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Mineralogy of the McLean kimberlite and associated glacial sediments, Lake Timiskaming, Ontario

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ABSTRACT

In 1999 the Geological Survey of Canada, as part of the Targeted Geoscience Initiative (TGI), excavated several shallow trenches into the McLean kimberlite in the Lake Timiskaming kimberlite field of northeastern Ontario. Samples were collected to document the mineralogical and geochemical signatures of the kimberlite and the till. The McLean kimberlite, which has been dated at 141.9±2.8 Ma, intruded the Paleoproterzoic Firstbrook Member of the Gowganda Formation consisting dominantly of thinly to medium bedded argillite/siltstone, with minor wacke and arenite. It is a multi-phase intrusion which consists of diatreme and hypabyssal kimberlite. The exposed portion of the McLean kimberlite sampled for this study is aphanitic, characterized by a scarcity of megacrysts, xenoliths and phenocrysts and unusually indicator mineral-poor as compared to other kimberlites in the region, and drillcore from the same kimberlite. The relative abundance of indicator minerals in the McLean kimberlite is: olivine>> Cr-diopside>Cr-pyrope>Mg-ilmenite >chromite. Comparison of indicator mineral compositions and abundances reveal that glacial dispersal from the McLean kimberlite is best defined by the presence of kimberlite pebbles, and the abundance of olivine. Till sampled to the south of the McLean kimberlite contains kimberlite indicator minerals that are distinctly different in composition from those of the McLean kimberlite, which suggests the presence of another kimberlite source(s) up-ice (northeast). Some of the chromite, Cr-diopside and all of the MgO-poor ilmenite in till are not from kimberlite, but most likely from regional mafic or ultramafic rocks. Pyrope garnet and Mg-ilmenite, however, have compositions that indicate that they are from the McLean kimberlite further up-ice or from some other unknown kimberlite source up-ice.

INTRODUCTION

Since 1992, the Geological Survey of Canada (GSC) has carried out investigations in the vicinity of known kimberlites in the Kirkland Lake and Lake Timiskaming areas of northeastern Ontario. The purpose of these studies is to document kimberlite mineralogy as well as glacial dispersal patterns and surficial geochemical signatures associated with the kimberlites. Kimberlite debris has been glacially eroded and transported down-ice and the kimberlites are covered by glacial sediments a few metres to 100 m thick leaving no surface expression. Because of the glacial dispersal and resultant cover of sediments, indicator mineral and geophysical methods have been used in the past 30 years to explore for kimberlites in the region. To date, 26 kimberlite pipes have been discovered in the Kirkland Lake and Lake Timiskaming fields (Brummer et al., 1992a; McClenaghan, 1993; Zalnieriunas and Sage, 1995; Sage, 1996, 1998, 2000).

Several kimberlites from the Kirkland Lake kimberlite field (C14, B30, A4, Diamond Lake, Buffonta) located 80 km north of Lake Timiskaming, as well as the Peddie kimberlite, near Lake Timiskaming, were examined previously and these results have been published in several GSC reports (Table 1). In 1999, several shallow trenches were excavated into the McLean kimberlite in the Lake Timiskaming kimberlite field (Fig. 1). Samples were collected to document the mineralogical and geochemical signature in kimberlite and till in an area between 20 m up-ice (north) and 1 km down-ice (south) of the kimberlite. This report summarizes the results of this work.

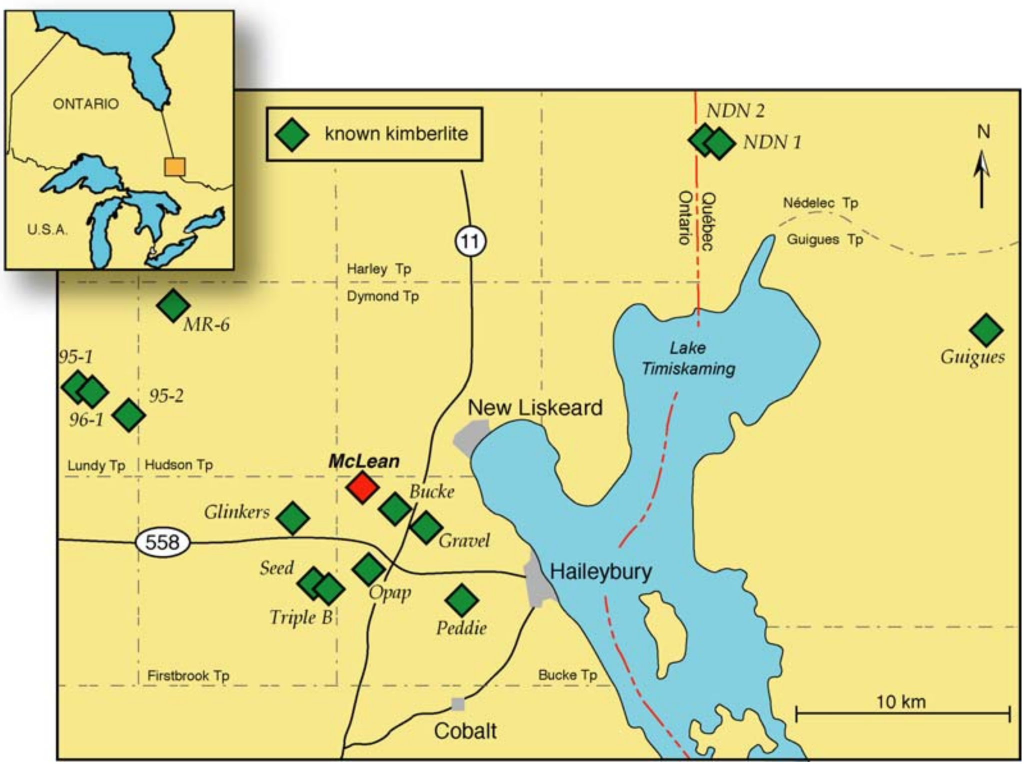

Figure 1. Location of the McLean kimberlite in the Lake Timiskaming kimberlite field.

Location and access

The Lake Timiskaming kimberlite field comprises twelve known kimberlites in northeastern Ontario, near the towns of Haileybury and New Liskeard and three in western Quebec (Fig. 1). The McLean kimberlite is located at 47°29'10"N and 79°45' 30"W (UTM Zone 17, Easting 593600, Northing 5256000, NAD27) in Bucke Township, 6 km southwest of the town of New Liskeard. The kimberlite is on the McLean Farm, south of South Wabi Creek, in a wooded area 300 m west of the natural gas pipeline right of way (Fig. 2).

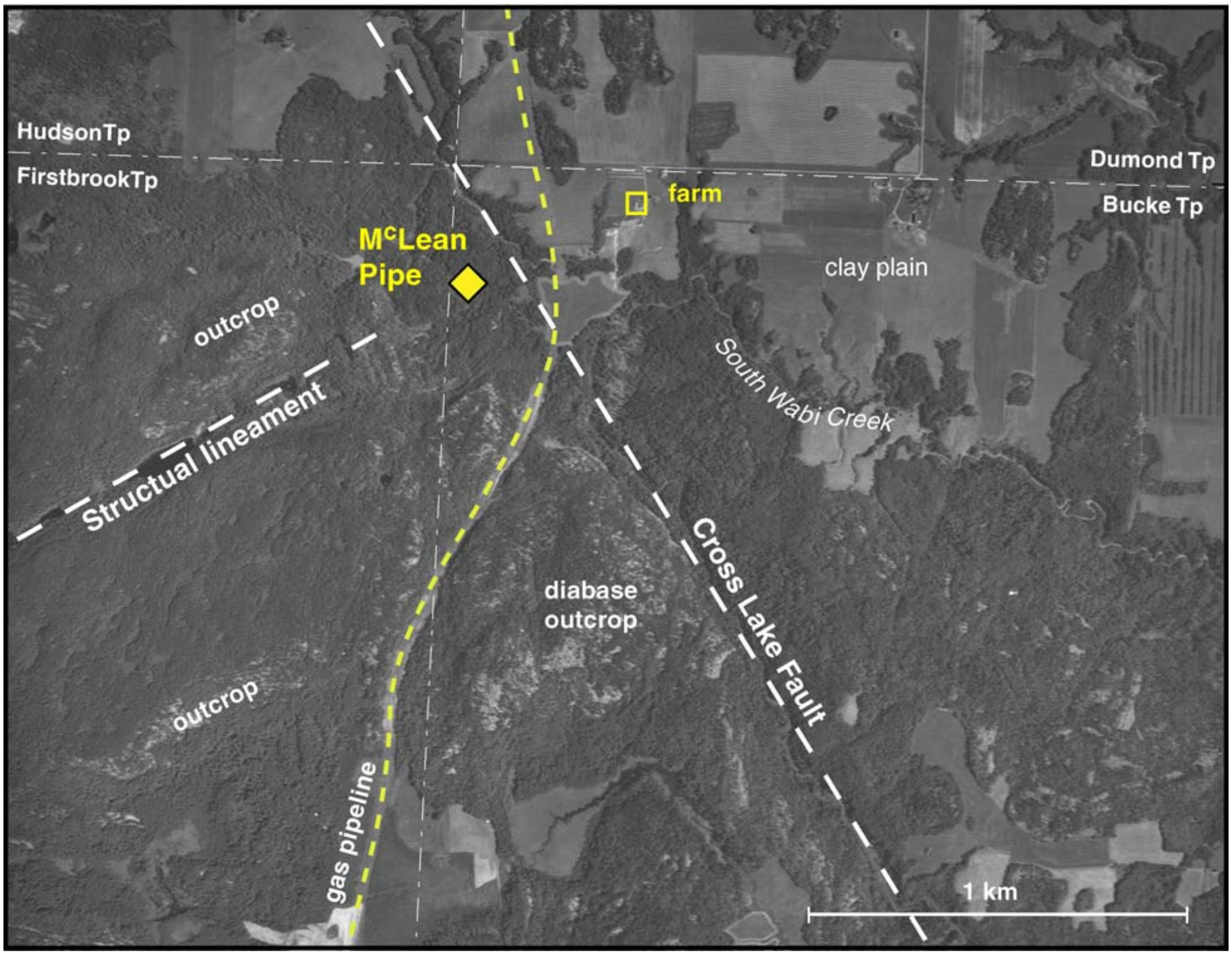

Figure 2. Location of the McLean kimberlite and significant bedrock structural features (structural features from Veillette (1986) and Card and Lumbers (1975)).

Bedrock geology

The McLean kimberlite is located adjacent to (within 150 m of) the Cross Lake Fault, and appears to be directly on an un-named structural lineament which trends at 045° (Fig. 2). It is suspected that the Bucke and Gravel kimberlites (Fig. 1) also lie along the Cross Lake Fault (Sage, 2000). The McLean kimberlite outcrops (1 m x 0.4 m) adjacent to a small ephemeral stream on the southeast side of the body (Fig. 3). It intrudes the Paleoproterzoic Firstbrook Member of the Gowganda Formation (Fig. 4). Rocks of the Firstbrook Member are comprised dominantly of thinly to medium bedded argillite/siltstone, with minor wacke and arenite. Paleoproterozoic Nipissing diabase sills intrudes the Gowganda Formation, and form extensive areas of outcrop and cliffs just to the south (Fig. 2).

