earth Sciences*, Volume 25, pages 790–792.

Smith, I.R., Plouffe, A., Paulen, R.C., Fenton, M. and Pawlowicz, J.G. (in press): Surficial geology, southwest Zama Lake, Alberta (NTS 84L/SW); *Geological Survey of Canada*, Open File 4754, scale 1:100 000.

Stott, D.F. (1982): Lower Cretaceous Fort St. John group and upper Cretaceous Dunvegan formation of the foothills and plains of Alberta, British Columbia, District of MacKenzie and Yukon Territory; *Geological Survey of Canada*, Bulletin 328, 124 pages.

Thompson, R.I. (1977): Geology of Beatton River, Fontas River and Petitot River map-areas, northeastern British Columbia; *Geological Survey of Canada*, Paper 75-11, 8 pages.

Villeneuve, M.E., Ross, G.M., Thérialt, R.J., Miles, W., Parrish, R.R. and Broome, J. (1993): Tectonic subdivision and U-Pb geochronology of the crystalline basement of the Alberta basin, Western Canada; *Geological Survey of Canada*, Bulletin 447, 93 pages.

Voormeij, D.A. and Simandl, G.J. (2004a): A Map of ultramafic rocks in British Columbia: applications in CO_2 sequestration and mineral exploration, *BC Ministry of Energy and Mines*, GeoFile 2004-1.

Voormeij, D.A. and Simandl, G.J. (2004b): Ultramafic rocks in British Columbia: delineating targets for mineral sequestration of CO_2; *in* Summary of Activities, *BC Ministry of Energy and Mines*, pages 157–167.

Wyatt, B.A., Baumgartner, M., Ancar, E. and Grütter, H. (2004): Compositional classification of "kimberlitic" and "non-kimberlitic" ilmenite; *Lithos*, Volume 77, pages 819–840.

Zhang, R.Y, Liou, J.G. and Zheng J.P (2004): Ultrahigh-pressure corundum-rich garnetite in garnet peridotite, Sulu Terrane, China; *Contributions to Mineralogy and Petrology*, Volume 147, pages 21–31.

Table 2. Microprobe analysis of garnets (%).

