# Heavy Mineral Survey and its Significance for Diamond Exploration Fort Nelson Area, British Columbia, Canada.

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## EXECUTIVE SUMMARY

Parts of northeast 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" (Simandl, 2004). 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 presence of kimberlite indicator minerals (KIMs) in Quaternary sediments (Simandl, 2004; Figure 1). This study concentrates mainly on KIMs present in Late Pleistocence glaciofluvial sands and gravels. Of 20 samples collected and processed, 14 contain KIMs such as purple pyrope, yellowish eclogitic garnet, Cr-diopside, olivine, ilmenite, or spinel. It is possible that these minerals are derived from primary, secondary or tertiary sources within the Fort Nelson area. It is also possible, however, that they were brought into the region from the Northwest Territories and Alberta by Late Pleistocene glacial and glaciofluvial systems. Corundum and diaspore were also recovered from collected samples. At this stage, semiquantitative data does not allow for a definitive interpretation as to whether this corundum is kimberlite-related. The location of samples indicating kimberlite indicator minerals shown on Figure 1.

## INTRODUCTION

The objective of this study is to collect and process glaciofluvial sands and gravels to analyze for the presence or absence of kimberlite indicator minerals (KIMs) in the Fort Nelson area (Figure 1). The majority of the study area occurs within the Fort Nelson Lowlands physiographic region, a subdivision of the Interior Plains. In general, this area can be characterized as having flat to subdued topography, which is an expression of the horizontally to subhorizontally bedded sedimentary rocks that underlie the region (Holland, 1976). 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. Larger river systems, such as the Fort Nelson, Prophet, and Petitot rivers, however do occur in the region. In contrast to the lowlands, the Etsho Plateau (~700 m above sea level; Figure 2) forms a topographic high, 140 by 80 km, that trends northwest-southeast.