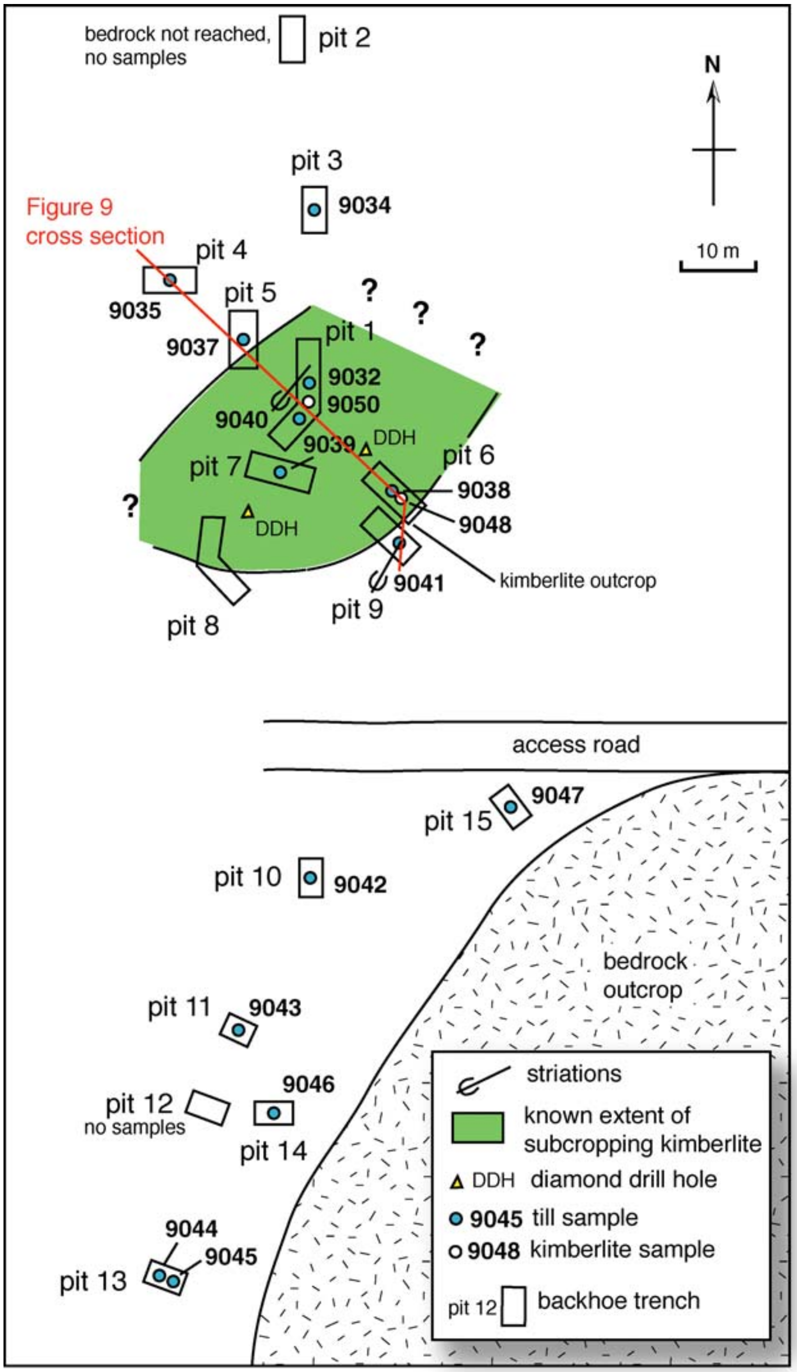

Figure 3. Location of backhoe trenches and till samples around the McLean kimberlite.

Figure 4. Contact between the Jurassic-age McLean kimberlite (background) and Paleoproterozoic Firstbrook Member metasediments (foreground) in pit 9. Note more resistant ledge in the metasediments, due to the formation of a contact aureole.

The McLean kimberlite is characterized by a circular, negative isomagnetic anomaly (Fig. 5) approximately 150 m in diameter (Sage, 2000). A radiometric age of 141.9±2.8 Ma was determined by the U-Pb in perovskite for the McLean kimberlite (Heaman and Kjarsgaard, 2000). This age suggests the McLean kimberlite is contemporaneous with the Guigues kimberlite in western Quebec (142.3± 6.6 Ma), and lies in the middle of the age range of the eight Lake Timiskaming kimberlites dated so far, which vary from 155.4 ±1.5 Ma (Bucke) to 133.9±1.5 Ma (Glinker) in age (Heaman and Kjarsgaard, 2000). From drill core studies it is known that the McLean kimberlite is a multi-phase intrusion which consists of diatreme and hypabyssal kimberlite (Sage, 1996, 2000; Hodder, 2002). The kimberlite sampled at the surface is a hypabyssal aphanitic kimberlite, which is characterized by a scarcity of megacrysts, xenoliths and phenocrysts (Fig. 6). Based on the occurrence and relationship of diatreme and hypabyssal kimberlite in drill core and at surface, the approximate level of erosion of the McLean kimberlite is shown in Figure 7. Burgers et al. (1998) describe the McLean kimberlite as a hypabyssal “porphyritic” spinel-rich calcite monticellite kimberlite and note a paucity of olivine macrocrysts. The hypabyssal aphanitic kimberlite is here termed a spinel monticellite calcite kimberlite, and in the drill core the diatreme kimberlite is best classified as a spinel calcite serpentine kimberlite.

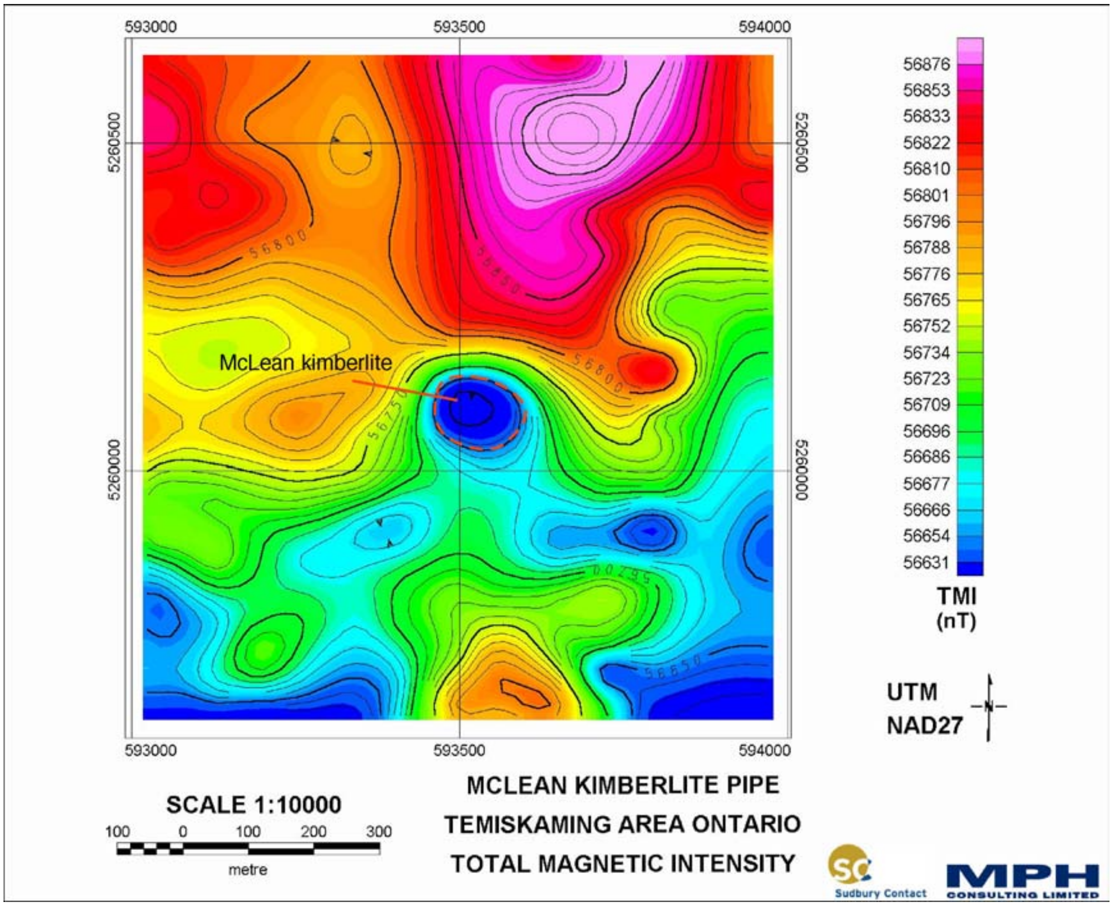

Figure 5. Airborne magnetic survey showing the negative magnetic anomaly associated with the McLean kimberlite. Likely extent of the kimberlite outlined by red dashed line. (unpublished data from MPH Consulting Ltd. and Sudbury contact Mines Ltd., 2003).

Figure 6a. Aphanitic cap of McLean kimberlite as seen in boulders from Pit 6.

Figure 6b. Aphanitic McLean kimberlite in polished hand specimen.

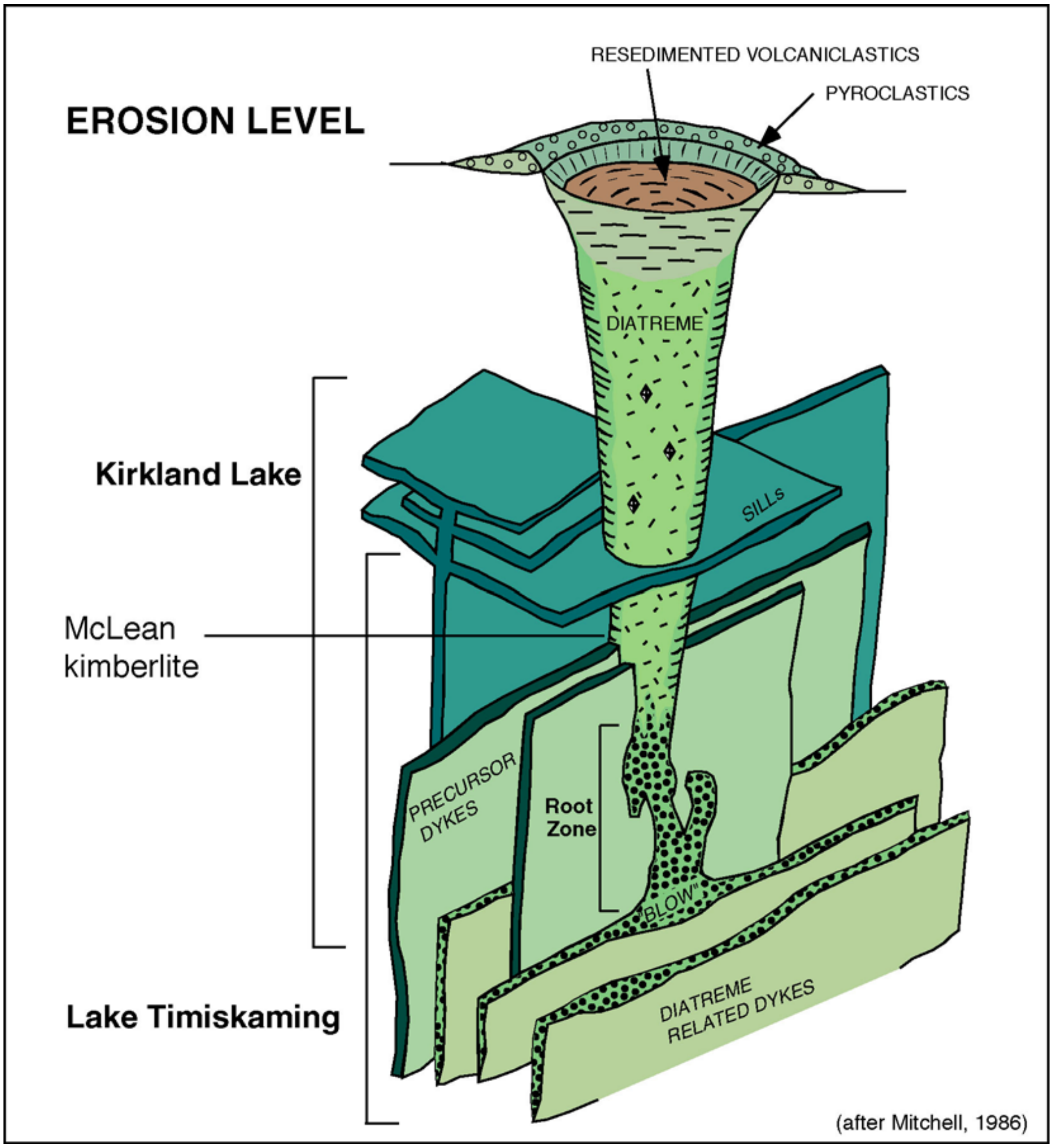

Figure 7. Model of a kimberlite (from Mitchell,1986) showing variation in the present day erosion levels for kimberlites in Kirkland Lake and Lake Timiskaming regions, and the inferred erosion level of the McLean kimberlite.

Glacial geology

The Lake Timiskaming region was covered by the Laurentide Ice Sheet during the Wisconsinan which eroded local bedrock and deposited a silty sand till (Veillette, 1996). Ice flowed west to southwest during the main phase of glaciation (Fig. 8), then south and finally southeast during deglaciation (Veillette, 1989, 1996: Veillette and McClenaghan, 1996). As the glacier retreated northward approximately 9500 years ago, glacial Lake Barlow developed in front of the ice sheet and thick sequences of fine grained glaciolacustrine sediments were deposited over top of the till and bedrock (Vincent and Hardy, 1979; Veillette, 1988, 1989, 1996). Glacial Lake Barlow receded from the area approximately 8000 years ago (Veillette, 1994), and the McLean site has been exposed to postglacial weathering and soil forming processes since that time. The McLean kimberlite is covered by up to 0.3 m of grey, silty sand till, which is overlain by up to 3 m of glaciolacustrine silt (Figs.

9,10). Striations on kimberlite surfaces in Pits 1 and 9 indicate that ice flowed toward 212° to 218°. On the southeast edge of the kimberlite, small pockets of postglacially weathered kimberlite were observed (Fig. 10).

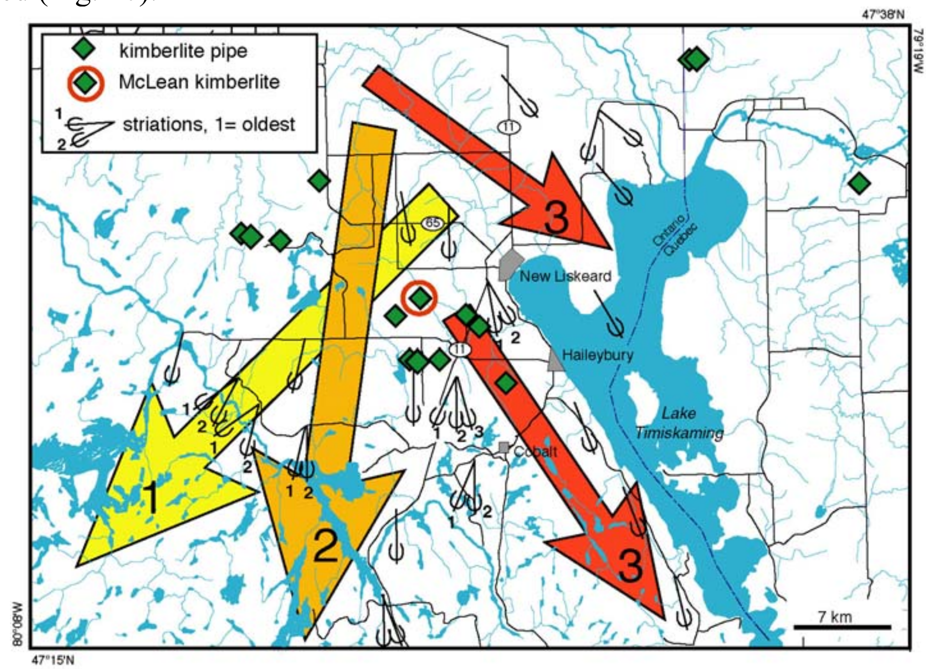

Figure 8. The three main phases of ice flow that crossed the area (indicated by large, numbered arrows, 1= oldest, 3= youngest) and location of selected striations. Ice flow sequence from Veillette (1996) and McClenaghan et al. (2001).

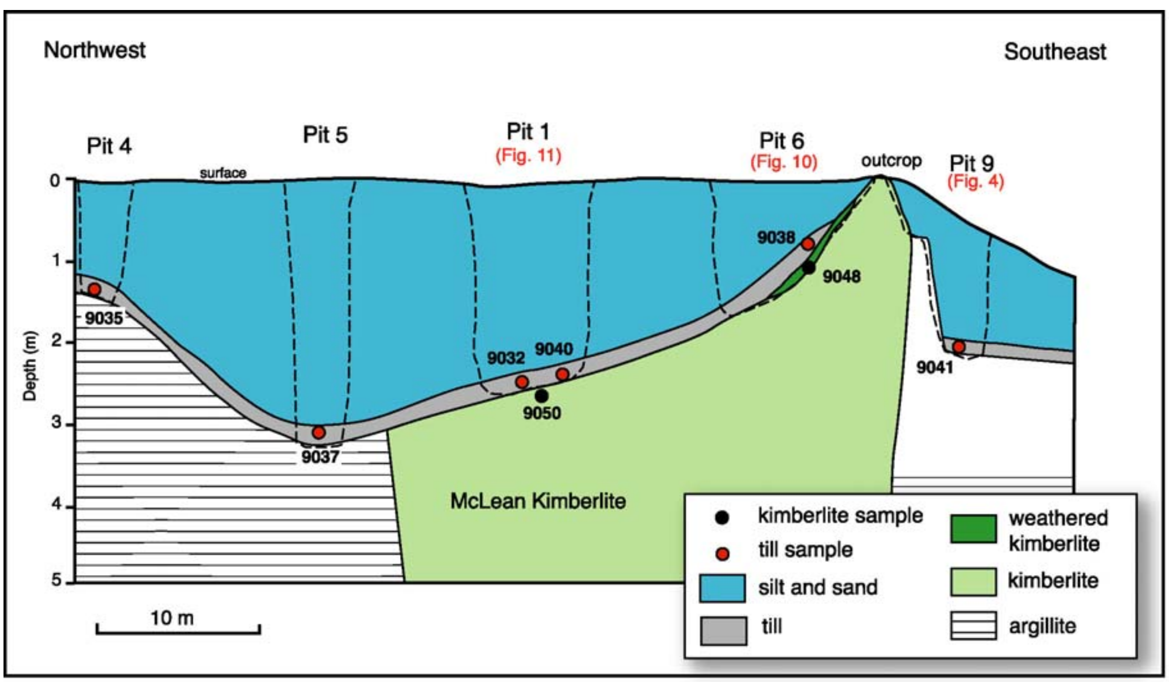

Figure 9. Schematic northwest-southeast cross section over the McLean kimberlite showing glacial sediment thickness and sample locations (not all samples shown).

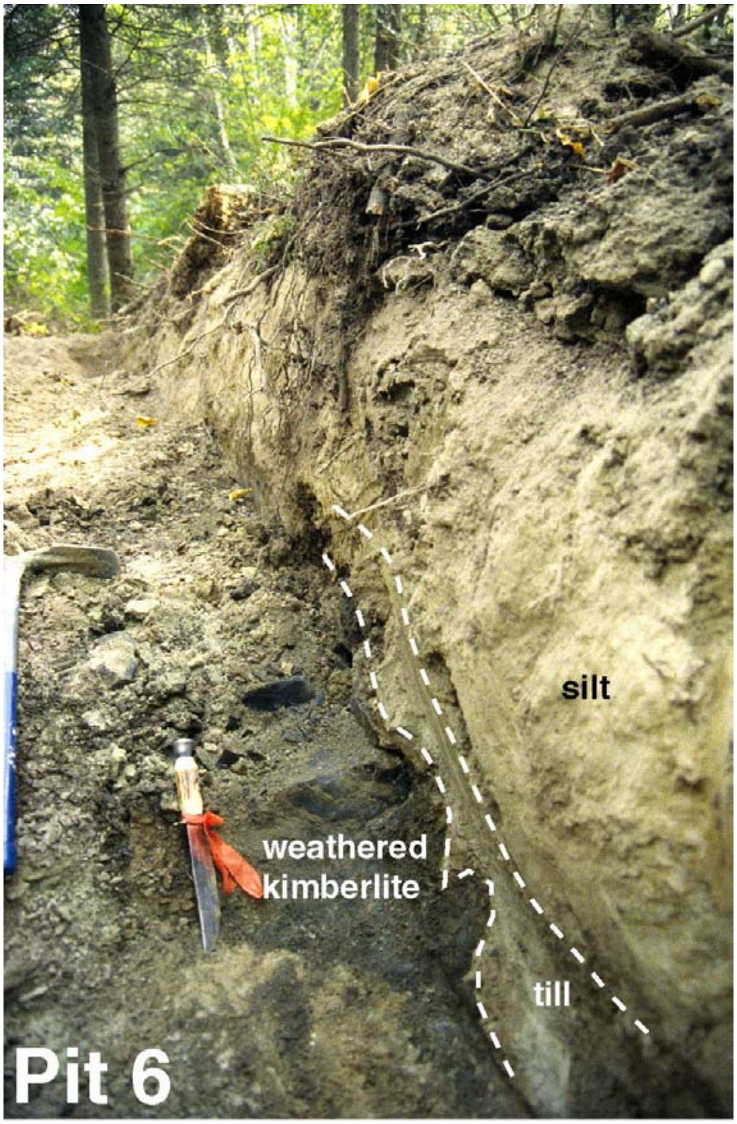

Figure 10. a) Post-glacially weathered kimberlite exposed in pit 6.

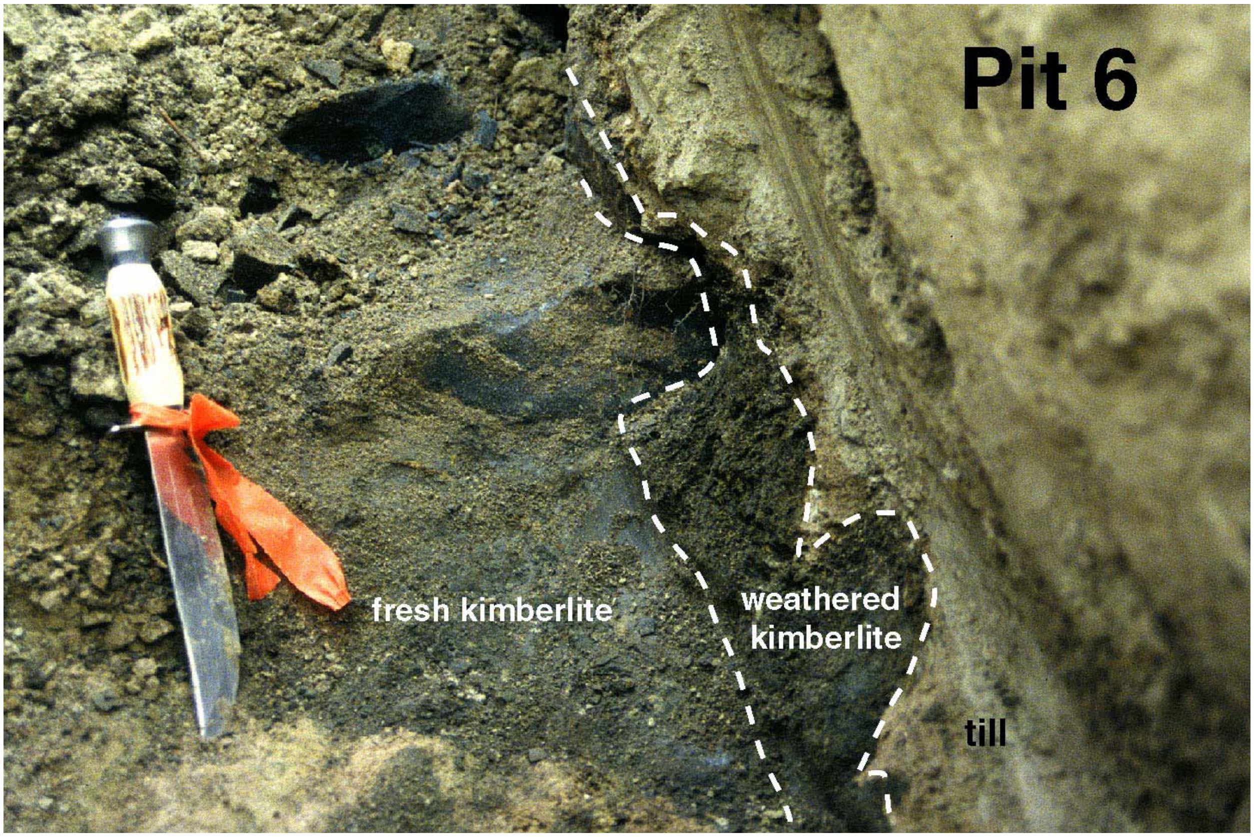

Figure 10b. Detail of weathered kimberlite.

Previous kimberlite research in the Lake Timiskaming area
Information on the indicator mineral chemistry of the Lake Timiskaming kimberlites has been published by Schulze (1995, 1996a,b), Schulze et al. (1995), and Sage (1996, 2000), McClenaghan et al. (1999a, 2002a,b). No in depth investigation of the McLean kimberlite has been undertaken previously.

METHODS

Sample collection

Fifteen pits 2 to 3 m deep were excavated using a backhoe to collect bulk (10-kg) samples of weathered and fresh kimberlite as well as glacial sediments overlying, up-ice and down-ice of the kimberlite (Figs. 3 and 9). A total of 14 till samples were collected from the 15 pits. Four pits were excavated north of the kimberlite (Fig. 3) to collect till samples to determine background till geochemical patterns and background concentrations of kimberlite indicator minerals. Five pits were excavated overlying the kimberlite to collect till samples and kimberlite. Six pits were dug up to 100 m south of the kimberlite to detect glacial dispersal of kimberlite down-ice. Pits could not be dug to the southwest of the kimberlite due to surface ground conditions.

Weathered kimberlite (sample 9048) was collected from backhoe pit 6 and fresh kimberlite (sample 9050) was collected from pit 1 to compare mineralogy and geochemistry of weathered and unweathered kimberlite. One till sample (9049) was collected 4 km northeast of the kimberlite (UTM 596450, 5262300, NAD27) to determine background concentrations of indicator minerals up-ice.

Sample preparation
Till samples were processed by Overburden Drilling Management Ltd., Nepean, Ontario, to recover heavy mineral concentrates for examination of kimberlite indicator minerals, using methods (Fig. 11) similar to those reported in McClenaghan et al. (1999a). Weathered kimberlite samples were soaked in water prior to sample processing and fresh kimberlite sample 9050 was subjected to mechanical crushing prior to sample preparation. Three size fractions of the heavy mineral concentrate were prepared from till for indicator mineral picking: 1) 0.25 to 0.5 mm, 2) 0.5 to 1.0 mm; and, 3) 1.0 to 2.0 mm. Kimberlite sample 9050 was crushed to < 1.0 mm, thus results are reported only for the 0.25 to 0.5 mm and 0.5 to 1.0 mm size fractions.

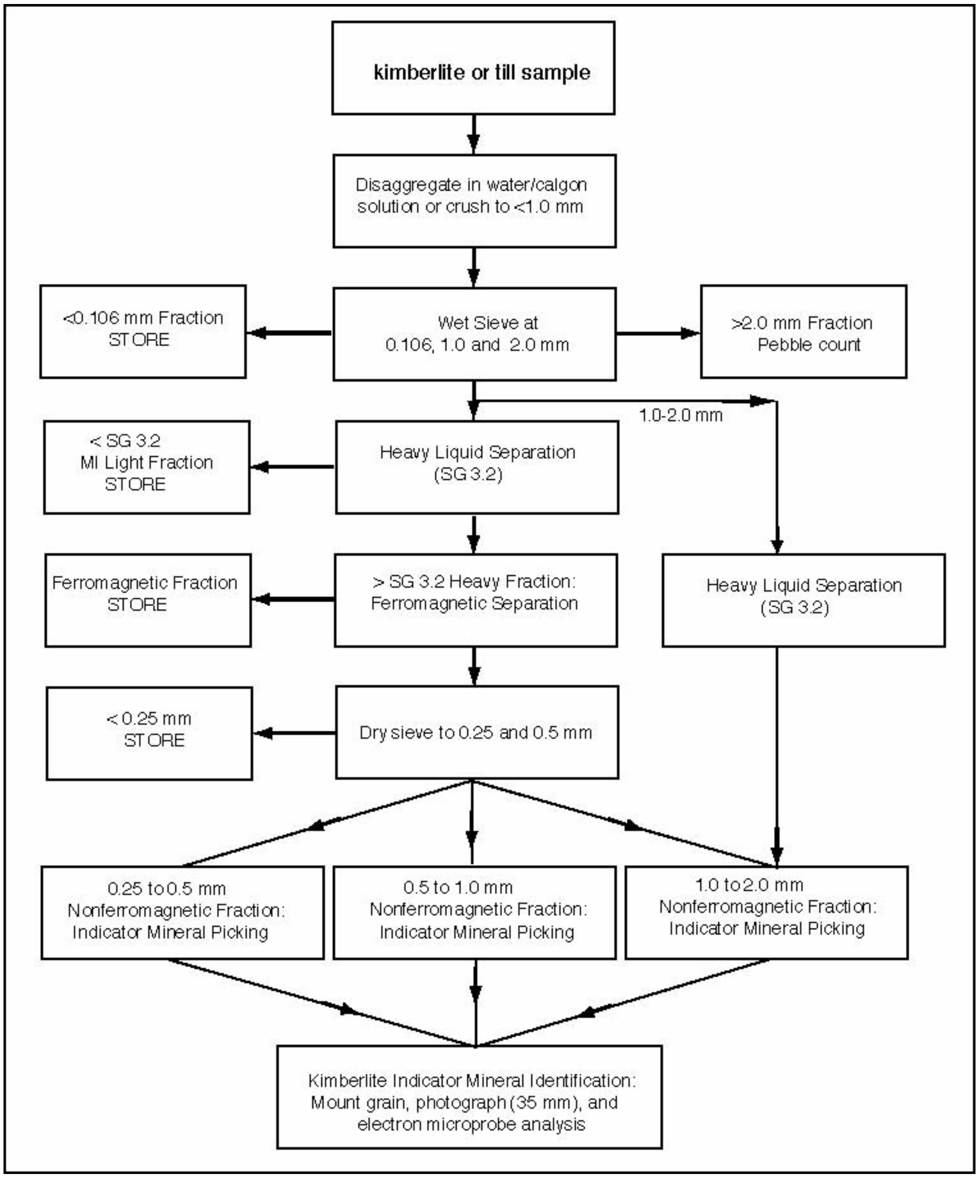

Figure 11. Sample processing flow sheet for preparing heavy mineral concentrates from kimberlite and glacial sediment.

Kimberlite indicator mineral identification

The 0.25 to 0.5 mm, 0.5 to 1.0 mm and 1.0 to 2.0 mm fractions were examined by I. & M. Morrison Geological Services, Delta, B.C., using stereoscopic and petrographic microscopes and potential kimberlite indicator minerals were selected. Indicator minerals were identified on the basis of visual properties, such as colour, grain morphology and/or the presence of adhering kimberlite matrix material. Minerals picked included purple Cr-pyrope, red-brown Ti-Cr pyrope, green Cr-diopside, black Mg-ilmenite, black chromite, and pale yellow/green olivine. Picked grains were mounted in 25 mm epoxy mounts and polished at Lakefield Research, Lakefield, Ontario in preparation for electron microprobe analysis to confirm their identity and further classify them using mineral chemistry. Electron microprobe analyses were carried out at the GSC using operating conditions and mineral sorting routines similar to those described by McClenaghan et al. (1999a). All indicator mineral grains in each sample were picked and probed, with the exception of olivine in sample 9050 (fresh kimberlite). Only a selection of olivine grains were picked and probed from sample 9050 to document their compositional range. Microprobe analyses for all minerals identified as kimberlite indicator minerals are listed in Appendix C.1 to C.5 and the total number of each indicator mineral present in individual samples are reported in Table 2.

Pebble lithology

The 0.8 to 5 cm (pebble) fraction was screened from the >2.0 mm (+10 mesh) fraction of till samples removed during sampling processing (Fig. 12). Approximately 200 clasts were examined by Consorminex Inc., Gatineau, Quebec, and classified into categories that reflect the major rock types in the region: felsic to intermediate intrusive; mafic intrusive; ultramafic intrusive; metavolcanic; metasedimentary; Huronian metasediments; Paleozoic carbonate; kimberlite; and other or unknown rock types. Pebble lithology abundances are listed in Appendix D as raw counts (Appendex D.1) and as frequency % (Appendix D.2). A colour photograph of the pebble fraction of each sample is in files Pebble-9032.jpg to Pebble-9049.jpg on the CD-ROM.

RESULTS

Fresh kimberlite sample 9050 contains approximately 1 g of heavy minerals/kg of sample, of which 20% of the heavy minerals are ferromagnetic. In contrast, weathered kimberlite sample 9048 contains 24 g of heavy minerals/kg of sample, of which 90% of the heavy minerals are feromagnetic.

Kimberlite indicator mineral chemistry

Pyrope garnet

Mineral chemistry, size and colour for 88 (Cr-) pyrope grains from glacial sediments and the McLean kimberlite are listed in Appendix C.1. Most garnets (61 out of 88) occur in the kimberlite samples. The garnets can be assigned to two different groups: 1) megacryst garnets (n=5), and 2) peridotitic garnets (n=83), including lherzolitic, harzburgitic and wehrlitic garnets, and garnets from sheared (metasomatized) lherzolites (Fig. 13, Appendix C.1). Garnets from sheared/metasomatized lherzolites are similar in composition to megacryst garnets (e.g. high TiO_2) but have higher Cr_2O_3 (>3.5 wt.%) (Fig. 13). The peridotitic garnet population contains only two grains that plot below the 85% line of Gurney (1984), one of which (from Sage, 2000) is sufficiently subcalcic to plot in Sobolev's (1977) field for subcalcic garnets associated with diamonds (Fig. 13). A comparison of the grains from till samples and the McLean kimberlite shows that the till contains garnets that are generally more CaO rich and do not exceed > 6.5 wt.% Cr_2O_3, whereas the kimberlite contains more Cr-rich pyropes (up to 11 wt.% Cr_2O_3). Three crustal almandine-spessartine grains were found in kimberlite sample 9050, and one in sample 9049; one crustal grossular-andradite garnet was found in till sample 9041.

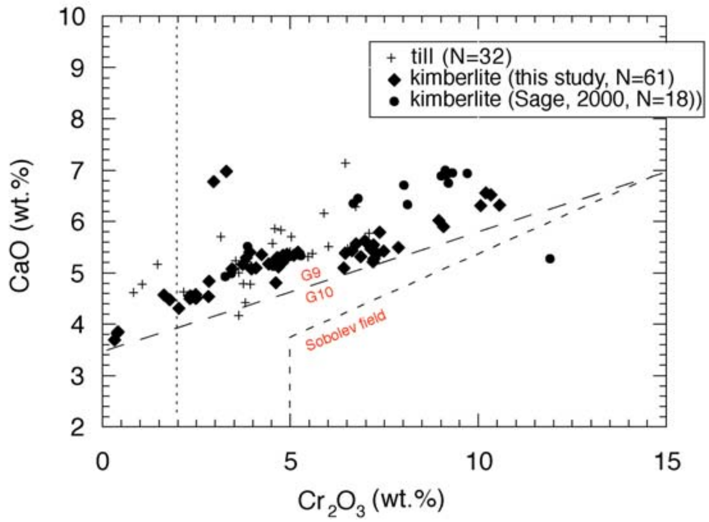

Figure 12. Bivariate plot of Cr_2O_3 versus CaO for garnet from the McLean kimberlite from this study and from Sage (2000), as compared to garnet from till samples overlying and surrounding the McLean kimberlite (this study). Sobolev field is from Sobolev et al. (1973, 1993), dashed diagonal line separating G9 and G10 garnets is from Gurney (1984), dashed vertical line at 2 wt.% Cr_2O_3 is from Fipke et al. (1995).

Diopside

A total of 196 diopside grains, as well as six enstatite grains visually picked as Cr-diopside, were analyzed (Table 2) and range in composition from 0.32 to 2.79 wt.% Cr_2O_3. Most Cr-diopside fall in the range of 0.5 to 1.5 wt.% Cr_2O_3. Most diopside grains from till, as well as a few grains from the kimberlite sample fall into a tight compositional cluster characterized by 0.6 to 1.4 wt.% Cr_2O_3 and Mg numbers (100Mg/(Mg+Fe)) between 84 to 87 (Fig. 13). Diopside of this particular composition has been identified in till across the region, however, generally not in kimberlite samples (McClenaghan et al., 1998; 1999a,b,c, McClenaghan et al., 2002a,b). They are most likely derived from non-kimberlitic mafic to ultramafic rocks, which are common in the region of the study area. Cr-diopside with higher Mg numbers (88 to 95) and Cr_2O_3 up to 2.79 wt.% typical of peridotitic assemblages (Vicker, 1997) are found in the McLean kimberlite, as well as in the till. Till samples contain several peridotitic Cr-rich (>1.4 wt.% Cr_2O_3) diopside grains that are not found in the McLean kimberlite (Fig. 13). In contrast, the McLean kimberlite contains a few diopside grains with <0.5 wt.% Cr_2O_3 and Mg numbers between 85 and 90, which could be kimberlite-derived megacrysts.

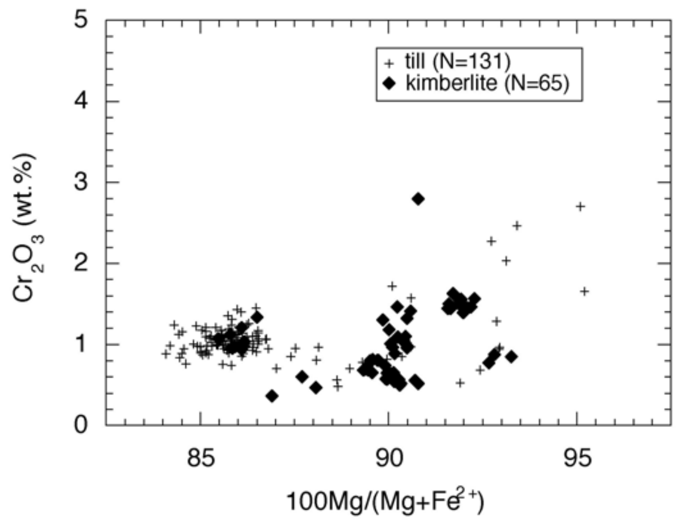

Figure 13. Bivariate plot of Mg number versus Cr_2O_3 for Cr-diopside from the Mclean kimberlite and till samples overlying and surrounding the McLean kimberlite.

Ilmenite

Chemistry, size and colour for individual ilmenite grains are reported in Appendix C.3. A total of 92 grains of regional (non-kimberlitic) ilmenite with <3.5 wt.% MgO were picked and analyzed because they could not be visually distinguished from kimberlitic Mg-ilmenite. Mg-ilmenite (>5.0 wt.% MgO) is most abundant in the fresh kimberlite sample 9050, but absent in weathered kimberlite (sample 9048; Table 2). Mg-ilmenite in till ranges from 5.5 to 13.7 wt.% MgO, with Cr_2O_3 contents up to 3.29 wt.% (Fig. 14), whereas the McLean kimberlite is characterized by Mg-ilmenite with 10.5 to 14.6 wt.% MgO and Cr_2O_3 up to 4.17 wt.%. Comparison of ilmenite from the kimberlite and till show almost mutually exclusive compositional fields (Fig. 14). Only three grains from till samples 9032, 9035 and 9042 overlap with the compositional field of McLean kimberlite ilmenite. Ilmenite in the till samples show two separate trends: 1) low (<0.7 wt.%) Cr_2O_3 and low (5 to 10 wt.%) MgO (samples 9032 and 9039 – 9045); and, 2) parabolic trend represented by grains from samples 9032, 9038, 9040 and 9046 ranging from 3.3 wt.% Cr_2O_3 at about 8 wt.% MgO to 1 wt% Cr_2O_3 at 14 wt.% MgO, where they overlap with the Mg-ilmenite from the McLean kimberlite.

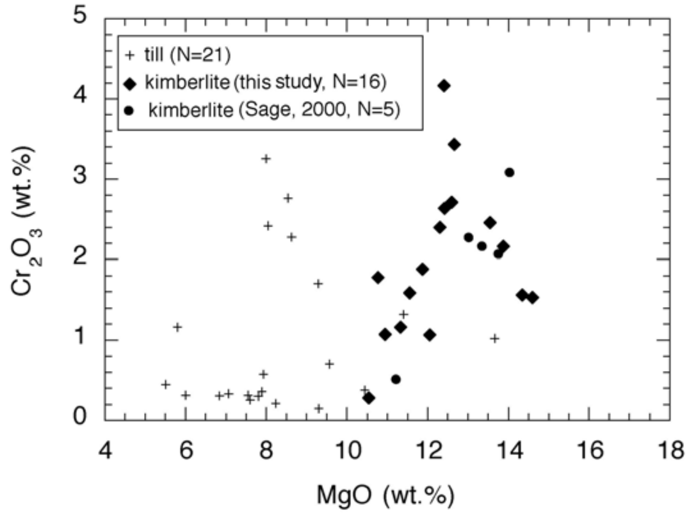

Figure 14. Bivariate plot of MgO versus Cr_2O_3 for Mg-ilmenite from the McLean kimberlite from this study and from Sage (2000) compared to Mg-ilmenite in till samples overlying and surrounding the McLean kimberlite (this study).

Cr-spinel

Size, colour and mineral chemistry for Cr-spinel grains are reported in Appendix C.4. In contrast to garnet and Mg-ilmenite, which are far more abundant in the kimberlite compared to the till samples, chromite occurs in similar abundances in till and kimberlite samples (due to its a relative scarcity in the kimberlite). The analyzed chromite grains have a comparatively narrow range of Cr_2O_3, ranging from 40 to 63 wt.% Cr_2O_3 with the exception of a few outliers at lower Cr_2O_3 levels. Comparison of the kimberlite and the till samples (Fig. 15) shows that the kimberlite chromite grains have a narrower compositional range than chromite in till, which have lower MgO levels, indicating a trend towards Fe_2CrO_4 (chromite *sensu stricto)* + Fe_3O_4 (magnetite) at the expense of Mg_2AlO_4 (spinel *sensu stricto)*. None of the chromite grains contain sufficient MgO and Cr_2O_3 to plot in the diamond inclusion field defined by Fipke et al. (1989), although chromite grains recovered from the McLean kimberlite drillcore by Sage (2000) straddle the boundaries of both the diamond intergrowth and inclusion fields; they are generally more Cr-rich than the few kimberlite chromites found in this study.

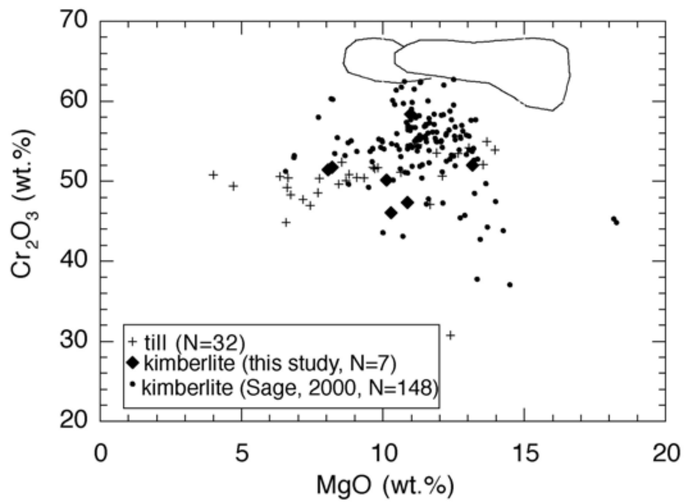

Figure 15. Bivariate plot of MgO versus Cr_2O_3 for chromite from the McLean kimberlite from this study and from Sage (2000) compared to chromite in till samples overlying and surrounding the McLean kimberlite (this study). Diamond inclusion and intergrowth fields are from Fipke et al. (1995).

Olivine

Olivine is the most numerous indicator mineral (>1000 grains) in the heavy mineral fraction (Table 2) of the McLean kimberlite and in till samples 9032, 9034, 9037, and 9040. A plot of NiO versus Mg number (100 Mg/(Mg+Fe)) shows that most olivine grains from till and kimberlite cluster in a field defined by Mg numbers (Fo) of 88.8 to 90.8 and NiO > 0.30 wt.% (Fig. 16). The distinct group with Mg numbers >91 are considered to be olivine from (disaggregated) mantle peridotites. The main population of grains, with Mg numbers <91 are considered to be kimberlitic phenocrysts.

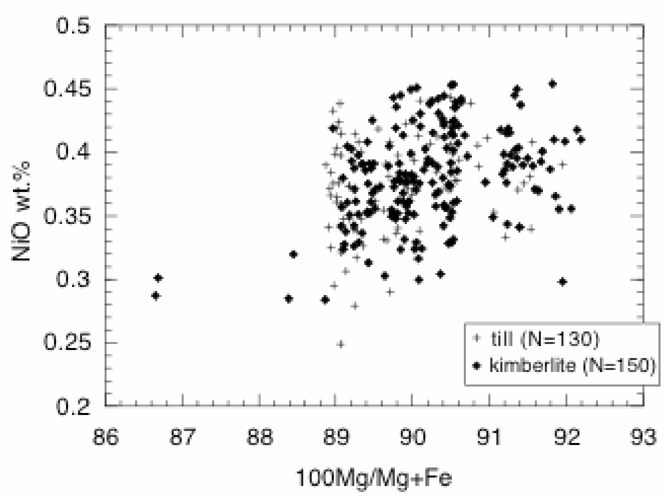

Figure 16. Mg number versus NiO for olivine from the McLean kimberlite and till samples overlying and surrounding the McLean kimberlite.

Other Minerals
Other minerals recovered from the heavy mineral concentrates include: one perovskite in fresh kimberlite sample 9050, a common kimberlite groundmass phase; several grains of Fe-rich rutile and pure rutile in till samples 9042, 9043 and 9049, picked because they resembled Mg-ilmenite; three epidote grains from till samples, picked because they resembled olivine; and, three andradite garnets picked because they resembled diopside.

Kimberlite indicator mineral abundances
Indicator mineral grain counts for the McLean kimberlite (samples 9048 and 9050), as well as for surrounding till (9032 to 9047 and 9049), are low compared to other kimberlites in the Lake Timiskaming field (e.g. the Peddie kimberlite, McClenaghan et al., 1999a, 2002a). Olivine is by far the most abundant mineral in the McLean kimberlite, with over 95% of the heavy mineral concentrate consisting of olivine. After olivine, (Cr-) pyrope and Cr-diopside are the most abundant indicator minerals in the fresh kimberlite sample (99MPB9050) followed by Mg-ilmenite and chromite (Table 2). The indicator mineral suite of most other kimberlites in the area is dominated by ilmenite, chromite or garnet (Sage, 1996; McClenaghan et al., 1999a, 2002a) with Cr-diopside being the least abundant.

Weathered kimberlite sample 9048 is indicator mineral-poor; it contains a few Cr-diopside and chromite grains, and no olivine. The absence of olivine is consistent with the olivine altering during postglacial weathering of the kimberlite. The absence of garnet and Mg-ilmenite are not easily explained by weathering, because Cr-diopside, which alters even more easily than garnet or Mg-ilmenite, is still present. Another explanation might be that the weathered portion of the kimberlite contained mafic or ultramafic crustal xenoliths which contained Cr-diopside and chromite. This seems likely considering that down-ice till samples are also dominated by these two minerals, with low counts for pyrope garnet and Mg-ilmenite (Table 2) but consistently high numbers of normal (crustal) ilmenite.

Based on indicator mineral abundances and distribution, the till samples can be divided into two groups: 1) sample 9032 through 9040, located up-ice of the known kimberlite subcrop, contain olivine and comparatively low chromite contents; 2) samples 9041 through 9049, located south of the kimberlite, contain higher amounts of chromite and MgO-poor ilmenite and no olivine. Garnet and Mg-ilmenite are scarce and Cr-diopside is common, but variable in both groups.

Indicator minerals in both kimberlite and till are most abundant in the finest (0.25 to 0.5 mm), non-magnetic heavy mineral fraction (Table 2), with only a few grains in the 0.5 to 1.0 mm fraction, and none in the largest size fraction (1.0 to 2.0 mm).

Pebble lithology
The pebble fraction (0.8 to 5 cm) of till samples around the McLean kimberlite is comprised mainly of Huronian metasedimentary rocks (range 25 to 73%) and Paleozoic carbonate rocks (range 0 to 47%) (Appendix D.2). Samples 9032, 9038, 9039 and 9040, which overlie the kimberlite, contain 1 to 6.5% kimberlite pebbles. Samples 9034 and 9035 contain 2% kimberlite pebbles. Till samples down-ice (9041 to 9047) contain no kimberlite clasts.

DISCUSSION

Indicator minerals in the McLean kimberlite

Due to the aphanitic nature of the kimberlite sampled at the surface, both the fresh and weathered kimberlite samples from the McLean pipe are indicator mineral-poor compared to other kimberlites in the region (Sage, 1996, 2000; McClenaghan et al., 1999a). The Peddie kimberlite, for example, yielded tens of thousands of indicator minerals in 10 kg (McClenaghan et al., 1999a). Among the few indicator minerals recovered from McLean, garnet and Cr-diopside far outnumber Mg-ilmenite and chromite. Olivine, however, is by far the most abundant (> 10000 grains) in the fresh kimberlite. Olivine compositions fall into a narrow, but bimodal range (Fo88.8 to 90.8 and Fo 91 to 92, all with NiO ≥ 0.3 wt.%) which are interpreted to be phenocrysts (Mg number <91), or from disaggregated peridotite (Mg number >91).

Sage (2000) also reports finding few pyrope garnet and Mg-ilmenite and abundant olivine in a 3 kg drill core sample of hypabyssal facies kimberlite from the McLean pipe. In addition, he recovered numerous grains of chromite that overlap with compositions of chromite analyzed in this study and extend towards slightly more Cr_2O_3 rich compositions. This might be simply due to the number of samples, n= 148 in Sage (2000) versus n=7 in this study, combined with slight mineralogical differences in kimberlite facies sampled. In this study, chromite from only the non-ferromagnetic fraction was examined. Sage (2000), however, picked grains from the heavy mineral fraction with had not been subjected to ferromagnetic separation. Chromite grains rimmed with magnetite would be more abundant in the ferromagnetic fraction, and this could account for the greater chromite abundances reported by Sage (2000).

Mg-ilmenite and garnet compositions compare well with those reported by Sage (2000). Rare Mg-ilmenite megacrysts are MgO-rich (10 to 15 wt.%) and formed under reducing conditions (strongly increasing Cr_2O_3 with increasing MgO). This is a characteristic also shared by Mg-ilmenite in other kimberlites of the Lake Timiskaming field, e.g. Bucke, Gravel (Sage, 1996) and Peddie (McClenaghan et al., 1999a).

Garnet grains analysed have compositions which indicate that few are from the megacryst suite, but are mainly lherzolitic derived (G9) Cr-pyrope, and a few grains from sheared/metasomatized lherzolite. The lack of both subcalcic harzburgitic (G10) garnet as well as eclogitic garnet, indicates that the diamond potential of the McLean pipe is very low. However, Sage (2000) found one G10 garnet in the drill core sample concentrate.

Cr-diopside recovered from the McLean kimberlite belongs to at least three different populations including peridotite (Cr_2O_3 > 0.8 wt.%, Mg number >90), megacryst (Cr_2O_3 < 0.8 wt.%, Mg number ≥ 89), and regional mafic and ultramafic rocks (Cr_2O_3 from 0.6 to 1.4, Mg number from 84 to 87). The latter is the predominant composition of Cr-diopside grains found in till. It is suspected that mafic crustal xenoliths containing these Cr-diopside grains were incorporated into the McLean kimberlite (see also discussion of chromite below).

Weathered kimberlite sample 9048 contains similar (normalized) amounts of Cr-diopside and chromite as fresh kimberlite sample 9050, however, olivine, Mg-ilmenite and garnet are almost absent. Although olivine might have succumbed to weathering, it seems unlikely that Mg-ilmenite and garnet were altered by weathering because Cr-diopside and chromite were not. This suggests the highly weathered kimberlite is a different phase of the kimberlite, and has a different indicator mineral content. It is further suggested that the chromite and Cr-diopside grains recovered from the weathered sample (and possibly also from the fresh kimberlite sample) are from inclusions of mafic crustal xenoliths (e.g. Nipissing diabase).

Indicator minerals in till

Due to the scarcity of commonly used kimberlite indicator minerals in the surface samples of the kimberlite, olivine is the most useful indicator mineral for tracing glacial dispersal from the McLean kimberlite. Mg-ilmenite, however, although scarce can add additional information.

Comparison of Mg-ilmenite compositions reveal striking differences between those from till samples and from fresh McLean kimberlite (Fig. 14), indicating that the source of Mg-ilmenite grains in the till is likely one or more different (undiscovered ?) kimberlite bodies up-ice (N to NE of McLean). Sage's (2000) Mg-ilmenite compositions for McLean drill core match those for the aphanitic cap (Fig. 14), indicating that Mg-ilmenite megacrysts of the same composition occur throughout the McLean kimberlite pipe.

Of four till samples (9032, 9038, 9039, 9040) collected overlying the kimberlite, only sample 9032 contains kimberlite pebbles, abundant olivine and Mg-ilmenite with compositions resembling those found in the McLean kimberlite, which indicates it contains debris derived from the McLean kimberlite. The other three samples also contain kimberlite pebbles but only a few grains of olivine, indicating lower concentrations of kimberlite material (or alteration of olivine). Till samples collected south of the kimberlite (samples 9042 to 9047) contain no kimberlite pebbles, nor olivine, and only one McLean type Mg-ilmenite (in sample 9042). However, they do contain some Cr-pyrope garnet and comparatively high concentrations of chromite, which is the least abundant indicator mineral in the aphanitic cap of the McLean kimberlite. These till samples obviously contain kimberlite indicator minerals that are different from that of the McLean kimberlite. Striations on the McLean kimberlite surface indicate glacial transport was to the SW and no known kimberlites exist for several tens of kilometers N or NE of McLean, suggesting that either: 1) the indicator minerals are derived from an unknown kimberlite situated NE of the sample locations; and/or, 2) the chromite and ilmenite grains were derived from rocks other than kimberlite, e.g. from regional mafic or ultramafic rocks.

Samples 9034, 9035 and 9037 were collected within 20 m north of the inferred northwest edge of the kimberlite and should represent background. However, samples 9034 and 9035 contain kimberlite pebbles, sample 9035 also contains one Mg-ilmenite with McLean kimberlite composition, and samples 9034 and 9037 contain olivine. The presence of kimberlite pebbles and olivine in these three samples suggests that they were located not up-ice but down-ice and very close to the McLean kimberlite. If this is true, kimberlite debris was likely glacially transported southwest (220°, based on striations on the kimberlite) from a more northeasterly, hitherto unknown extension of the McLean kimberlite (Fig. 17). The absence of kimberlite pebbles and olivine in samples 9042 to 9047 could also be explained by southwest ice flow which did not cross the McLean kimberlite (Fig. 17), or by glacial comminution (total destruction) of kimberlite pebbles and postglacial weathering of olivine grains. The occurrence of one Mg-ilmenite matching those from McLean in composition in sample 9042 directly south of the kimberlite indicates a possible transport direction directly from the north. This points to the possibility that kimberlitic (and non kimberlitic) material in till samples south of the McLean kimberlite could come from a known or unknown kimberlite to the north.

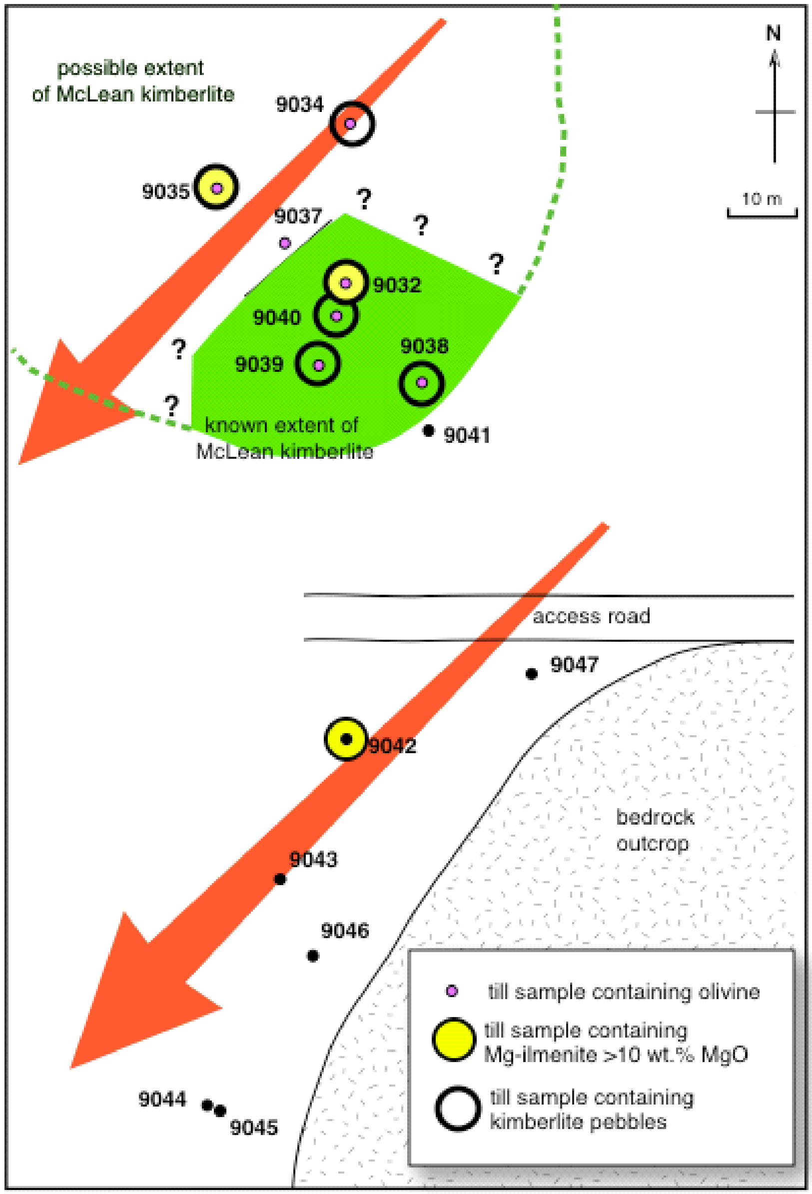

Figure 17. Known and possible extent of subcropping McLean kimberlite and local southwest-trending (218°) ice flow paths (red arrows).

CONCLUSIONS

The exposed subcrop of the McLean kimberlite sampled for this study is aphanitic, and unusually poor in indicator minerals as compared to other kimberlites in the region, and drillcore from the same kimberlite (Sage, 2000). The relative abundance of indicator minerals in the McLean kimberlite is: olivine>> Cr-diopside>Cr-pyrope>Mg-ilmenite >chromite. Oxide minerals are scarce, particularly chromite, which occurs in greater abundance in the drill core samples (Sage, 2000) of macrocrystic kimberlite.

Due to the scarcity of indicator minerals in the McLean kimberlite, glacial dispersal of indicator minerals is short (<50 m). Till sampled to the south of the McLean kimberlite contains kimberlite indicator minerals that are distinctly different in composition from those of the McLean kimberlite, which suggests another kimberlite source(s) up-ice (northeast). Some of the chromite, Cr-diopside and all of the MgO-poor ilmenite in till are not from kimberlite, but most likely from regional mafic or ultramafic rocks. Pyrope garnet and Mg-ilmenite, however, have compositions that indicate that they are from the McLean kimberlite further up-ice or from some other unknown kimberlite source up-ice.

The subcrop of McLean kimberlite delineated with backhoe trenching is small (30 x 40 m) compared to its likely extent (100 m across) indicated by the pipe's magnetic signature in Figure 5. The presence of kimberlite indicator minerals and kimberlite pebble in till samples (samples 9034, 9035 and 9037) north of the known subcrop (Fig. 17) indicate that the Mclean kimberlite likely subcrops just north of sample 9034. If this is true, then argillite country rock in pits 3, 4, and 5 (sample sites 9034, 9035, and 9037) was not penetrated by the kimberlite in this part of the intrusion or may be xenoliths within the kimberlite.

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REFERENCES

Averill, S.A. and McClenaghan, M.B.
1994: Distribution and character of kimberlite indicator minerals in glacial sediments, C14 and Diamond Lake kimberlite pipes, Kirkland Lake, Ontario; Geological Survey of Canada, Open File 2819, 46 p.

Burgers, K.M., Boucher, D. and Kong, J.
1998: The petrography of the OPAP kimberlites, New Liskeard area, Ontario, Canada; Extended Abstracts, 7th International Kimberlite conference, Cape Town (unpaginated addendum).

Brummer, J.J., MacFadyen, D.A. and Pegg, C.C.
1992a: Discovery of kimberlites in the Kirkland Lake area, Northeastern Ontario, Part I: Early surveys and surficial geology; Exploration and Mining Geology, v. 1, p. 339-350.

Brummer, J.J., MacFadyen, D.A. and Pegg, C.C.
1992b: Discovery of kimberlites in the Kirkland Lake area, Northeastern Ontario, Part II: Kimberlite discoveries, sampling, diamond content, ages and emplacement; Exploration and Mining Geology, v. 1, p. 351-370.

Card, K.D. and Lumbers, S.B.
1975: Geological Compilation Series: Sudbury-Cobalt: Algoma, Manitoulin, Nipissing, Parry Sound, Sudbury and Timiskaming Districts: Ontario Division of Mines, Map 2361, scale 1:253 440.

Dawson J.B. and Stephens W.E.
1975: Statistical classification of garnets from kimberlite and associated xenoliths; Journal of Geology, v. 83, p. 589-607.

Deer, W.A., Howie, R.A. and Zussman, J.
1978: Rock Forming Minerals, Volume 2A, Single Chain Silicates, Second Edition; Longman Group Limited, New York, USA, 668 p.

Deer, W.A., Howie, R.A. and Zussman, J.
1982: Rock Forming Minerals, Volume 1A, Orthosilicates, Second Edition; Longman Group Ltd., New York, USA, 919 p.

DiLabio, R.N.W.
1990: Classification and interpretation of the shapes and surface textures of gold grains from till on the Canadian Shield; in Current Research, Part C., Geological Survey of Canada, Paper 90-1C, p. 323-329.

Dunn, C.E. and McClenaghan, M.B.
1996: Biogeochemical studies of kimberlites; in Searching For Diamonds in Canada, A.N. Le Cheminant, D.G. Richardson, R.N.W. DiLabio, K.A. Richardson (eds.); Geological Survey of Canada, Open File 3228, p. 219-223.

Eggler, D.H., McCallum, M.E. and Smith, C.B. (1979): Megacryst assemblages in kimberlites from northern Colorado and southern Wyoming: petrology, geothermometry-barometry and areal distribution. In: Boyd, F.R. and Meyer, H.O.A. (eds): The Mantle Sample: Inclusions in kimberlites and other volcanics. American Geophysical Union, Washington: 213-226.

Fipke, C.E. Gurney, J.J., Moore, R.O., and Nassichuk, W.W.
1989: The development of advanced technology to distinguish between diamondiferous and barren diatremes; Geological Survey of Canada, Open File 2124, 1183 p.

Fipke, C.E., Gurney, J.J. and Moore, R.O.
1995: Diamond exploration techniques emphasizing indicator mineral geochemistry and Canadian examples; Geological Survey of Canada, Bulletin 423, 86 p.

Grant, W.T. and Owsiacki, L.
1987: An evaluation of the Lake Timiskaming Paleozoic outlier for potentially exploitable limestone and dolostone deposits; Ontario Geological Survey, Open File 5661, 152.

Gurney, J.J.
1984: A correlation between garnets and diamonds in kimberlites; in Kimberlite Occurrence and Origin: a basis for conceptual models in exploration; Geology Department and University Extension, University of Western Australia, Publication No. 8, p. 143-166.

Gurney, J.J.
1989: Diamonds; in Kimberlites and Related Rocks: Their Crust/Mantle Setting, Diamonds and Diamond Exploration; Geological Society of Australia, Special Publication 14, p. 935-965.

Gurney, J.J. and Moore, R.O.
1993: Geochemical correlations between kimberlitic indicator minerals and diamonds; in Diamonds: Exploration, Sampling and Evaluation, Short Course Proceedings; Prospectors and Developers Association of Canada, p. 147-171.

Gurney, J.J. and Zweistra, P.
1995: The interpretation of the major element compositions of mantle minerals in diamond exploration; Journal of Geochemical Exploration, v. 53, p. 293-309.

Haggerty, S.E.
1975: The chemistry and genesis of opaque minerals in kimberlites; Phys. Chem. Earth, v. 9, p. 295-307.

Heaman, L.M. and Kjarsgaard, B.A.
2000. Timing of eastern North American kimberlite magmatism: continental extension of the Great Meteor hotspot track?; Earth and Planetary Science Letters, v. 178, p. 253-268.

Hodder, S.L.
2002: Petrography and mineral chemistry of the McLean and Peddie kimberlites, Lake Timiskaming, Ontario, Canada. M.Sc. thesis, University of Calgary, Alberta, 278 p.

LeMaitre, R.W.
1982: Numerical Petrology- statistical interpretation of geochemical data developments in petrology; Elsevier Science Publishing, Amsterdam, New York, 281 p.

Lightfoot, P.C., De Souza, H. and Doherty, W.
1993: Differentiation and source of the Nipissing Diabase intrusions, Ontario, Canada; Canadian Journal of Earth Sciences, v. 30, p. 1123- 1140.

MacFadyen, D.A.
1993: Discovery of kimberlites in the Kirkland Lake area, northern Ontario, Canada (Part III): a decisive contribution by aeromagnetic data analysis in conditions of deep overburden; in Mid-continent Diamonds; Geological Association of Canada, Symposium Volume, p. 31-34.

McCandless T.E. and Gurney, J.J.
1989: Sodium in garnet and potassium in clinopyroxene: criteria for classifying mantle xenoliths; in Kimberlites and Related Rocks. Vol. 2. (ed) J. Ross; Geological Society of Australia, v. 14, p. 827-832.

McClenaghan, M.B.
1993: Location of known kimberlite bedrock, float and indicator minerals in drift in the Kirkland Lake area; Geological Survey of Canada, Open File Map 2636, scale 1:100 000.

McClenaghan, M.B.
1996: Geochemistry and indicator mineralogy of drift over kimberlites, Kirkland Lake, Ontario; in Searching For Diamonds in Canada; Geological Survey of Canada, Open File 3228, p. 213-217.

McClenaghan, M.B. and Dunn, C.E.
1995: Biogeochemical survey over kimberlites in the Kirkland Lake area, northeastern Ontario; Geological Survey of Canada, Open File 3005, 69 p.

McClenaghan, M.B., Kjarsgaard, I.M., Stirling, J.A., Pringle, G. and Crabtree, D.
1993: Chemistry of kimberlitic indicator minerals in drift from the Kirkland Lake area, northeastern; Geological Survey of Canada, Open File 2761, 375 p.

McClenaghan, M.B., Kjarsgaard, I.M., Crabtree, D. and DiLabio, R.N.W.
1995: Mineralogy and geochemistry of till and soil overlying the Buffonta kimberlite dyke, Kirkland Lake, Ontario; Geological Survey of Canada, Open File 3007, 111 p.

McClenaghan, M.B., Kjarsgaard, I.M., Schulze, D.J., Stirling, J.A., Pringle, G. and Berger, B.R.
1996: Mineralogy and geochemistry of the B30 kimberlite and overlying glacial sediments, Kirkland Lake, Ontario; Geological Survey of Canada, Open File 3295, 245 p.

McClenaghan, M.B., Kjarsgaard, I.M., Schulze, D.J., Stirling, J.A., Pringle, G. and Berger, B.R.
1998: Mineralogy and geochemistry of the Diamond Lake kimberlite and associated esker sediments, Kirkland Lake, Ontario; Geological Survey of Canada, Open File 3576.

McClenaghan, M.B., Kjarsgaard B.A., Kjarsgaard I.M., and Paulen, R.C.
1999a: Mineralogy and geochemistry of the Peddie kimberlite and associated glacial sediments, Lake Timiskaming, Ontario; Geological Survey of Canada, Open File 3775.

McClenaghan, M.B., Kjarsgaard I.M., Stirling, J.A.R., Pringle G., Kjarsgaard B.A., Berger, B.
1999b: Mineralogy and geochemistry of the C14 kimberlite and associated glacial sediments, Kirkland Lake, Ontario; Geological Survey of Canada, Open File 3719.

McClenaghan, M.B., Kjarsgaard I.M., Kjarsgaard B.A., Stirling, J.A.R., Pringle G., Berger, B.
1999c: Mineralogy and geochemistry of the A4 kimberlite and associated glacial sediments, Kirkland Lake, Ontario; Geological Survey of Canada, Open File 3769.

McClenaghan, M.B., Kjarsgaard, I.M. and Kjarsgaard B.A.
2001. Reconnaissance-scale till survey in the New Liskeard-Temagami-region, Ontario: kimberlite indicator mineral and geochemistry; Geological Survey of Canada, Open File 4086.

McClenaghan, M.B., Kjarsgaard B.A., Kjarsgaard I.M. and Paulen, R.C.
2002: Indicator mineral content and geochemistry of till around the Peddie kimberlite, Lake Timiskaming, Ontario; Geological Survey of Canada, Open File 4262.

McClenaghan, M.B., Kjarsgaard I.M., Kjarsgaard B.A. and Heaman, L.M.
2002: Mineralogy of kimberlite boulders from eskers in the Lake Timiskaming and Kirkland Lake areas, northeastern Ontario; Geological Survey of Canada, Open File 4361.

McClenaghan, M.B., Veillette, J.J. and DiLabio, R.N.W.
1995: Ice flow patterns in the Timmins and Kirkland Lake area, northeastern Ontario; Geological Survey of Canada, Map, Open File 3014, scale 1:200 000.

Mitchell, R.H.
1973: Magnesian ilmenite and its role in kimberlite petrogenesis; Journal of Geology, v. 81, p. 301-311.

Mitchell, R.H.
1986: Kimberlites: mineralogy, geochemistry, and petrology; Plenum Publishing Corporation, New York, 442 p.

Sage, R.P.
1996: Kimberlites of the Lake Timiskaming structural zone; Ontario Geological Survey, Open File Report 5937, 435 p.

Sage, R.P.
1998: Structural patterns and kimberlite emplacement; Summary of Field Work and Other Activities-1998; Ontario Geological Survey, p. 224-229.

Sage, R.P.
2000: Kimberlite of the Lake Timiskaming structural zone: supplement; Ontario Geological Survey, Open File Report 5937, 123 p.

Schulze, D.J.
1993a: Garnet xenocryst populations in North American kimberlites; in Diamonds: Exploration, Sampling and Evaluation, Short Course Proceedings; Prospectors and Developers Association of Canada, p. 359-377.

Schulze, D.J.
1993b: An introduction to the recognition and significance of kimberlite indicator minerals; in Techniques in Exploration For Diamonds, Short Course Notes; Canadian Institute of Mining, Metallurgy and Petroleum.

Schulze, D.J.
1995: A guide to the recognition and significance of kimberlite indicator minerals; in Diamonds-Theory and Exploration; Geological Association of Canada, Short Course 20, p. 1-39.

Schulze, D.J.
1996a: Ultramafic xenoliths and xenocrysts in kimberlite and alnöite: windows to the upper mantle; in Searching For Diamonds in Canada; Geological Survey of Canada, Open File 3228, p.129-133.

Schulze, D.J.
1996b: Kimberlites in the vicinity of Kirkland Lake and Lake Temiskaming, Ontario and Quebec; in Searching For Diamonds in Canada; Geological Survey of Canada, Open File 3228, p. 73-78.

Schulze, D.J.
1996c: Chromite macrocrysts from southern African kimberlites: mantle xenolith sources and post-diamond re-equilibration: Africa Geoscience Review, v. 3, p. 203-216.

Schulze, D.J.
1999: The significance of eclogite and Cr-poor megacryst garnets in diamond exploration; Exploration and Mining Geology, v. 6, p. 349-366.

Schulze, D.J., Anderson, P.F.N., Hearn B.C., and Hetman, C.M.
1995: Origin and significance of ilmenite megacrysts and macrocrysts from kimberlite; International Geology Review, v. 37, p. 780-812.

Shee, S. R. and Gurney, J.J. (1979): The mineralogy of xenoliths from Orapa, Botswana; in Boyd, F.R. and Meyer, H.O.A. (eds),The Mantle Sample: Inclusions in Kimberlites and Other Volcanics; American Geophysical Union, Washington, p. 37-49.

Sobolev, N.V.
1971: On mineralogical criteria of a diamond potential of kimberlites; Geol. Geofiz., v. 12 (3), p. 70-78 (in Russian).

Sobolev, N.V.
1977: Deep seated inclusions in kimberlites and the problem of the composition of the upper mantle; American Geophysical Union, Washington, 279 p.

Sobolev, N.V.
1993: Kimberlites of the Siberian Platform: their geological and mineralogical features: in Diamonds: Exploration, Sampling and Evaluation, Short Course Proceedings; Prospectors and Developers Association of Canada, p. 343-357.

Sobolev, N.V., Lavrent'ev, Y.G., Pospelova, L.N and Sobolev, E.V.
1973: Chrome-rich garnets from the kimberlites of Yakutia and their parageneses; Contributions to Mineralogy and Petrology, v. 40, p. 39-52.

Sobolev, N.V., Pokhilenko, N.P., Afanas'ev, V.P.
1993: Kimberlitic pyrope and chromite morphology and chemistry, as indicators of diamond grade in Yakutian and Arkhangelsk provinces; in Mid-continent diamonds; Geological Association of Canada, Symposium Volume, p. 63-69.

Sobolev, N.V., Pokhilenko, N.P., Lavrent'ev, Y.G., and Yefimova, E.S.
1977: Deep-seated xenoliths, xenocrysts in kimberlites and crystalline inclusions in diamonds from Udachnaya kimberlite pipe; in Extended Abstracts, 2nd International kimberlite conference American Geophysical Union.

Stephens, W.E. and Dawson, J.B.
1977: Statistical comparison between pyroxenes from kimberlites and their associated xenoliths; Journal of Geology, v. 85, p. 433-449.

Stirling, J.A.R. and Pringle, G.J.
1996: Tools of investigation; the electron microprobe and scanning electron microscope; in Searching For Diamonds in Canada; Geological Survey of Canada, Open File 3228, p. 47-54.

Veillette, J.J.
1986: Surficial geology, Haileybury, Ontario-Quebec: Geological Survey of Canada, Map 1642A, scale 1:100 000.

Veillette, J.J.
1988: Déglaciation et évolution des lacs proglaciares Post-algonquin et Barlow au Témiscamingue, Québec et Ontario; Geógraphie physique et Quaternaire, v. 42, p. 7-31.

Veillette, J.J.
1989: Ice movements, till sheets and glacial transport in Abitibi-Timiskaming, Quebec and Ontario; in Drift Prospecting (ed.) R.N.W. DiLabio and W.B. Coker; Geological Survey of Canada, Paper 89-20, p. 139-154.

Veillette, J.J.
1994: Evolution and paleohydrology of glacial lakes Barlow and Ojibway; Quaternary Science Reviews, v. 13, p. 945-971.

Veillette, J.J.
1996: Géomorphologie et géologie du Quaternaire du Témiscamingue, Québec et Ontario; Geological Survey of Canada, Bulletin 476, 269 p.

Veillette, J.J. and McClenaghan, M.B.
1996: Sequence of ice flow in the Abitibi-Timiskaming region: implications for mineral exploration and dispersal of carbonate rocks from the Hudson Bay Basin, Quebec and Ontario; Geological Survey of Canada, Open File 3033, scale 1:500 000.

Vicker, P.A.
1997: Garnet peridotite xenoliths from kimberlite near Kirkland Lake, Canada; M.Sc. thesis, University of Toronto, 125 p.

Vincent, J.-S. and Hardy, L.
1979: Evolution of Glacial Lakes Barlow and Ojibway, Quebec and Ontario; Geological Survey of Canada, Bulletin 316, 18 p.

Willis, J.P.
1993: Course on the theory and practice of XRF spectrometry; University of Western Ontario, p. 5-17 to 5-24.

Young, G.M. and Nesbitt, H.M.
1999: Paleoclimatology, and provenance of the glaciogenic Gowganda Formation (Paleoproterozoic), Ontario, Canada: a chemostratigraphic approach; Geological Society of America Bulletin, v.111, p.264 - 274.

Zalnieriunas, R.V. and Sage, R.P.
1995: Known kimberlites of Eastern Ontario; Ontario Geological Survey, Preliminary Map P. 3321, scale various.