Sample ID	UTM Easting	UTM Northing	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	NiO	MgO	CaO	Na_2O	K_2O	Total	Garnet Type
03-01	589380	6518892	40.65	0.06	19.33	6.40	8.59	0.56	0.04	17.18	7.30	0.03	0.00	100.15	G12
03-02	628743	6566536	36.37	0.00	20.73	0.00	32.79	9.15	0.00	1.04	0.31	0.04	0.02	100.46	G0
03-02	628743	6566536	39.20	0.10	22.05	0.04	22.36	0.42	0.00	6.74	9.93	0.00	0.00	100.85	G3
03-02	628743	6566536	36.25	0.08	17.53	0.00	3.23	0.04	0.00	2.18	37.37	0.01	0.00	96.68	G0
03-03	578801	6554264	41.68	0.03	21.91	3.61	7.96	0.53	0.00	19.76	5.26	0.03	0.00	100.77	G9
03-03	578801	6554264	38.34	0.08	21.05	0.05	26.72	0.95	0.00	4.67	7.95	0.02	0.00	99.82	G3
03-03	578801	6554264	39.52	0.07	22.08	0.13	22.27	0.88	0.00	9.26	6.08	0.01	0.00	100.30	G3
03-03	578801	6554264	38.93	0.13	21.45	0.00	24.10	0.75	0.00	7.36	7.25	0.03	0.01	100.01	G3
03-04	568767	6571934	40.67	0.02	18.43	7.56	8.32	0.52	0.00	17.29	7.59	0.00	0.00	100.40	G12
03-04	568767	6571934	41.14	0.05	19.46	6.33	7.66	0.43	0.00	18.85	6.30	0.04	0.00	100.27	G9
03-04	568767	6571934	41.12	0.12	19.10	6.77	8.86	0.54	0.00	18.27	6.14	0.03	0.03	100.97	G9
03-04	568767	6571934	37.17	0.00	21.08	0.00	33.59	3.78	0.00	3.62	1.05	0.01	0.03	100.34	G0
03-04	568767	6571934	38.66	0.06	21.18	0.11	24.41	0.69	0.00	6.37	8.32	0.00	0.01	99.81	G3
03-05	618460	6601324	41.68	0.06	19.84	4.96	8.14	0.44	0.06	18.71	5.74	0.01	0.00	99.65	G9
03-05	618460	6601324	41.96	0.28	21.39	2.79	8.81	0.42	0.02	19.85	4.18	0.07	0.00	99.77	G9
03-05	618460	6601324	40.30	0.03	22.63	0.02	19.37	0.48	0.03	10.16	7.82	0.00	0.00	100.83	G3
03-05	618460	6601324	37.75	0.04	21.28	0.00	30.21	0.48	0.00	3.81	7.31	0.01	0.01	100.92	G3
03-05	618460	6601324	39.15	0.17	21.62	0.07	24.34	0.63	0.01	6.63	7.47	0.03	0.00	100.11	G3
03-06	637217	6536614	37.76	0.11	20.43	0.00	27.37	2.53	0.00	1.93	9.94	0.03	0.00	100.11	G0
03-06	637217	6536614	37.82	0.15	20.97	0.03	28.57	1.92	0.01	2.97	8.09	0.03	0.01	100.58	G0
03-06	637217	6536614	36.64	0.09	20.10	0.00	16.01	22.27	0.01	0.71	3.79	0.04	0.01	99.65	G0
03-07	552529	6488984	36.68	0.02	20.34	0.00	28.92	13.48	0.05	0.49	0.10	0.00	0.00	100.08	G0
03-08	517999	6510824	39.02	0.08	21.91	0.00	21.97	0.60	0.05	5.09	11.87	0.00	0.01	100.59	G3
03-10	567804	6580616	41.10	0.14	17.38	8.11	8.34	0.45	0.06	17.20	7.04	0.03	0.02	99.87	G9
03-10	567804	6580616	42.02	0.27	19.89	4.49	7.83	0.42	0.00	19.90	4.90	0.05	0.00	99.78	G9
03-10	567804	6580616	38.43	0.01	21.69	0.02	30.58	0.91	0.07	6.61	2.39	0.01	0.00	100.72	G0
03-10	567804	6580616	37.50	0.03	20.93	0.02	33.80	0.18	0.04	2.40	5.88	0.01	0.00	100.80	G0
03-10	567804	6580616	36.84	0.05	21.15	0.00	36.35	2.67	0.02	2.76	0.54	0.03	0.00	100.41	G0
03-11	628357	6566434	41.52	0.00	18.13	7.53	8.73	0.45	0.00	16.56	7.74	0.02	0.03	100.69	G12
03-12	545700	6489131	37.87	0.03	21.17	0.00	31.97	2.91	0.04	4.17	2.29	0.01	0.03	100.48	G0
03-13	548386	6486636	40.78	0.09	17.32	8.04	7.58	0.50	0.00	17.73	6.87	0.02	0.01	98.94	G9
03-13	548386	6486636	37.24	0.00	21.04	0.00	35.38	1.01	0.00	3.03	2.64	0.01	0.00	100.37	G0
03-13	548386	6486636	38.88	0.11	21.72	0.00	25.19	0.61	0.03	6.17	7.91	0.02	0.00	100.64	G3
03-13	548386	6486636	39.35	0.07	22.15	0.05	23.76	0.60	0.04	7.57	6.82	0.02	0.00	100.42	G3
03-14	642386	6549584	36.29	0.00	20.90	0.02	38.17	3.01	0.00	1.62	0.60	0.03	0.00	100.63	G0
03-14	642386	6549584	36.92	0.11	21.27	0.02	37.14	0.32	0.05	4.14	0.66	0.02	0.01	100.66	G0
03-14	642386	6549584	37.31	0.06	20.46	0.00	31.91	1.07	0.06	2.45	6.85	0.00	0.02	100.17	G0
03-14	642386	6549584	39.14	0.11	21.78	0.00	21.97	0.44	0.01	6.56	9.42	0.03	0.00	99.45	G3
03-16	656803	6606763	37.84	0.09	21.10	0.01	32.67	0.81	0.00	3.33	4.92	0.00	0.01	100.78	G0
03-16	656803	6606763	36.86	0.03	21.00	0.00	36.42	2.72	0.01	2.71	0.79	0.01	0.00	100.53	G0
03-16	656803	6606763	38.49	0.03	21.01	0.04	26.38	1.10	0.00	2.89	10.83	0.02	0.00	100.77	G0
03-16	656803	6606763	37.21	0.00	21.07	0.01	36.78	1.65	0.00	2.56	0.80	0.02	0.01	100.12	G0
03-17	581298	6540066	38.88	0.05	21.51	0.07	29.63	0.31	0.06	5.42	4.90	0.01	0.00	100.83	G0
03-17	581298	6540066	36.68	0.25	18.29	0.02	2.97	0.46	0.00	1.81	36.41	0.03	0.01	96.93	G0
03-20	516911	6515041	36.64	0.00	21.13	0.01	34.91	3.23	0.04	2.30	1.02	0.01	0.00	99.28	G0
03-20	516911	6515041	37.39	0.12	21.12	0.02	23.48	8.19	0.00	0.74	9.11	0.01	0.03	100.21	G0

Table 3. Microprobe analysis of diopside (%).