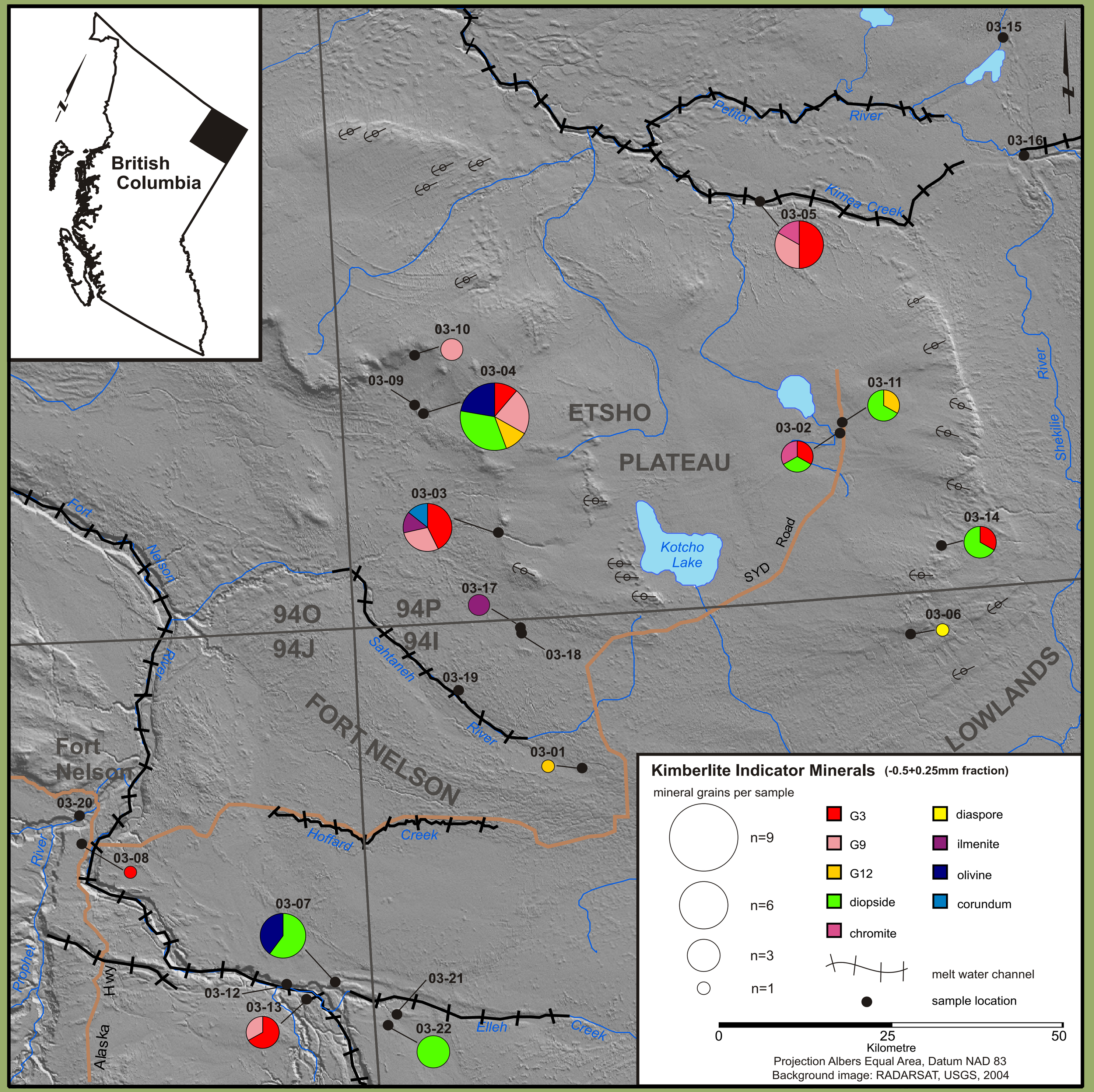



**Figure 1.** Distribution of kimberlite indicator minerals in glaciofluvial sands and gravels. The data is not corrected for sample weight.

## BEDROCK GEOLOGY

The Fort Nelson area is underlain by a Precambrian basement that belongs to the North American craton (Hoffman, 1988, 1989, 1991; Villeneuve *et al.*, 1993; Ross *et al.*, 1991 and 1995) which is overlain by a thick Phanerozoic sequence consisting of the Lower Cretaceous Fort St. John Group. 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 (Stott, 1982; Thompson, 1977). The stratigraphy and sedimentology of the Dunvegan Formation recently have been discussed in detail by Plint *et al.* (2001), and Plint and Wadsworth (2003).

## SURFICIAL GEOLOGY

Silt and clay-rich morainal deposits are the dominant surfical material. They typically occur at surface in better drained forested areas, and are invariably overlain by organic materials and (or) glaciolacustrine sediments in poorly drained areas. Morainal landforms include low relief plains, crevasse-squeeze ridges, flutes, and rolling, recessional, and interlobate moraines. Glaciofluvial landforms are uncommon, however, eskers, kames, fans, deltas and terraces can occasionally be observed. Most of the larger terraces occur within the Kimea Creek Petitot River meltwater channel system (Figure 1). Other large meltwater channel systems occur in the 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), however, 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 lithologies from the Canadian Shield (*e.g.* 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.

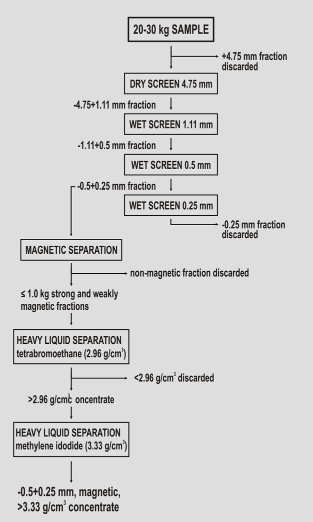
## QUATERNARY HISTORY

The Late Pleistocene regional ice-flow record is preserved in flutes and crag-and-tail ridges that occur on, and along, the periphery of Etsho Plateau (Figure 1). The Laurentide ice sheet moved into the region from the east and northeast, however, there is variability in the details of this advance. 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 (Figure 1). While the orientations of some features likely indicate divergent flow around topographic barriers (*e.g.* southeast portions of Etsho Escarpment), the orientations of other features in the northeast and east-central portion 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 flowing west, away from the retreating Laurentide ice sheet. Glacial lakes developed along the ice margin as drainage down the regional slope to the east was blocked by ice (Mathews, 1980). For example, Glacial Lake Hay formed in the lowlands southeast of Kotcho Lake, and extended east into Alberta. This resulted in the widespread deposition of clay-rich glaciolacustrine