Sample ID	UTM Easting	UTM Northing	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	NiO	MgO	CaO	Na_2O	K_2O	Total	100Mg/ (Mg+Fe)
03-02	628743	6566536	53.40	0.08	3.08	1.61	3.01	0.04	0.08	14.74	22.18	1.19	0.00	99.42	89.72
03-02	628743	6566536	52.34	0.36	6.77	1.28	2.25	0.04	0.10	14.40	21.24	1.55	0.03	100.37	91.95
03-04	568767	6571934	53.10	0.17	1.26	0.44	3.30	0.10	0.00	16.42	24.60	0.24	0.00	99.64	89.87
03-04	568767	6571934	53.78	0.19	2.61	1.08	4.52	0.15	0.10	14.49	22.95	0.78	0.02	100.66	85.11
03-04	568767	6571934	54.49	0.10	0.77	0.65	2.15	0.04	0.07	17.42	24.08	0.16	0.00	99.94	93.52
03-07	552529	6488984	55.14	0.08	1.44	0.32	3.59	0.15	0.09	16.31	23.25	0.46	0.01	100.83	89.02
03-07	552529	6488984	55.18	0.12	2.00	1.02	5.16	0.11	0.12	13.97	20.70	2.00	0.01	100.39	82.85
03-07	552529	6488984	55.42	0.03	0.55	0.59	2.60	0.11	0.03	17.61	23.30	0.20	0.00	100.43	92.35
03-11	628357	6566434	54.31	0.07	1.43	0.59	3.58	0.04	0.14	15.76	23.71	0.56	0.00	100.18	88.71
03-14	642386	6549584	55.18	0.13	1.29	0.67	4.02	0.13	0.19	15.73	23.10	0.50	0.00	100.94	87.46
03-14	642386	6549584	53.98	0.14	1.29	0.43	5.37	0.17	0.12	16.06	21.38	0.63	0.00	99.56	84.21
03-14	642386	6549584	53.95	0.15	2.47	1.03	5.26	0.07	0.06	18.50	18.13	0.27	0.00	99.90	86.24
03-14	642386	6549584	54.27	0.07	1.86	0.35	5.37	0.18	0.00	14.97	22.66	0.86	0.00	100.59	83.26
03-16	656803	6606763	54.48	0.00	1.49	0.48	4.50	0.17	0.11	15.12	23.37	0.47	0.00	100.19	85.68
03-16	656803	6606763	54.18	0.06	1.53	0.17	5.18	0.33	0.04	14.26	23.57	0.64	0.03	99.99	83.08
03-16	656803	6606763	53.01	0.00	0.29	0.01	6.49	1.85	0.00	12.56	25.61	0.06	0.00	99.87	77.52
03-20	516911	6515041	53.74	0.06	1.71	0.40	6.14	0.19	0.06	14.18	22.35	0.77	0.00	99.62	80.46
03-22	560045	6482451	52.23	0.48	7.13	1.00	3.03	0.12	0.03	14.75	19.71	1.66	0.00	100.14	89.68
03-22	560045	6482451	52.71	0.29	6.75	0.82	3.04	0.09	0.01	15.07	20.46	1.33	0.00	100.56	89.83
03-22	560045	6482451	55.17	0.19	1.09	0.45	2.93	0.14	0.00	17.35	23.73	0.10	0.00	101.16	91.35

Table 4. Microprobe analysis of ilmenite (%).

Sample ID	UTM Easting	UTM Northing	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	ZnO	SiO_2	V_2O_3	NiO	Total
03-17	581298	6540066	**48.13**	**0.37**	**0.06**	**41.09**	**0.25**	**7.55**	**0.01**	**0.00**	**0.03**	**0.23**	**0.01**	**97.95**
03-17	581298	6540066	**51.07**	**0.43**	**0.54**	**35.67**	**0.24**	**10.11**	**0.02**	**0.05**	**0.03**	**0.21**	**0.08**	**98.72**
03-03	578801	6554264	**50.75**	**0.66**	**0.31**	**33.64**	**0.30**	**12.30**	**0.02**	**0.00**	**0.02**	**0.17**	**0.13**	**98.55**

Table 5. Microprobe analysis of olivine (%).