## SAMPLE COLLECTION

Twenty two samples of glaciofluvial sands and gravels were collected (Figure 1; Table 1). Average sample size ranged from 20 to 30 kg with some up to 40 kg. An effort was made to exclude clasts >4 mm in size and include as much sand-sized material as possible. Sample sites were vertical walls in gravel pits or road cuts and pits dug by an excavator. The sample distribution was limited due to the scarcity of glaciofluvial material. The sample depth was typically 1 to 4 m below surfaceand collected from undisturbed material. Heavy mineral concentrates were produced by Vancouver Indicator Processors Inc., as outlined in Figure 2. The -0.5+0.25 mm heavy mineral fractions were sent to I. & M. Morrison Geological Services Ltd. for KIM picking. Potential KIM's were sent to I. Kjarsgaard (Consulting Mineralogist) for microprobe analysis. From 197 mineral grains, 46 grains were confirmed as KIMs.

FIGURE 2:
SAMPLE PROCESSING
FLOWCHART




## GLACIOFLUVIAL ENVIRONMENTS

Table 1. Sampled glaciofluvial systems, features, and depositional

| Sample ID | Glaciofluvial System | Glaciofluvial Feature Sampled and Size | Depositional Environment | Clast Lithologies | Paleoflow Direction |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

1. High energy meltwater systems, with channel widths from 1 to > 2.5 km, 10 to 30 m deep, and > 40m long, and long transported distances (many 10's to 100's km).

2. Collected from small-scale esker systems (5 to 10 m wide, up to 5 m high, and >1 km long). Although dominated by sand-sized material, transport distances could potentially be long.

3. Smaller-scale melt water systems situated along the periphery of the Etsho Plateau; channels typically 10 to 30 m wide, 5 to 10 m deep, and up to 10 km long, dominated by sand-sized material, and likely have much shorter transport distances.

4. As they are now burried, it is difficult to assess the size of the transport and depositional systems.

5. Likely deposited in an aggregational and less

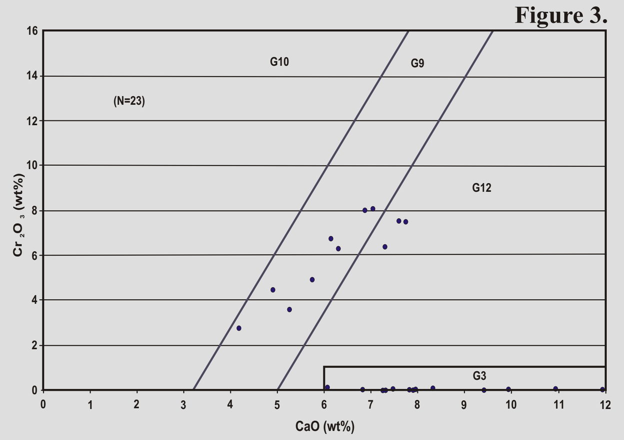
## INTERPRETATION OF INDICATOR MINERALS

Of the 20 samples collected for this study, 14 contain KIMs. Of these, eight contain more than one indicator mineral. In total 46 KIM's were confirmed by microbe analyses. The following section presents microprobe data, and includes a discussion of KIMs identified in this study. The spatial distribution of KIM's is shown in Figure 1.

### Garnet

Mantle-derived garnets are the most important KIM's. The scheme described by Grütter et al. (2004) is used to classify garnets. In this classification, 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 any of the twelve categories, including crustal garnets, are referred to as G0. Microprobe analyses of hand-picked garnets, and results of classification are provided in Table 2. Of the 46 garnets that were visually picked and analysed, at least 23 can be considered as KIMs. Although there are no G10 garnets present, one of the G9 garnets plots close to the G9-G10 boundary (Figure 3). Eight of the mantle-derived garnets are lherzolitic (G9), three are wehrlitic (G12) and twelve can be considered as eclogitic (G3). The remaining garnets are classified as G0. The garnets with significant Cr content (G9) follow a trend from the G10-G9 to G9-G12 boundaries, forming an acute angle with the lherzolite field (Figure 3). No G3 garnets recovered in this study have $Na_2O$ content of more than 0.07 wt%. With one possible exception, kelyphitic rims were not observed, but some grains have orange-peel texture. This suggests that these garnets were subject to some degree of transport, or at least local reworking, after being liberated from their host rock.

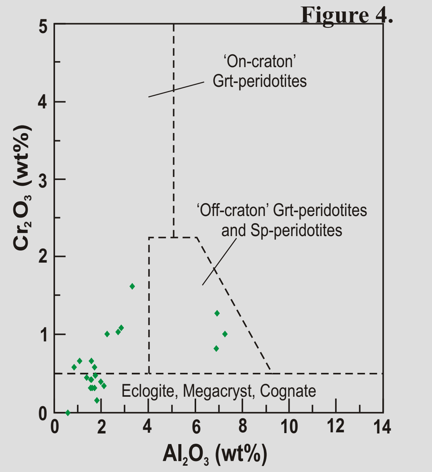
Figure 3.




### Clinopyroxene (Cr-Diopside)

Cr-bearing clinopyroxenes (CPXs) are easy to identify in concentrates, and can be associated with diamonds. Unfortunately, CPXs with similar characteristics to those present in kimberlites are also found in other lithologies; Microprobe analyses are required to identify kimberlite-related CPXs. Twenty CPX grains were picked from concentrates. Their chemical composition is provided in Table 3. The Mg# (100Mg/(Mg+Fe) of these CPXs vary from 77.52 to 93.52. Cr-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#, there is 10 CPXs classified as KIM's. The discrimination plot $Cr_2O_3$-$Al_2O_3$ of Ramsey and Tompkins (1994) is used to further refine this interpretation. Of the 10 CPXs identified as KIM's based on the Mg#, 4 plot within the 'on craton' field, and 3 plot within the 'off craton' field (Figure 4). For additional CPXs plot within this field, however they have an Mg# <88. Of the 20 CPXs identified during this study, 14 could be considered as KIMs.

Figure 4.



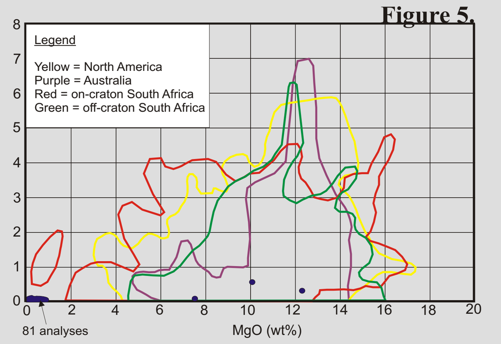

### Spinel

Based on microprobe analyses, only one visually picked mineral grain is chromite (sample 03-05; Figure 1). 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 components 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 MgO values 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% $Cr_2O_3$. Due to its association with other indicator minerals, however, this grain was identified as a potential KIM.

### Ilmenite

The $Cr_2O_3$ and MgO plot suggests that the three ilmenite grains in Figure 5 are kimberlite-related. All of them have higher MgO values, and two of them have higher $Cr_2O_3$ content than their non-kimberlitic counterparts. The fields of typical North American, South African (on and off craton), and Australian kimberlitic ilmenites are provided in Figure 5, and are based on data from Wyatt et al. (2004). Most of the non-kimberlitic ilmenites have low MgO values and probably originated from the same, non-kimberlitic, crustal protolith (Figure 5).

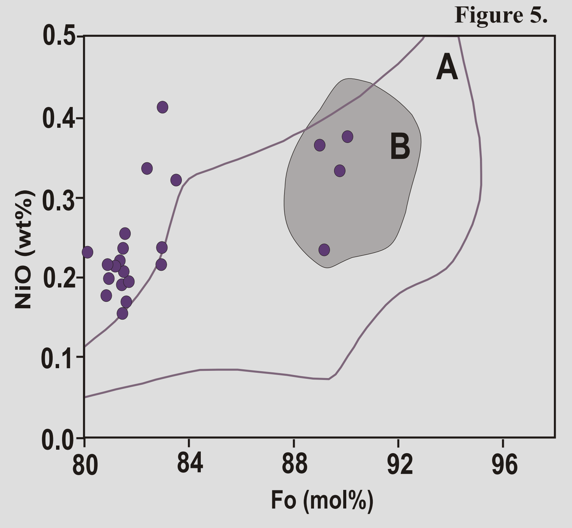
Figure 5.