Sample ID	UTM Easting	UTM Northing	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	NiO	MgO	CaO	Na_2O	K_2O	Total	100Mg/ (Mg+Fe)
03-01	589380	6518892	38.96	0.04	0.05	0.05	17.68	0.23	0.22	41.80	0.20	0.04	0.00	99.25	80.82
03-01	589380	6518892	39.31	0.00	0.04	0.04	16.04	0.18	0.22	43.59	0.23	0.03	0.00	99.67	82.89
03-01	589380	6518892	39.23	0.02	0.03	0.04	17.26	0.20	0.19	42.24	0.26	0.02	0.00	99.51	81.35
03-02	628743	6566536	39.08	0.01	0.06	0.03	17.21	0.23	0.22	42.94	0.30	0.00	0.00	100.08	81.64
03-02	628743	6566536	38.93	0.01	0.05	0.02	17.57	0.21	0.19	42.42	0.22	0.02	0.01	99.65	81.14
03-02	628743	6566536	38.86	0.00	0.01	0.02	17.17	0.22	0.17	42.34	0.21	0.01	0.00	99.02	81.47
03-02	628743	6566536	39.14	0.03	0.06	0.06	17.14	0.23	0.24	42.56	0.20	0.00	0.00	99.66	81.57
03-02	628743	6566536	39.55	0.00	0.04	0.04	15.90	0.22	0.23	43.45	0.23	0.02	0.00	99.68	82.97
03-02	628743	6566536	38.86	0.02	0.05	0.06	18.38	0.25	0.21	41.45	0.24	0.02	0.03	99.56	80.08
03-02	628743	6566536	39.23	0.01	0.03	0.04	17.10	0.22	0.16	42.21	0.26	0.00	0.00	99.26	81.48
03-02	628743	6566536	38.63	0.01	0.07	0.06	17.18	0.19	0.20	42.29	0.22	0.01	0.01	98.87	81.44
03-04	568767	6571934	39.20	0.01	0.04	0.03	16.90	0.19	0.34	42.46	0.24	0.00	0.01	99.42	81.75
03-04	568767	6571934	39.04	0.02	0.04	0.05	16.33	0.20	0.31	42.80	0.22	0.02	0.00	99.02	82.37
03-04	568767	6571934	38.67	0.02	0.02	0.02	19.43	0.21	0.15	40.78	0.26	0.03	0.02	99.61	78.91
03-04	568767	6571934	38.81	0.05	0.04	0.05	18.87	0.18	0.24	41.15	0.22	0.00	0.00	99.60	79.54
03-04	568767	6571934	40.25	0.06	0.02	0.00	10.48	0.14	0.39	48.35	0.04	0.00	0.01	99.75	89.16
03-04	568767	6571934	38.36	0.02	0.03	0.06	19.55	0.26	0.24	40.68	0.22	0.00	0.02	99.42	78.77
03-04	568767	6571934	39.31	0.01	0.04	0.04	17.30	0.19	0.37	42.64	0.20	0.00	0.00	100.09	81.46
03-04	568767	6571934	40.20	0.03	0.02	0.00	10.54	0.18	0.38	47.82	0.05	0.00	0.00	99.21	89.00
03-05	618460	6601324	38.74	0.01	0.04	0.04	17.73	0.16	0.32	42.20	0.22	0.02	0.00	99.48	80.93
03-05	618460	6601324	39.45	0.00	0.04	0.07	15.30	0.16	0.25	43.38	0.23	0.00	0.02	98.90	83.48
03-05	618460	6601324	38.85	0.00	0.08	0.04	17.25	0.18	0.25	42.63	0.23	0.02	0.00	99.54	81.50
03-05	618460	6601324	38.61	0.01	0.05	0.04	18.64	0.27	0.22	41.37	0.22	0.02	0.00	99.45	79.82
03-06	637217	6536614	38.06	0.06	26.12	0.00	9.98	0.11	0.00	0.00	24.07	0.00	0.00	98.41	0.00
03-07	552529	6488984	40.68	0.00	0.00	0.02	9.60	0.19	0.33	48.77	0.03	0.00	0.00	99.65	90.06
03-07	552529	6488984	40.75	0.04	0.02	0.01	9.91	0.18	0.41	48.74	0.02	0.00	0.01	100.09	89.76
03-07	552529	6488984	39.69	0.05	0.05	0.02	16.06	0.23	0.18	43.76	0.22	0.01	0.01	100.27	82.93
03-17	581298	6540066	38.93	0.01	0.06	0.02	17.65	0.24	0.24	41.89	0.22	0.02	0.00	99.28	80.88

Table 6. Microprobe analysis of diaspore (%).

Sample ID	UTM Easting	UTM Northing	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	NiO	MgO	K_2O	Total
03-06	637217	6536614	0.00	0.04	81.28	0.00	3.95	0.03	0.02	0.02	0.00	85.32
03-02	628743	6566536	0.00	0.01	81.92	0.00	2.83	0.00	0.03	0.00	0.01	84.81