### Olivine

Although olivine is a common rock-forming mineral in kimberlites, it is also present in a variety of other ultramafic rocks. The Mg-rich variety of olivine identified in samples from Fort Nelson area is commonly pale yellow-green in colour, equidimensional, subrounded to rounded, and has a fresh appearance. Microprobe analyses are therefore required to establish provenance. Microprobe data on 28 olivine grains recovered from collected samples are presented in Table 5, while NiO/Fo diagram using the same data is presented in Figure 5. The MgO content of these olivines ranges from ~41 to 50 wt% and that of FeO between ~8 to 19 wt%. Kimberlite-related grains plot in the field delineated by curve A (Eccles et al., 2004; Figure 5). Curve B (Figure 5) delineates a more restricted field, which represents the typical composition of olivine grains from the northern Alberta kimberlite province. Four of the most Mg-rich grains from this study fall within this field.

Figure 5.




### Corundum

A single purple corundum grain was recovered during this study. Its colour and high Cr content indicate that it is similar to ruby. This grain is composed almost entirely of $Al_2O_3$, with minor concentrations of $Cr_2O_3$ (0.54%) and FeO (0.19%), and even less NiO (0.03%) and MnO (0.01%). Laser ICP-MS, or energy dispersive spectrometry, would be necessary if further interpretation is required. Similar Cr-corundum is reported in association with spinel in kimberlite pipes from Buffalo Head Terrane, Alberta (Hood and McCandless, 2004), in the Fort a la Corne area, Saskatchewan (Hutchison et al. 2004), and in Northwest Territories. Although corundum grains are also reported in some rocks within the alkaline province, eastward transport of KIM's is unlikely. Sample 03-03 (Firgure 1), which also contained several kimberlite indicators, including mantle-derived garnets and ilmenite, is worth follow-up both from diamond and gem corundum perspectives.

### Diaspore

Two yellow diaspore grains were visually picked from heavy mineral concentrates (samples 03-06 and 03-02; Figure 1). These grains have similar NiO values to those of the previously described corundum grain. The diaspore grains differ from the corundum grain by having no $Cr_2O_3$, higher FeO values, and detectable $TiO_2$ content (Table 6). The significance of these grains is not well understood. Diaspore is not typically considered a KIM. It commonly coexists with corundum in silica- undersaturated lithologies as a retrograde product in meta-morphosed corundum-bearing alumina-rich sedimentary rocks and bauxite deposits (Simandl and Paradis, 1999a; Hill, 1994) and with ultramafic-related corundum-bearing contact metamorphic rocks (Simandl and Paradis (1999b). However it may be present in corundum-bearing alkaline volcanics such as alkali basalts, kimberlites, and lamrophyres (Simandl and Paradis, 1999c). The chemical composition of these grains does not suggest a strong association with kimberlite indicators or the purple corundum grain.

## SUMMARY AND CONCLUSION

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 of the Fort Nelson area. From glaciofluvial sands and gravels 14 of the 22 samples collected contained KIMs, some 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 some degree of transportation or at least 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 possibly somewhere on the plateau itself. Others, particularly those occurring in large-scale, high energy glaciofluvial systems, were more likely transported into the area from Alberta and Northwest Territories. Possible sources include known diatremes located east of the study area in Buffalo Head Terrane and in the Slave Craton and undiscovered pipes cutting Mesozoic to Paleozoic-age sedimentary rocks in Fort Nelson area itself. The geology of the Precambrian basement in northeast British Columbia is poorly understood, and it should not be ignored in diamond exploration.

## ACKNOWLEDGEMENTS

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## REFERENCES

[illegible]

Table 2. Microprobe analysis of hand-picked garnet (values given in %).

| Sample ID | UTM Easting | UTM Northing | grain | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Cr_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Table 3. Microprobe analysis of hand-picked diopside (values given in %).

| Sample ID | UTM Easting | UTM Northing | grain | [illegible] |
|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Table 4. Microprobe analysis of hand-picked ilmenite (values given in %).

| Sample ID | UTM Easting | UTM Northing | grain | [illegible] |
|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Table 5. Microprobe analysis of hand-picked olivine (values given in %).

| Sample ID | UTM Easting | UTM Northing | grain | [illegible] |
|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Table 6. Microprobe analysis of hand-picked diaspore (values given in %).

| Sample ID | UTM Easting | UTM Northing | grain | [illegible] |
|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |