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Publications in this series have not been edited; they are released as submitted by the author.

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# Reconnaissance-scale till survey in the New Liskeard-Temagami region, Ontario: kimberlite indicator minerals and geochemistry

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## ABSTRACT

This report describes results of a reconnaissance-scale kimberlite indicator mineral (KIM) till survey in the area south of the known Lake Timiskaming kimberlite field, between New Liskeard and Marten River. The survey provides information on the regional background content of KIM in till, the nature of KIM signatures in till just down-ice of known kimberlites, and the distribution of KIM anomalies that warrant further investigation.

Three phases of flow are associated with erosion, transportation and deposition of till in the region. The main carriers of glacial debris, however, were the two oldest ice flows to the southwest and south. A large dispersal train of Paleozoic limestone derived from upper Lake Timiskaming trends south-southwest across the area, but has been truncated in its proximal part (Latchford area) by the last southeast ice flow indicating that in this area, southeast ice flow was a major carrier of debris. These situations have to be taken into consideration in the interpretation of dispersal trains formed by the three major ice flows.

Mg-ilmenite is the most abundant and widespread KIM in the till in the study area. Chromite occurs in approximately the same till samples that contain Mg-ilmenite, but is generally present in lower abundances. Pyrope in till is approximately half as abundant as Mg-ilmenite. Cr-diopside is similar in abundance to pyrope and is present in almost every sample. Elevated Cr-diopside abundances that are not accompanied by other KIMs likely are not from kimberlite. Anomalous concentrations of kimberlite indicator minerals in till occur: on the Red Squirrel Road; near Temagami; along Highway 11 in the central part of the study area; on the east side of Lake Timiskaming; and on the Rabbit Lake forest access road. Some of these anomalies coincide with anomalies identified by the OGS in their recent stream sediment survey (Allan, 2001). Additional till sampling combined with geophysics should be conducted to determine the extent of the KIM anomalies and trace them to their bedrock source, with a sample spacing that is much smaller (<500 m) than used in this reconnaissance survey.

## INTRODUCTION

The Geological Survey of Canada (GSC), in collaboration with the Ontario Geological Survey (OGS, Operation Treasure Hunt), conducted a regional kimberlite indicator mineral (KIM) till survey in the area south of the Lake Timiskaming kimberlites, between New Liskeard and Marten River. This area is thought to be prospective for kimberlites because of its proximity to and similar bedrock structural features with that of the Lake Timiskaming and Kirkland Lake kimberlite fields further north (Allan, 2001). The Ontario Geological Survey recently released the results of a KIM regional stream sediment survey for the Temagami-Marten River area (Fig. 1) (Allan, 2001). The GSC collected widely spaced till samples over a slightly larger area, extending further north to the known kimberlite field near New Liskeard (Fig. 1). These new data complement the OGS stream sediment data, and provide geological information to further aid in the interpretation of indicator mineral anomalies identified by the OGS survey.

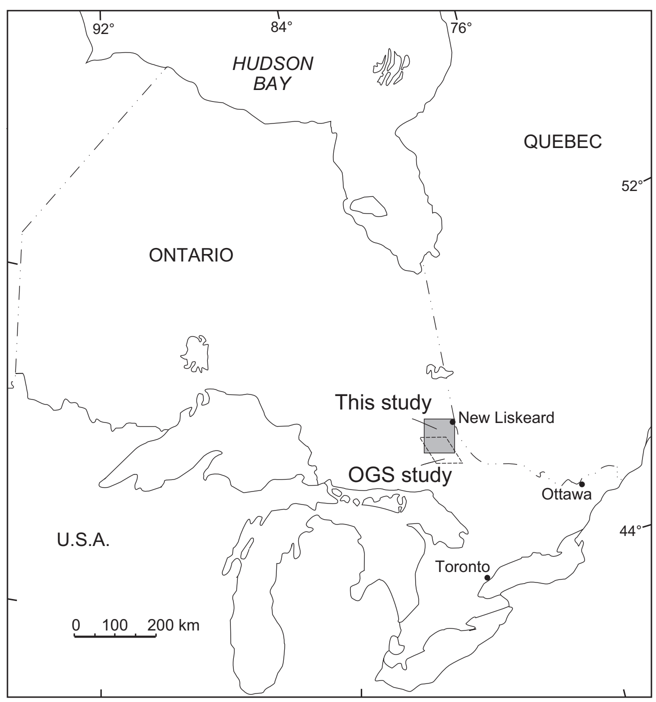



**Figure 1.** Location of areas covered by this study (grey shaded box) and the Ontario Geological Survey stream sediment heavy mineral survey (dashed line) in northeastern Ontario.

Till sampling was carried out in 2000 at a reconnaissance-scale. Results from the sampling: 1) provide information on the regional ice-flow patterns that may have dispersed indicator minerals; 2) document the glacial dispersal of Paleozoic carbonate rocks from the New Liskeard area; 3) provide information on the distribution and extent of glacial dispersal of kimberlite indicator minerals from the known kimberlites near New Liskeard; and 4) identify indicator mineral anomalies in till warrant further investigation.

## Location and access

Samples were collected over a 2400 km$^2$ area between 47°38' and 46°48'N and 78°19' and 80°08'W (Fig. 2 and 3), which cover parts of six NTS map sheets: 31M/12, 31M/5, 31M/4, 31L/3, 31L/14, 41P/1. The area, which is bisected north to south by Highway 11 and east to west by several forest access roads, includes the towns of New Liskeard, Cobalt, Latchford and Temagami. Lake Temagami forms the western boundary and Lake Timiskaming trends southeast along the east side of the study area.

## Previous kimberlite exploration

In the Lake Timiskaming region, the search for diamonds dates to the early 1900s (e.g. The Mining Journal, 1906). Exploration activities on the east side of Lake Timiskaming continued in the 1960s (Brummer et al., 1992a,b). Monopros Ltd. discovered the first kimberlite in the region, the Bucke pipe, in 1984 (Brummer et al., 1992a,b). Since the initial discovery, three kimberlites have been discovered northeast of Lake Timiskaming in Quebec and nine additional kimberlites have been discovered west of Lake Timiskaming in Ontario (Figs. 2 and 3). The most recent discoveries are the three kimberlites northwest of New Liskeard, found by Sudbury Contact Mines Ltd. in 1995 (Zalnieriunas and Sage, 1995; Sage, 1998). Kimberlite boulders have been found in eskers near Cobalt and Lac Baby (Fig. 2). Sage (1996, 2000) has published descriptions and mineral chemistry for most of the Lake Timiskaming kimberlites.

## Quaternary geology

During the Wisconsin, the Lake Timiskaming region was covered by the Laurentide Ice Sheet, which deposited a silty sand till. Till thickness varies from <1 m to occasionally >5 m (Photo 1). Where the till is thin, it is generally more locally derived (Photo 2). Striated bedrock across the region records evidence of three major ice-flow phases (Fig. 4). The oldest flow (Phase 1) was towards the southwest. This flow likely was associated with the main phase of the Laurentide ice sheet. During deglaciation, ice flow shifted southward (Phase 2). During final deglaciation of the area, local ice tongues from the main ice sheet occupied the structural depressions of the Montreal River and Lake Timiskaming, resulting in ice flow towards the southeast (Phase 3). All three phases of ice flow are associated with erosion, and transportation and deposition of till in the region. The main carriers of glacial debris, however, were the two oldest ice flows.

**Photo 1.** Thick silty sand till exposed on the east side of Highway 11 during construction in the summer of 2000, near North Milne Lake (NTS 31L/13). Till samples were collected from several of these fresh roadcuts as part of the regional till sampling program.

**Photo 2.** Small hummock of locally derived stony sandy till near Portage Bay on Bay Lake (NTS 31M/5). Till samples were collected from many sites such as these as part of the regional till sampling program.

A large dispersal train of Paleozoic limestone derived from upper Lake Timiskaming trends south-southwest across the area (Veillette, 1996), but has been truncated in its proximal part by the last southeast ice flow (Veillette, 1989, 1996). Discontinuous patches of carbonate-rich till occur up to 35 km south of the outlier (Fig. 4). Bedrock outcrops exposed along forest access roads and in the town of Temagami provide excellent sites to examine striated bedrock (Photos 3 and 4) and evidence of the three phases of ice flow (Photo 5). The locations of sites in Photos 1 to 5 are indicated on Figure 4.

Glaciofluvial deposits occur along bedrock valleys, generally in the form of eskers, and consist of sand and

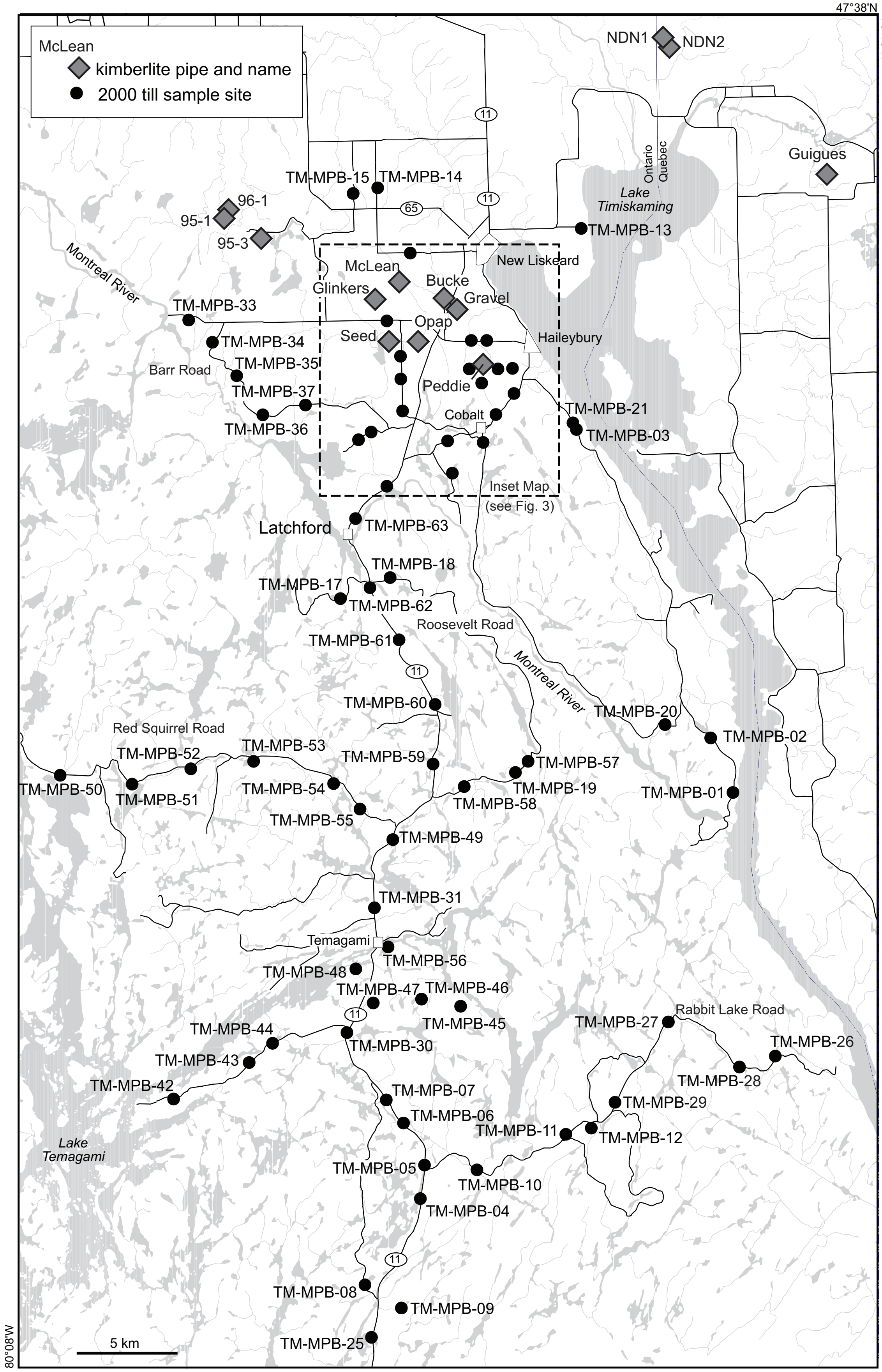



**Figure 2.** Location of the Lake Timiskaming kimberlite field and Geological Survey of Canada till samples.

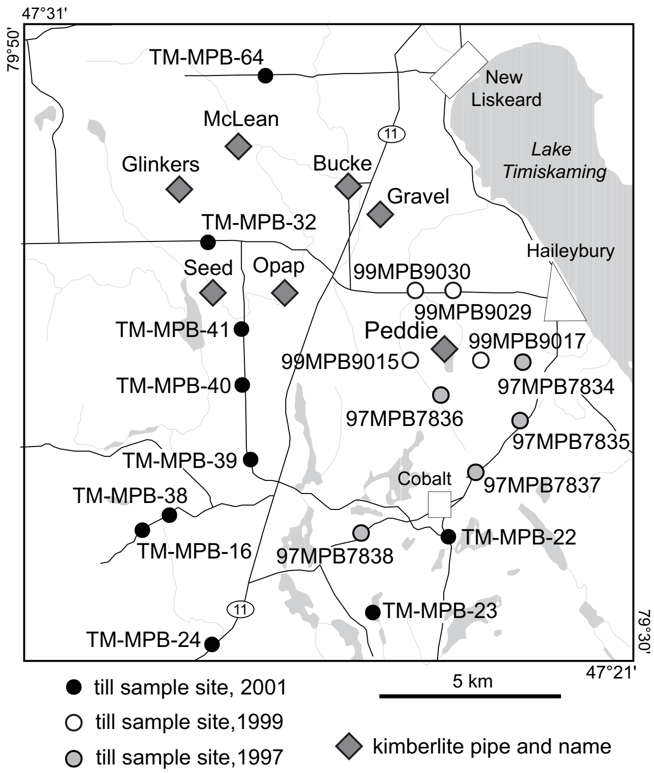



**Figure 3.** Inset map for Figure 2 showing the location of kimberlites and regional till samples collected near New Liskeard and Cobalt.

gravel (Boissoneau, 1968; Veillette, 1986a, 1996). In the southeast part of the area, the Lake McConnell recessional moraine trends northeast. As the glacier retreated northward approximately 9500 years ago, glacial Lake Barlow ponded in front of the ice sheet and thick sequences of fine-grained glaciolacustrine sediments were deposited (Vincent and Hardy, 1979; Veillette, 1988, 1989, 1996). Glacial Lake Barlow receded from the New Liskeard area approximately 8000 years ago (Veillette, 1994) and surficial sediments, including till, have been exposed to normal postglacial weathering and soil-forming processes.

## METHODS

### Field methods

A total of 64 sites (Appendix A) were sampled in the summer of 2000 from roadcuts or hand-dug pits along Highway 11 or forest access roads between New Liskeard and Marten River (Figs. 2 and 3). At each site, a 10 to12 kg till sample was collected for kimberlite indicator mineral analysis and a 2 kg till sample was collected for geochemical analysis of the fine till fraction. In addition to the 64 till samples, information for 9 till samples (99MPB9015, 99MPB9017, 99MPB9029, 99MPB9030, 97MPB7834, 97MPB7835, 97MPB7836, 97MPB7837, 97MPB7838) collected by the GSC in earlier sampling programs in New Liskeard are included in this data release to provide a broader sam-

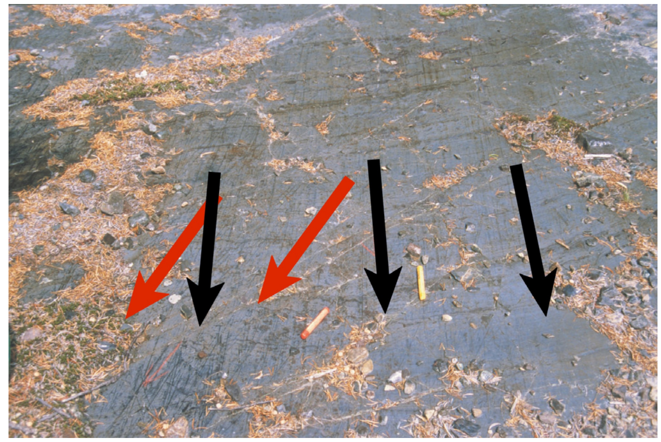


**Photo 3.** Cross-striated outcrop of metasedimentary rocks on the Barr Forest access road, north of the Montreal River showing evidence of two phases of ice flow: (1) older flow towards 230° (red arrows) and (2) younger flow towards 205° (black arrows) (NTS 31M/5).

**Photo 4.** Broad flat expanses of striated metasedimentary rocks are well exposed on the Roosevelt Forest access road, east of Highway 11. Bedrock at this site is striated at 165° (black arrows) (NTS 31M/5).

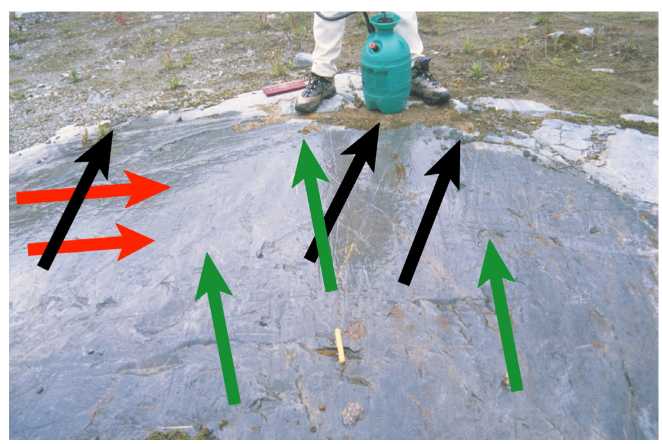


**Photo 4.** Cross-striated bedrock on the access road to the Temagami Fire Tower showing evidence of three phases of ice flow (oldest to youngest): (1) 255° (red arrows), (2) 180° (black arrows), and (3) 155° (green arrows) (NTS 31M/4).

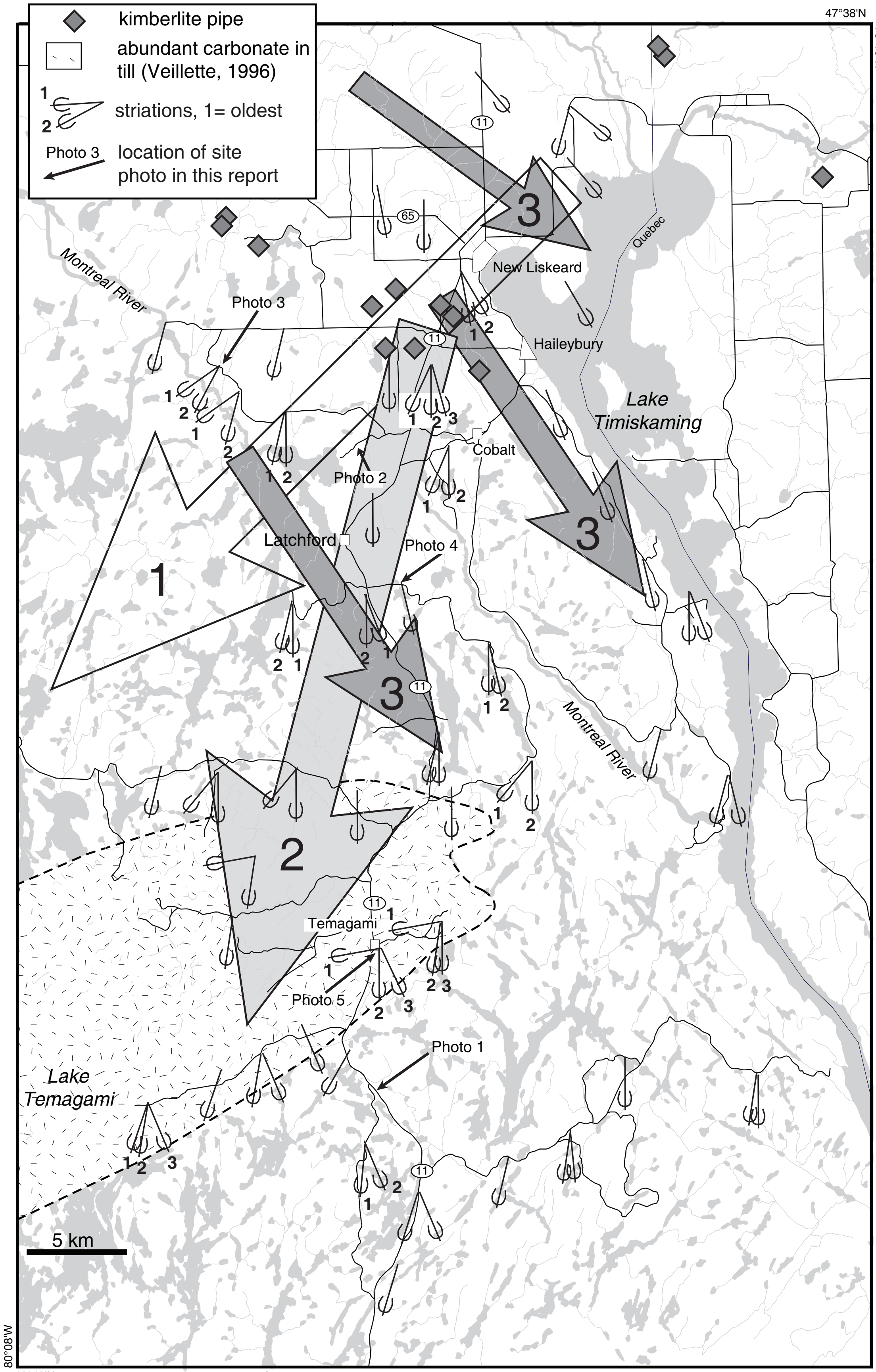



**Figure 4.** Selected striations in the study area and locations of Photos 1 to 5. Large arrows indicate the 3 main phases of ice flow (1 = oldest). Ice-flow sequence from Veillette (1996).

ple coverage across the survey area, especially around the known kimberlites (Appendix A). The 73 till samples in this study were collected for several purposes: 1) to demonstrate the nature of anomalous kimberlite indicator minerals signatures in till immediately down-ice of known kimberlites; 2) to provide information on background concentrations of KIMs; 3) to identify anomalous KIM concentrations further down-ice and in areas that do not contain known kimberlites that warrant further investigation; and 4) to document the glacial dispersal of carbonate-rich till from the New Liskeard outlier. Striations were measured on fresh, well polished bedrock outcrops exposed mainly along forest access roads between New Liskeard and Marten River. These new striation data were combined with those of Veillette (1986b, unpublished data) to provide an overview of local and regional ice-flow patterns that could have dispersed indicator minerals. Striation data for approximately 350 sites across the study area have recently been released as GSC Open File 3385 (McClenaghan and Veillette, 2001) and are summarized in Figure 4.

## Sample preparation

Sample preparation and processing is summarized in Figure 5. The 10 to 12 kg till samples were processed by Overburden Drilling Management Ltd., Nepean, Ontario, to recover heavy mineral concentrates for examination of kimberlite indicator minerals as well as gold grains (sample A, Fig. 5). Weights for all sample fractions produced during the processing procedure are reported in Appendix B. The >2 mm (+10 mesh) material was screened and retained for pebble lithology classification. The <2 mm (-10 mesh) fraction was screened to obtain the <1.0 mm fraction, which was then processed using a combination of tabling and heavy liquid separation.

The <1.0 mm material was passed over a shaking table twice to obtain a preconcentrate, which was then panned to recover and count gold grains. The preconcentrate was then further refined using heavy liquid separation in methylene iodide (MI) diluted with acetone to a specific gravity (S.G.) of 3.2 to separate the light and heavy mineral fractions. Methylene iodide was diluted from full strength (S.G. 3.3) to maximize the recovery of Cr-diopside (S.G. ≥ 3.2), the kimberlite indicator mineral with the lowest specific gravity. The ferromagnetic heavy minerals were removed using a hand magnet, leaving a <1.0 mm non-ferromagnetic heavy mineral fraction for picking. This combination of tabling and heavy liquid separation was used to recover kimberlite indicator minerals because it also allows for the recovery of gold and sulphide grains, an important consideration in parts of the study area. The <1.0 mm non-ferromagnetic heavy mineral concentrates were then sieved into three fractions: <0.25 mm (-60 mesh), 0.25 to 0.5 mm (-35+60 mesh), and 0.5 to 1.0 mm (-18+35 mesh), of which only the 0.25 to 0.5 mm fraction was picked for KIMs.

The 2 kg till samples (sample B, Fig. 5) were freeze dried and sieved through stainless steel sieves at the GSC Sedimentology Lab to recover the <0.063 mm fraction for geochemical analysis at commercial labs. Samples were analyzed in the GSC Sedimentology Lab to determine grain-size characteristics (% clay, silt and sand) and to determine carbonate content of the <0.063 mm fraction using the Leco method.

## Kimberlite indicator mineral identification

The 0.25 to 0.5 mm fraction of each till sample was examined by I. & M. Morrison Geological Services, Delta, B.C., using stereoscopic and petrographic microscopes and potential KIM were selected. Indicator minerals were identified based on visual properties, such as colour, grain morphology and/or the presence of adhering kimberlite matrix material. The visually distinguishing characteristics of each indicator mineral are summarized in Table 1. Minerals picked included Cr-pyrope; pyrope, Cr-diopside, Mg-ilmenite, chromite, and olivine. All picked grains were mounted in 25 mm epoxy mounts and polished by Lakefield Research in preparation for electron microprobe analysis to confirm their identity.

Electron microprobe analyses were carried out at the GSC using operating conditions similar to those described by McClenaghan et al. (1999). Analyses were completed using a four spectrometer Cameca SX50 electron microprobe and all grains were analyzed using what is referred to internally as the “DIAMOND” routine for silicates (garnets, clinopyroxene, olivine) and the "SPINEL" routine for the oxides. These routines were developed by the GSC to analyze for the major elements required to identify the potential mineral species using a minimum of probe time. Microprobe analyses are included in Appendix C1 (digital data file only). Microprobe analyses for those minerals identified as kimberlite indicator minerals are listed in Appendix C2 to C5.

Microprobe data were sorted by chemical composition and the grains were labeled with mineral names. For minerals and mineral groups that form solid solution series, theoretical end-member compositions (Table A13 *in* LeMaitre, 1982, ) were used to calculate threshold values (at approximately 50:50 mol%) for individual members of binary solid solution series. These threshold values are shown in Table 2. For minerals that contain substantial amounts of more than two end members (which is the case for most garnets and spinels), the threshold values were lowered accordingly (<50 mol% of one end member). In equivocal

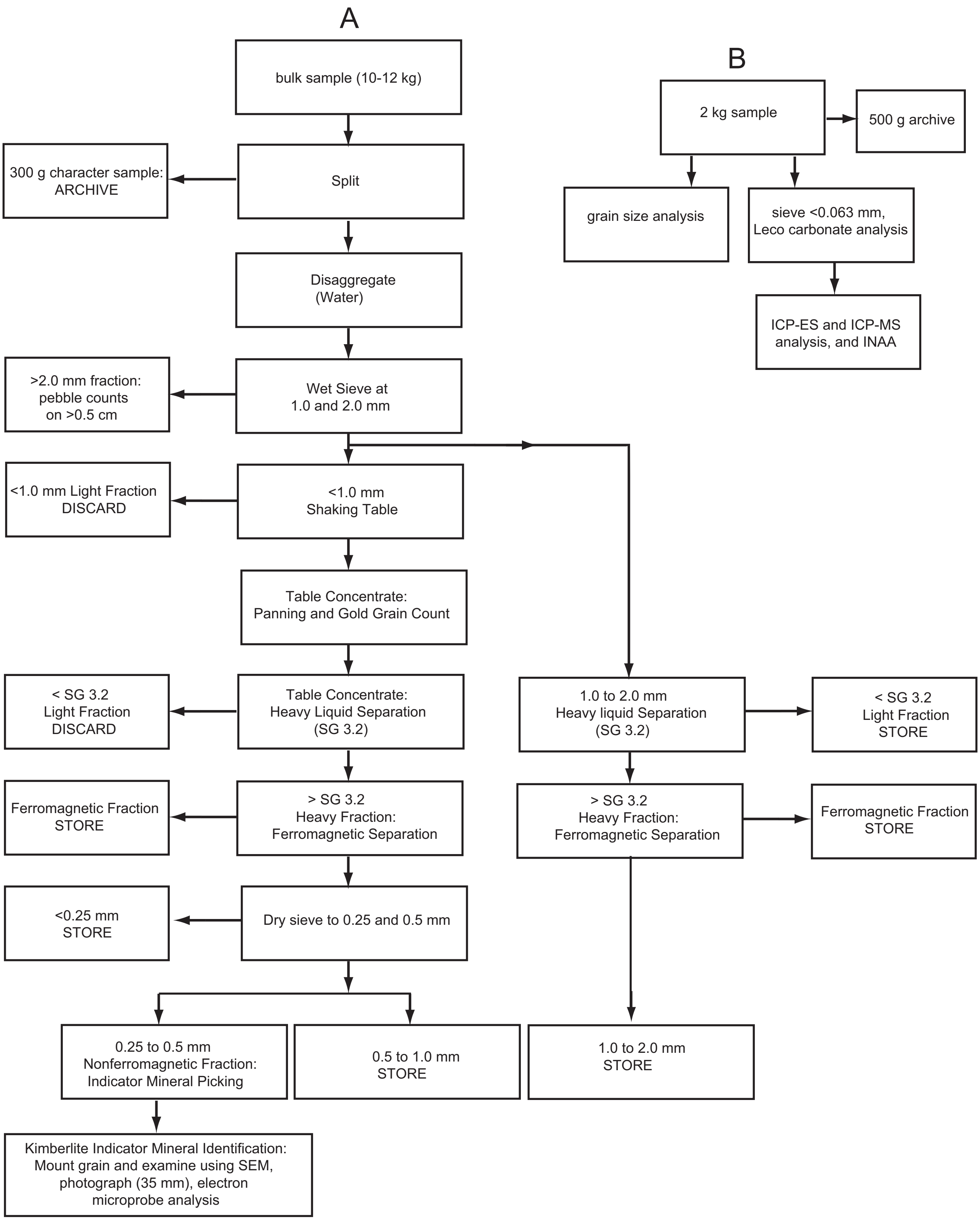



**Figure 5.** Sample processing flow diagram for **(A)** 10 to 12 kg till samples, for preparation of non-ferromagnetic heavy mineral concentrates and picking of kimberlite indicator minerals from the 0.25 to 0.5 mm fraction and **(B)** 2 kg till samples for geochemical analysis of the <0.063 mm till fraction.

**Table 1.** Summary of distinguishing characteristics used to visually identify kimberlite indicator minerals in heavy mineral concentrates.

| Mineral | Colour | Other distinguishing characteristics |
|---|---|---|
| Cr-pyrope | purple | kelyphite rims, adhering kimberlite matrix |
| Cr,Ti-pyrope | orange-red to deep red | kelyphite rims, adhering kimberlite matrix |
| Cr-diopside | emerald green | cleavage |
| Mg-ilmenite | black | unbroken grains appear as irregular- to round-shaped black grains with grey/white coatings, perovskite overgrowths; metallic black with conchoidal fractures on broken surfaces |
| chromite | black, reddish brown around grain edges | octahedral crystal shape to irregular shaped grains |
| olivine | colourless to pale yellow | conchoidal fracture |

cases, molar fractions of the critical oxides were calculated to assess the end member with the highest (name giving) proportion. Other minerals were identified by comparing wt% oxides to published analyses (e.g. Deer et al., 1978, 1982). Mineral names of grains with low totals were set in brackets. Prefixes were added to some of the indicator mineral names to emphasize elevated contents of petrogenetically critical elements such as Mg, Cr, and Ti, which are important in distinguishing between potential kimberlite minerals and those from other bedrock sources. Threshold values for these prefixes (see Table 2) were chosen arbitrarily and might differ from those used by other authors. Readers are encouraged to examine the microprobe data and reclassify indicator minerals using their own criteria.

Enlarged color prints and scanning electron microprobe (SEM) backscatter images of the grain mounts were used to aid mineral identification and to recognize possible inhomogeneities, intergrowths, or exsolutions within individual grains. Grain colour was also used to confirm mineral identification. Minerals were identified and named using criteria similar to those of McClenaghan et al. (1998, 1999) and are outlined above. A few grains could not be identified because their totals were too low. This was due to insufficient material on the surface of the grain mount, inhomogeneity, strong alteration of the grains. or compositions that contained elements that were not analyzed (e.g. S in sulphides). Grains that did not yield analyses with totals high enough to be unequivocally identified were labeled “unknown”.

The target KIM in diamond exploration are black Mg-ilmenite with ≥4 wt% MgO (also called magnesian- or picro-ilmenites); red-brown pyrope garnet; purple Cr-pyrope garnet (in particular those with low CaO, i.e., from subcalcic harzburgite or dunite peridotite assemblages); orange pyrope-almandine garnet with moderate MgO and high CaO content from eclogite xenoliths, including garnets that may contain significant trace amounts of $Na_2O$ and $TiO_2$ (i.e. diamond-inclusion eclogitic garnet); spinels with high chrome contents (>25 wt% $Cr_2O_3$), specifically black magnesio-chromite with >62 wt% $Cr_2O_3$ and >12 wt% MgO; emerald green Cr-diopside with high (≥1.0 wt%) $Cr_2O_3$; and forsteritic olivine (100*Mg/(Mg+Fe) >84).

## Gold grains

Gold grains were recovered from the 64 till samples collected in 2000 because the study area includes the Cobalt and Temagami mining camps. Gold grains in till were examined by Overburden Drilling Management Ltd. as part of the sample processing procedure (Fig. 5). Gold grains recovered from the <1.0 mm fraction during tabling and subsequent panning were counted, their size estimated, and then returned to the sample in preparation for geochemical analysis. Grains were classified using the three morphologic categories of DiLabio (1990), which reflect increasing distance of glacial transport: pristine, modified and reshaped (Appendix D). Pristine grains retain primary shapes and surface textures and appear not to have been damaged in glacial transport. Modified grains retain some primary surface textures but all edges and protrusions have been damaged during transport. Reshaped grains have undergone enough transport that all primary surface textures have been destroyed and the original grain shape is no longer discernible. The progression from pristine to reshaped grains is interpreted to represent increasing distance of glacial transport of grains as discrete particles in till. The abundance, size and shape of visible gold grains recovered from the till samples and the estimated gold assays for each sample, calculated by Overburden Drilling Management Ltd. based on the abundance and size of the gold grains recovered, are reported in Appendix D.

**Table 2.** Chemical classification criteria for identifying minerals.

| | Criterea | Mineral Name |
|---|---|---|
| Al-garnet | >21 wt% MnO | Spessartine |
| Al-garnet | >13 wt% MgO | Pyrope |
| Al-garnet | >17 wt% CaO | Grossular |
| Garnet | <11 wt% $Al_2O_3$ & >13 wt% CaO | Andradite |
| Garnet | >15 wt% $Cr_2O_3$ & >17 wt% CaO | Uvarovite |
| Andradite | >2 wt% $Cr_2O_3$ | Cr-Andradite |
| Andradite | >5 wt% MgO | Serpentinized (Cr-) andradite |
| Pyrope | >2 wt% $Cr_2O_3$ | Cr-Pyrope |
| Diopside | >0.5 wt% $Cr_2O_3$ | Cr-Diopside |
| Cr-Diopside | >1.5 wt% $Cr_2O_3$ | HiCr-Diopside |
| Chromite | $Cr_2O_3/Al_2O_3 < 1.5$ | Cr-Spinel |
| Chromite | >3 wt% $TiO_2$ | Ti-Chromite |
| Rutile | >15 wt% $FeO_{tot}$ | Fe-Rutile |
| Ilmenite | >4 wt% MgO | Mg-Ilmenite |
| Ilmenite | >53 wt% $FeO_{tot}$ | Ilmenite (altered) |
| Ilmenite | <30 wt% $TiO_2$ | FeTi-Oxide |
| Pyrope -Almandine -Gosslar | <22 wt% FeO & 5 wt% < MgO < 15 wt% & >4 wt% CaO & >0.07 wt% $Na_2O$ | diamond inclusion (Group I) eclogitic garnet |
| Olivine | Mg-number (mol% forsterite) > 84 | Olivine |

## Till geochemical analysis

The <0.063 mm fraction of till was analyzed at ACME Labs, Vancouver, B.C. Major elements were determined by ICP-ES. C and S were determined by Leco. Rare earth elements were determined using ICP-MS. Sample preparation for ICP-ES and ICP-MS analyses comprised fusion of a 0.2 g aliquot with $LiBO_2$ and subsequent acid dissolution. Base metals were determined using a 0.5 g aliquot digested in a 2-2-2 solution of HCl-$HNO_3$-$H_2O$/ICP-ES followed by ICP-ES. A separate 25 to 30 g split was analyzed using instrumental neutron activation analysis (INAA) by Activation Labs, Ancaster, Ontario. Analytical accuracy was monitored by analyzing GSC reference standards. Analytical precision was monitored by comparing duplicate analyses of selected samples; results are reported in Appendix E along with complete data listings for all analytical methods.

## Pebble lithology

The 0.5 to 5 cm (pebble) fraction was screened from the >2.0 mm (+10 mesh) fraction of till samples (Fig. 5) collected in 2000. Approximately 200 clasts were examined by Consorminex, Gatineau, Quebec, and classified into categories that reflect the major rocks types in the region: felsic to intermediate intrusive; mafic intrusive; ultramafic intrusive; metavolcanic; metasedimentary; iron formation; Huronian sediments; Paleozoic carbonate; kimberlite; and other or unknown rock types. Pebble lithology abundances are listed in Appendix F.

# RESULTS

## Indicator mineral chemistry

### *Mg-ilmenite*

A total of 252 grains of 591 grains picked as Mg-ilmenite were confirmed to be Mg-ilmenites with >5 wt% MgO. Mg-ilmenites are exclusively derived from kimberlite and do not occur in any other rock type in the region. A MgO versus $Cr_2O_3$ plot for Mg-ilmenite grains in till shows a wide range of MgO contents (5 to >16 wt%) with 0 to 6 wt% $Cr_2O_3$ (Fig. 6). Till samples that display compositional trends similar to Mg-ilmenite from the Peddie (McClenaghan et al., 1999; Sage, 2000) and Gravel (Sage, 1996) kimberlites are plotted in Figure 6a and show a clearly defined pattern of MgO-$Cr_2O_3$ composition. A similar pattern is also shown by Mg-ilmenite grains from till samples collected along Highway 11 near Latchford, the Red Squirrel Road, and near Temagami (Fig. 6b). However, the concentration of $Cr_2O_3$ is considerably less (<3 wt% $Cr_2O_3$) and there is a flat trend of low Cr-poor ilmenites with low MgO content (4-8 wt%) that is not exhibited by Mg-ilmenite in the Peddie or Gravel kimberlites. The chemistry of Mg-ilmenite from these till samples is similar to Mg-ilmenite grains recovered from stream sediments in the Temagami to Marten River area (Fig. 31 *in* Allan, 2001).

Mg-ilmenite grains in till samples 97MPB7834 to 97MPB7837 (south of kimberlites 95-1, 95-3, 96-1), TM-MPB-13, -14, (north of all known kimberlites), -16, -32, and -38 to -41 (south of Seed and Opap kim-

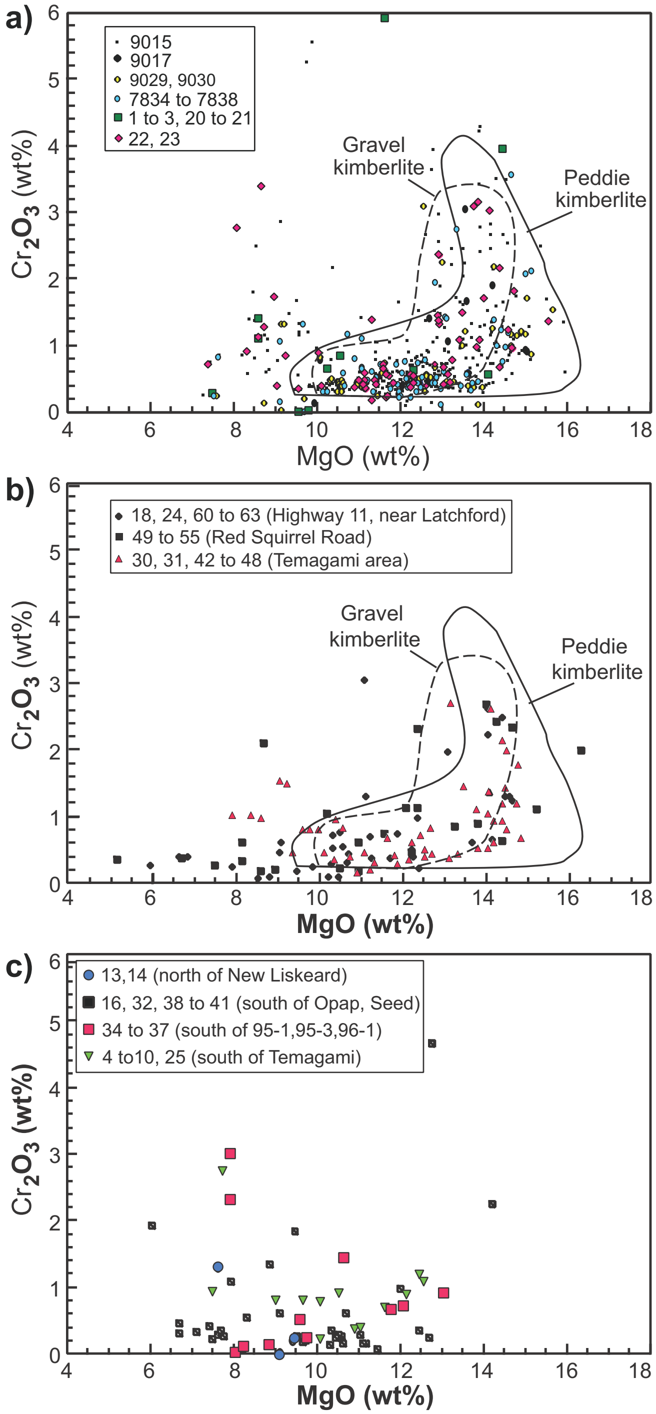



**Figure 6.** Plot of $Cr_2O_3$ versus MgO content of Mg-ilmenite grains in the 0.25 to 0.5 mm fraction of regional till samples: **a)** samples near the Peddie kimberlite; **b)** samples along Highway 11; and **c)** samples with a different composition. (Peddie kimberlite compositions from McClenaghan et al., 1999; Gravel kimberlite compositions from Sage, 1996).

berlites), and samples TM-MPB-04 to -10 and TM-MPB-25 (south of Temagami) (Fig. 2) display a chemical signature (Fig. 6c) that is different from the other regional till samples. These Mg-ilmenite grains are characterized by lower MgO content (6-14 wt%) and increasing $Cr_2O_3$ with decreasing MgO content.

### *Chromite*

The $Cr_2O_3$ versus MgO content of chromite grains in till was plotted along with the chromite compositions for the Peddie kimberlite (Fig. 7a). Chromite grains in the till samples show a broad compositional range. Chromite grains with low MgO content (<7 wt%) and high $Cr_2O_3$ content (40-50 wt%) could be from other ultramafic rocks in the region because there is no apparent equivalent to these compositions among chromites from known regional kimberlites (Sage, 1996, 2000; McClenaghan et al., 1999). A closer inspection of the distribution of the MgO-poor chromite grains reveals that they are not contained in any given till sample (Fig. 7b) but are dispersed over the study area, supporting the assumption that they may be from regionally widespread ultramafic rocks (e.g. Nipissing diabase sills and dykes). Chromite compositions for the till samples are similar those reported by Allan for stream sediments in the Temagami to Marten River area (Fig. 22 *in* Allan, 2001).

### *Garnet*

The composition of the pyropes in till range from Cr-poor Ti-bearing megacryst pyropes to Cr-pyropes with >8 wt% $Cr_2O_3$ (Fig. 8). The majority of the Cr-pyropes are of lherzolitic origin, however, 18 grains are G10 pyropes. Three grains from till samples TM-MPB-48 and -63, collected along Highway 11 (Fig. 2), plot in the subcalcic field of Sobolev et al. (1977). The only known kimberlite in the Cobalt/New Liskeard field that contains similar subcalcic garnet is Opap, however, Opap also contains a considerable proportion of Cr-rich harzburgitic to dunitic garnet (Sage, 2000), which does not appear in the till samples. It is possible that these three grains are from one of the western-most kimberlites (95-1, 95-3, or 96-1, Fig. 2), which are situated up-ice from the sample locations.

Comparison of till samples collected just south of the Peddie pipe with those from the entire study area reveal that the till down-ice of Peddie contains a higher number of Cr-rich pyrope and pyroxenitic/megacrystic Cr-poor pyrope grains, but less subcalcic garnet (Fig. 8). A total of 55 almandine garnets found in the regional till samples are deemed to be from regional metamorphic rocks. No eclogitic garnet was identified.

### *Cr-diopside*

A large number of Cr-diopside grains were recovered from the regional till samples. Only seven grains were Cr-poor (<0.5 wt% $Cr_2O_3$) diopside. The rest were Cr-diopside containing 0.5 to1.5 wt% $Cr_2O_3$ or HiCr-diopside with >1.5 wt% $Cr_2O_3$. A $Cr_2O_3$ versus Mg-number plot (Fig. 9a) shows that a large percentage of the Cr-diopsides have a very restricted composition around 1 wt% $Cr_2O_3$ and Mg-numbers between 84 and

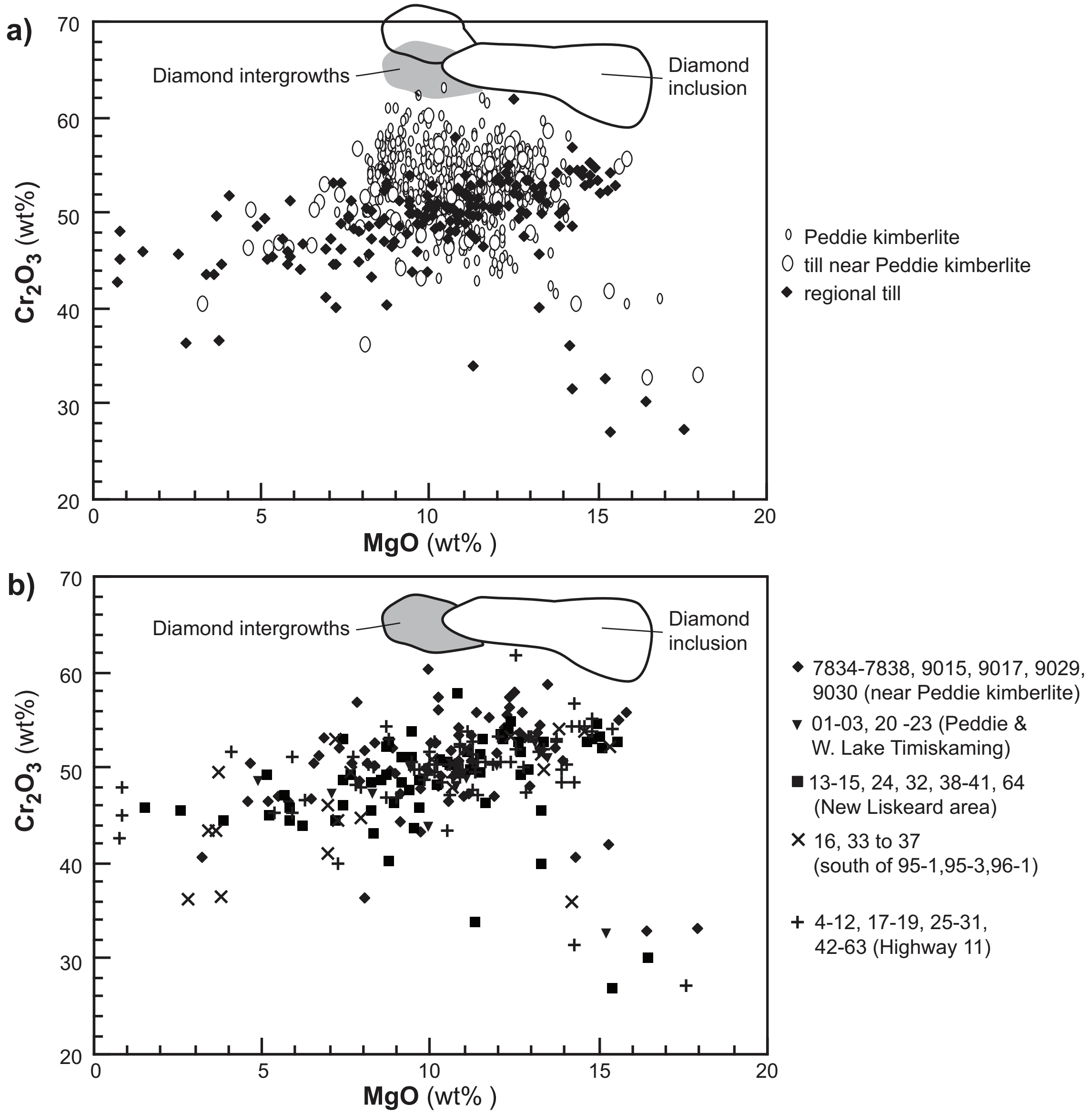
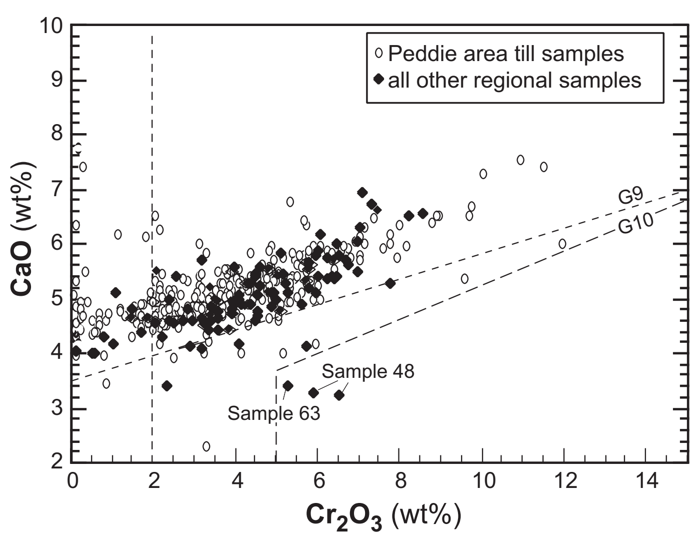



**Figure 7.** Plot of $Cr_2O_3$ versus MgO content of chromite grains in the 0.25 to 0.5 mm fraction of regional till samples: **a)** all till samples compared to the Peddie kimberlite; **b)** samples subdivided by location. Chromite compositions from the Peddie kimberlite are from McClenaghan et al. (1999). Diamond inclusion and intergrowth fields are from Fipke et al. (1995).

**Figure 8.** Plot of $Cr_2O_3$ versus CaO content for pyrope from regional till samples near the Peddie kimberlite and all other regional samples. Field below the lower dashed line is the composition of subcalcic garnets from the diamond stability field (Sobolev, 1977; Sobolev et al., 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).



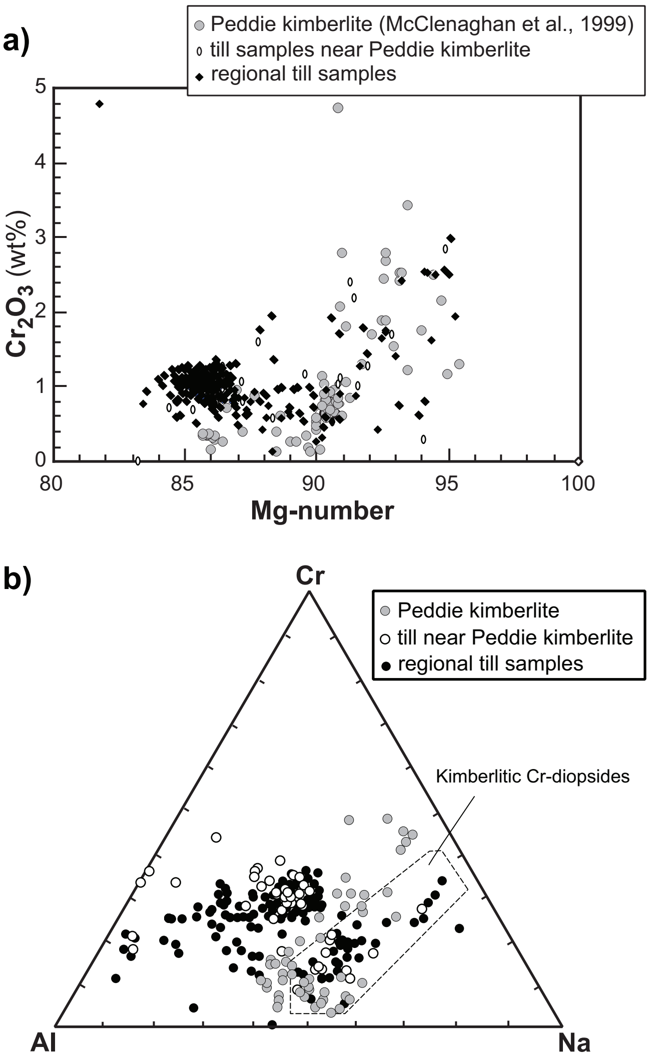



**Figure 9.** Cr-diopside in the 0.25 to 0.5 mm fraction of regional till samples: **a)** $Cr_2O_3$ versus Mg-number for till and the Peddie kimberlite; **b)** ternary plot of Cr-Al-Na (field of kimberlitic Cr-diopsides from Morris et al., 2000).

87. Cr-diopside grains with compositions similar to these reported here have been encountered in till samples from the Kirkland Lake and Lake Timiskaming areas (e.g. McClenaghan et al., 1993, 1999) but not in kimberlite. These grains are likely from ultramafic rocks and not from kimberlite.

Figure 9b displays the broad range in Cr-Al-Na content of Cr-diopside and HiCr-diopside from the regional till samples. Many of the grains plot inside the kimberlite composition field identified by Morris et al. (1999). Allan (Fig. 28, 2001) reported Cr-diopside with a similar range of Cr, Al and Na content as stream sediments collected in the Temagami to Marten River area.

HiCr-diopsides are exclusively found in mantle peridotite and are therefore kimberlite-derived. In this study, they occur in several till samples that also contain Cr-pyrope.

## Kimberlite indicator mineral distribution

Kimberlite indicator mineral abundances in individual till samples, which are listed in Table 3, have been normalized to 10 kg of <2 mm till in order to compare counts among samples of widely variable sample weight. Pyrope and Cr-pyrope abundances have been combined in Table 3 and are discussed together as "pyrope" below. Several sites contain anomalous KIM counts and the locations of these sites, which are summarized in Figure 10, are described briefly below.

Several anomalous till samples were collected just down-ice from the known kimberlites near New Liskeard and Cobalt. Anomalous concentrations of Mg-ilmenite and pyrope in till from site 23 are not unexpected since the site is 3 to 5 km down-ice of several kimberlites (Fig. 10). Samples 99MPB9015, 99MPB9030, 97MPB7836 and TM-MPB-23 contain anomalous concentrations of Mg-ilmenite, pyrope, chromite and Cr-diopside. Although these three sites are closest to the Peddie kimberlite, it is probably not the source of the KIMs as the Peddie kimberlite contains very little pyrope and Cr-diopside relative to Mg-ilmenite (McClenaghan et al., 1999). Instead the KIMs in these three samples are likely derived from the Gravel or Bucke kimberlites further north, which are known to contain a full suite of indicator minerals. Elevated counts of Mg-ilmenite and chromite in till samples TM-MPB-22, 97MPB7834 and 99MPB9017 are likely from the Mg-ilmenite-rich Peddie kimberlite. Till from sites 99MPB9016, TM-MPB-39 and TM-MPB-40 contains similar elevated concentrations of chromite and Mg-ilmenite with very little or no pyrope. This relative abundance pattern in the till is most similar to that for the Glinkers kimberlite (Sage, 2000), located 5 km to the north. Kimberlite 95-3 is the most likely source of the elevated counts of pyrope and Cr-diopside in the till at site 35, which is located approximately 6 km to the south of 95-3.

Further south from the known kimberlites, several till samples contain elevated concentrations of KIMs that are noteworthy: a) on the Red Squirrel forest access road, sample TM-MPB-51 contains elevated concentrations of chromite, Mg-ilmenite, pyrope and Cr-diopside, and sample TM-MPB-53 contains elevated concentrations of Mg-ilmenite and chromite; b) samples TM-MPB-49, -60, and -18, collected along Highway 11 in the central part of the study area, contain elevated concentrations of Mg-ilmenite and chromite; c) samples TM-MPB-03 and -01, collected near Lake Timiskaming, contain elevated concentrations of pyrope and Cr-diopside; d) collected near Temagami, till samples TM-MPB-48, -56, and -30 have elevated counts of Mg-ilmenite and pyrope; e) collected on the Rabbit Lake forest access road, southeast of Temagami, sample TM-MPB-10 contains elevated

**Table 3.** Kimberlite indicator mineral abundance in the 0.25 to 0.5 mm fraction of till normalized to 10 kg sample weight.

| Sample Number | Weight | Raw Counts | | | | | Normalized to 10 kg <1 mm table feed | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | <1 mm table feed | chromite | Mg-ilmenite | pyrope + Cr-pyrope | Cr-diopside | HiCr-diopside | chromite | Mg-ilmenite | pyrope + Cr-pyrope | Cr-diopside | HiCr-diopside |
| TM-MPB-01 | 6.9 | 0 | 1 | 7 | 5 | 0 | 0 | 1 | 10 | 7 | 0 |
| TM-MPB-02 | 6.2 | 0 | 0 | 2 | 10 | 0 | 0 | 0 | 3 | 16 | 0 |
| TM-MPB-03 | 6.9 | 2 | 5 | 4 | 29 | 2 | 3 | 7 | 6 | 42 | 3 |
| TM-MPB-04 | 6.4 | 2 | 4 | 4 | 2 | 0 | 3 | 6 | 6 | 3 | 0 |
| TM-MPB-05 | 6.7 | 2 | 3 | 1 | 8 | 0 | 3 | 4 | 1 | 12 | 0 |
| TM-MPB-06 | 5.1 | 0 | 0 | 2 | 6 | 0 | 0 | 0 | 4 | 12 | 0 |
| TM-MPB-07 | 7.2 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 6 | 0 |
| TM-MPB-08 | 6.1 | 0 | 1 | 0 | 5 | 0 | 0 | 2 | 0 | 8 | 0 |
| TM-MPB-09 | 5.4 | 1 | 0 | 4 | 10 | 0 | 2 | 0 | 7 | 19 | 0 |
| TM-MPB-10 | 4.2 | 2 | 4 | 2 | 5 | 0 | 5 | 10 | 5 | 12 | 0 |
| TM-MPB-11 | 7.6 | 1 | 0 | 4 | 2 | 2 | 1 | 0 | 5 | 3 | 3 |
| TM-MPB-12 | 7.3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| TM-MPB-13 | 7.2 | 2 | 1 | 3 | 6 | 0 | 3 | 1 | 4 | 8 | 0 |
| TM-MPB-14 | 6.3 | 5 | 2 | 2 | 5 | 0 | 8 | 3 | 3 | 8 | 0 |
| TM-MPB-15 | 6.3 | 4 | 0 | 1 | 6 | 2 | 6 | 0 | 2 | 10 | 3 |
| TM-MPB-16 | 6.1 | 5 | 8 | 1 | 1 | 1 | 8 | 13 | 2 | 2 | 2 |
| TM-MPB-17 | 3.2 | 1 | 0 | 0 | 1 | 0 | 3 | 0 | 0 | 3 | 0 |
| TM-MPB-18 | 5.3 | 2 | 6 | 0 | 5 | 0 | 4 | 11 | 0 | 9 | 0 |
| TM-MPB-19 | 7.8 | 3 | 0 | 1 | 12 | 0 | 4 | 0 | 1 | 15 | 0 |
| TM-MPB-20 | 5.7 | 1 | 2 | 2 | 1 | 0 | 2 | 4 | 4 | 2 | 0 |
| TM-MPB-21 | 7.2 | 1 | 4 | 2 | 6 | 0 | 1 | 6 | 3 | 8 | 0 |
| TM-MPB-22 | 6.9 | 6 | 14 | 1 | 2 | 0 | 9 | 20 | 1 | 3 | 0 |
| TM-MPB-23 | 3.7 | 2 | 46 | 7 | 1 | 0 | 5 | 124 | 19 | 3 | 0 |
| TM-MPB-24 | 4.0 | 5 | 3 | 0 | 1 | 0 | 13 | 8 | 0 | 3 | 0 |
| TM-MPB-25 | 7.4 | 1 | 1 | 0 | 4 | 0 | 1 | 1 | 0 | 5 | 0 |
| TM-MPB-26 | 7.8 | 3 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| TM-MPB-27 | 7.7 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 |
| TM-MPB-28 | 7.2 | 0 | 3 | 0 | 4 | 0 | 0 | 4 | 0 | 6 | 0 |
| TM-MPB-29 | 4.4 | 2 | 0 | 1 | 1 | 1 | 5 | 0 | 2 | 2 | 2 |
| TM-MPB-30 | 7.3 | 2 | 17 | 5 | 0 | 0 | 3 | 23 | 7 | 0 | 0 |
| TM-MPB-31 | 5.7 | 0 | 4 | 0 | 6 | 1 | 0 | 7 | 0 | 11 | 2 |
| TM-MPB-32 | 6.8 | 1 | 3 | 2 | 2 | 1 | 1 | 4 | 3 | 3 | 1 |
| TM-MPB-33 | 7.5 | 0 | 0 | 4 | 9 | 0 | 0 | 0 | 5 | 12 | 0 |
| TM-MPB-34 | 5.1 | 0 | 1 | 1 | 2 | 0 | 0 | 2 | 2 | 4 | 0 |
| TM-MPB-35 | 6.7 | 6 | 5 | 18 | 17 | 3 | 9 | 7 | 27 | 25 | 4 |
| TM-MPB-36 | 6.4 | 6 | 3 | 2 | 0 | 1 | 9 | 5 | 3 | 0 | 2 |
| TM-MPB-37 | 6.4 | 6 | 2 | 4 | 13 | 0 | 9 | 3 | 6 | 20 | 0 |
| TM-MPB-38 | 6.4 | 1 | 1 | 0 | 2 | 0 | 2 | 2 | 0 | 3 | 0 |
| TM-MPB-39 | 4.7 | 5 | 4 | 1 | 3 | 0 | 11 | 9 | 2 | 6 | 0 |
| TM-MPB-40 | 5.5 | 16 | 17 | 0 | 2 | 0 | 29 | 31 | 0 | 4 | 0 |
| TM-MPB-41 | 7.9 | 6 | 4 | 0 | 2 | 0 | 8 | 5 | 0 | 3 | 0 |
| TM-MPB-42 | 5.1 | 1 | 1 | 2 | 3 | 1 | 2 | 2 | 4 | 6 | 2 |
| TM-MPB-43 | 5.5 | 8 | 2 | 0 | 0 | 0 | 15 | 4 | 0 | 0 | 0 |
| TM-MPB-44 | 5.2 | 0 | 2 | 0 | 4 | 0 | 0 | 4 | 0 | 8 | 0 |
| TM-MPB-45 | 5.7 | 0 | 2 | 1 | 3 | 0 | 0 | 4 | 2 | 5 | 0 |
| TM-MPB-46 | 6.4 | 3 | 0 | 0 | 3 | 0 | 5 | 0 | 0 | 5 | 0 |
| TM-MPB-47 | 6.7 | 2 | 3 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 0 |
| TM-MPB-48 | 6.3 | 1 | 18 | 8 | 1 | 1 | 2 | 29 | 13 | 2 | 2 |
| TM-MPB-49 | 5.8 | 2 | 14 | 0 | 1 | 0 | 3 | 24 | 0 | 2 | 0 |
| TM-MPB-50 | 3.2 | 0 | 3 | 2 | 9 | 0 | 0 | 9 | 6 | 28 | 0 |
| TM-MPB-51 | 4.2 | 9 | 12 | 4 | 5 | 0 | 21 | 29 | 10 | 12 | 0 |
| TM-MPB-52 | 6.4 | 6 | 1 | 0 | 5 | 0 | 9 | 2 | 0 | 8 | 0 |
| TM-MPB-53 | 5.0 | 6 | 5 | 1 | 2 | 0 | 12 | 10 | 2 | 4 | 0 |
| TM-MPB-54 | 7.3 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| TM-MPB-55 | 7.0 | 3 | 3 | 0 | 1 | 0 | 4 | 4 | 0 | 1 | 0 |
| TM-MPB-56 | 2.9 | 0 | 0 | 4 | 1 | 0 | 0 | 0 | 14 | 3 | 0 |
| TM-MPB-57 | 6.4 | 1 | 0 | 4 | 4 | 1 | 2 | 0 | 6 | 6 | 2 |
| TM-MPB-58 | 5.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TM-MPB-59 | 5.9 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 2 | 0 | 0 |
| TM-MPB-60 | 4.9 | 4 | 9 | 4 | 4 | 0 | 8 | 18 | 8 | 8 | 0 |
| TM-MPB-61 | 4.4 | 2 | 0 | 0 | 2 | 0 | 5 | 0 | 0 | 5 | 0 |
| TM-MPB-62 | 5.8 | 3 | 4 | 4 | 4 | 0 | 5 | 7 | 7 | 7 | 0 |
| TM-MPB-63 | 6.4 | 2 | 3 | 1 | 7 | 0 | 3 | 5 | 2 | 11 | 0 |
| TM-MPB-64 | 8.2 | 18 | 0 | 1 | 8 | 0 | 22 | 0 | 1 | 10 | 0 |
| 97MPB7834* | 6.2 | 28 | 14 | 2 | 6 | 0 | 45 | 23 | 3 | 10 | 0 |
| 97MPB7835* | 7.3 | 1 | 4 | 2 | 2 | 0 | 1 | 6 | 3 | 3 | 0 |
| 97MPB7836* | 6.8 | 2 | 39 | 11 | 4 | 1 | 3 | 57 | 16 | 6 | 1 |
| 97MPB7837* | 9.2 | 1 | 2 | 3 | 1 | 0 | 1 | 2 | 3 | 1 | 0 |
| 97MPB7838* | 9.3 | 1 | 0 | 2 | 0 | 1 | 1 | 0 | 2 | 0 | 1 |
| 99MPB9015 | 8.1 | 27 | 319 | 283 | 12 | 3 | 33 | 394 | 349 | 15 | 4 |
| 99MPB9017 | 8.6 | 4 | 15 | 1 | 4 | 0 | 5 | 17 | 1 | 5 | 0 |
| 99MPB9029 | 5.0 | 2 | 2 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 0 |
| 99MPB9030 | 4.4 | 7 | 55 | 8 | 9 | 0 | 16 | 126 | 18 | 21 | 0 |

* Data from GSC Open File 3775 (McClenaghan et al., 1999)

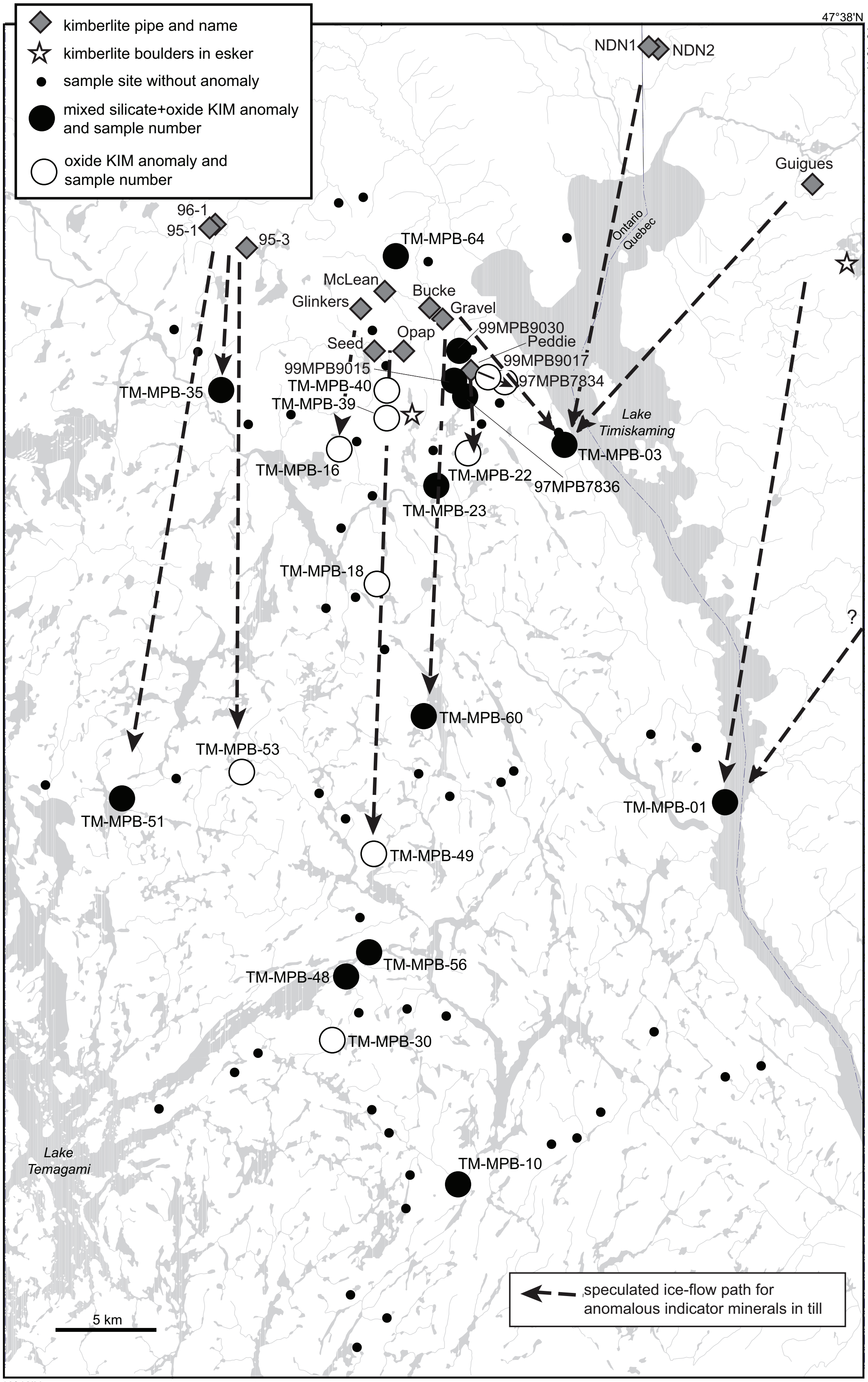



**Figure 10.** Location and name of known kimberlites and summary of kimberlite indicator mineral anomalies in regional till samples.

counts of Mg-ilmenite, pyrope and Cr-diopside; f) site TM-MPB-64, collected north of the known kimberlites, contains elevated concentrations of chromite and Cr-diopside.

## Gold grains

Gold grain data for the 64 till samples collected in 2000 are listed in Appendix D. Thirty-four of these 64 samples do not contain visible gold grains. The other 30 till samples contain background concentrations of between 1 and 11 gold grains. All gold grains recovered are small (<100 µm) and most are modified or reshaped.

## Till geochemistry

Geochemical data for the <0.063 mm fraction of till samples collected in 2000 are listed in Appendix E. Sample TM-MPB-23 contains elevated concentrations of Cu, Pb, Zn, Ni, As, Co, Cd and Fe. Sample TM-MPB-10 contains elevated concentrations of Cu, Co and Fe, and sample TM-MPB-59 has slightly elevated Cu and Cr content. Using 15 ppb as a threshold between background and anomalous Au concentrations in till (e.g. McClenaghan, 1992), six sites are considered to be anomalous: samples TM-MPB-10, -11, -16, -40, -42 and -60.

Several till samples contain elevated contents of both CaO and MgO (Appendix E1) and have elevated matrix carbonate contents (>2%) as determined by Leco (Appendix A), indicating the presence of abundant calcite and dolomite in the till matrix. In general, the matrix carbonate content of till is highest just south of the Paleozoic outlier, is low through the Latchford area, and is higher in the Temagami area and to the south (Fig. 11).

## Pebble lithology

Pebble lithology data for the 0.5 to 5.0 cm fraction of till samples collected in 2000 are listed in Appendix F. Till overlying and just south of the New Liskeard Paleozoic outlier contains the most carbonate clasts (Fig. 12). Carbonate clast content decreases significantly to 0 to 5 % between Latchford and Temagami and then increases around Temagami and further south, most notably for samples TM-MPB-19, at 20 km south of the outlier, and samples TM-MPB-05, -06, -07 and -11, 40 km south of the outlier (Fig. 2). The carbonate distribution patterns for pebbles and the matrix documented in this study are broadly similar to those reported by Veillette (1996) for surface till in the region. Ice flowing southwest (Phase 1) and south (Phase 2) across the New Liskeard region dispersed Paleozoic carbonate rocks more the 50 km down-ice from upper Lake Timiskaming. Carbonate-rich till near Temagami (Figs. 11 and 12) was deposited by these older ice flows (Veillette, 1996). The younger southeast (Phase 3) ice flow removed the carbonate-rich till in the part of the dispersal train near Latchford (Veillette, 1996). Most till samples that do not contain abundant carbonate pebbles are dominated by Huronian metasedimentary pebbles. Sample TM-MPB-23 is noteworthy because it contains 90% local mafic metavolcanic bedrock and no kimberlite clasts, yet it contains anomalous KIM concentrations.

# DISCUSSION AND CONCLUSIONS

Mg-ilmenite is the most abundant and widespread KIM in the till in the study area. Chromite occurs in approximately the same till samples that contain Mg-ilmenite, but is generally present in lower abundances than Mg-ilmenite, except immediately south of the 95-1, 95-3 and 96-1 kimberlites (samples TM-MPB-35 to -37, Fig. 2) and south of the Seed and Opap kimberlites (samples TM-MPB-39, -40, -41). In general, pyrope in till is approximately half as abundant as Mg-ilmenite. The reasons for this pattern may be that: 1) KIM sources in the area have a high concentration of megacryst ilmenite versus pyrope; 2) garnet is not as well preserved during glacial transport as ilmenite and chromite; or 3) garnet, due to its larger grain sizes (megacrysts), exceeds the size range of the fraction picked (0.25-0.5 mm). Elevated counts of Cr-diopside in till samples that are not accompanied by other KIMs may not be from kimberlite but from some other ultramafic rocks in the region.

Anomalous concentrations of Mg-ilmenite and chromite in till samples TM-MPB-51 and -53 on the Red Squirrel Road were collected close to the anomalous OGS stream sediment samples 23, 33, 27 and 423 (Allan, 2001) that contain various combinations of elevated counts of Mg-ilmenite, chromite and pyrope. The KIMs in these anomalous till and stream sediment samples may be the distal part of a dispersal train from kimberlites 95-1, 95-3 or 96-1, or they may be from more local, unknown kimberlites. Anomalous counts in till samples TM-MPB-48 and -56, collected near Temagami, are very close to OGS stream sediment sample 11 (Allan, 2001), which contains elevated abundances of Mg-ilmenite grains, chromite, and pyrope. The bedrock source of these KIMs is not known. Samples TM-MPB-03 and -01, collected near Lake Timiskaming, contain elevated concentrations of pyrope and Cr-diopside, which could have been transported southeast by Phase 3 ice flow from the kimberlites near Cobalt or southwest from kimberlites in Quebec by Phase 1 ice flow. Till from site 64, north of the known kimberlites, contains elevated concentrations of chromite and Cr-diopside, however, the absence of Mg-ilmenite and pyrope combined with the sample location north of the known kimberlites suggests these grains are not from the known kimberlites. Instead, they

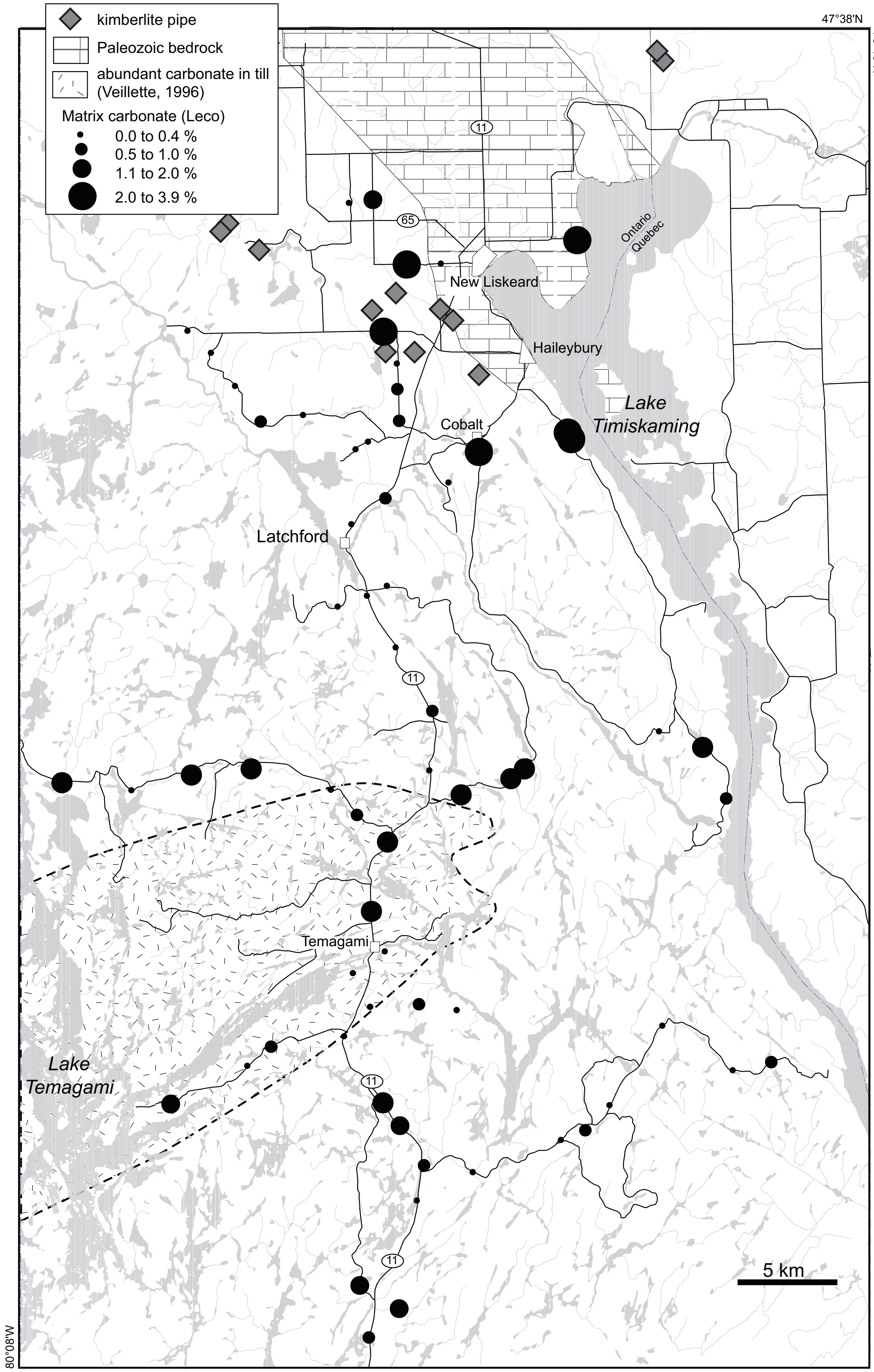



**Figure 11.** Distribution of Paleozoic carbonate bedrock (Grant and Osiacki, 1987) and till matrix (<0.063 mm fraction) carbonate determined by Leco.

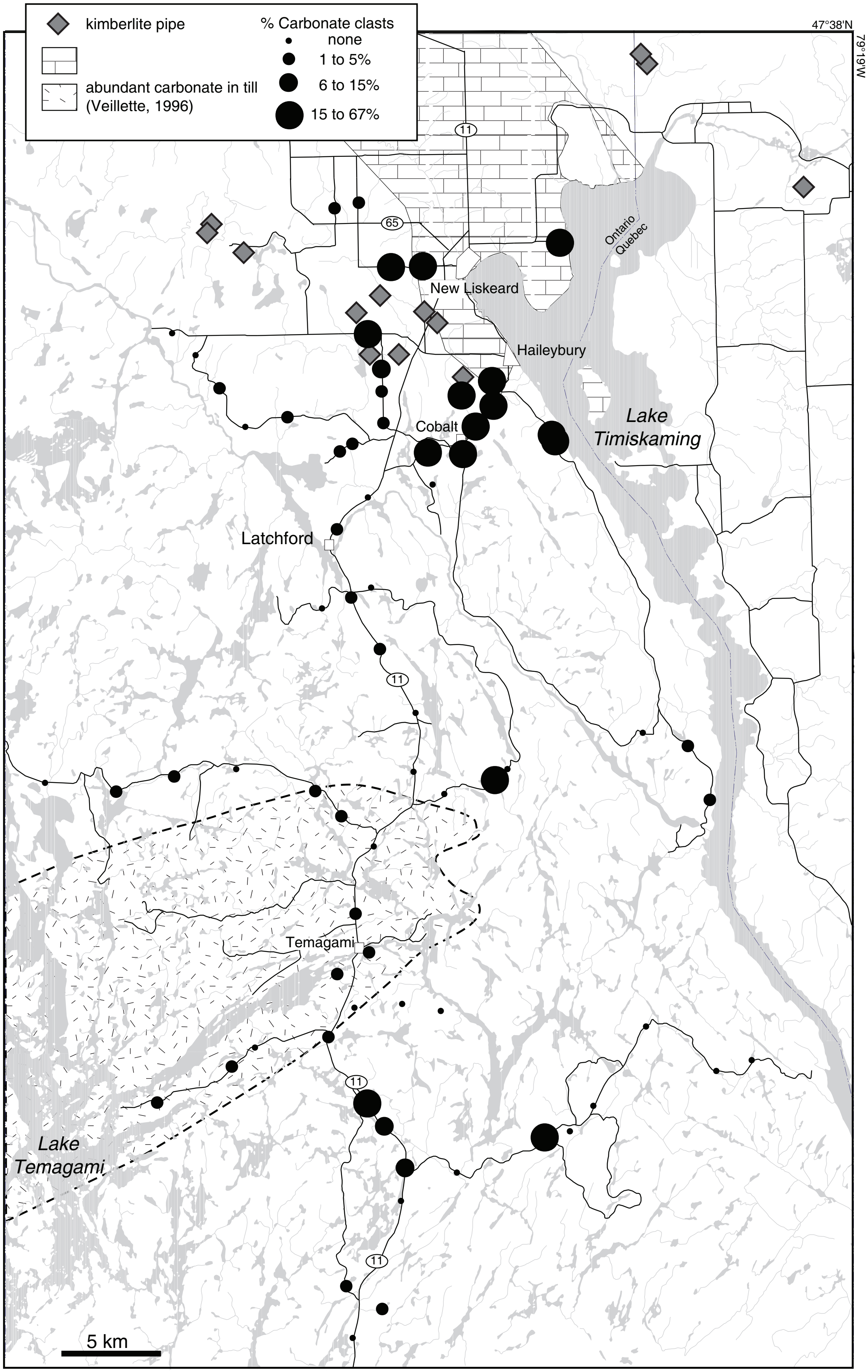



**Figure 12.** Areas underlain by Paleozoic carbonate bedrock (Grant and Osiacki, 1987) and distribution of carbonate clasts in the 0.5 to 5.0 cm fraction of till.

may be derived from Nipissing diabase, which also contains Cr-diopside and chromite (Edgar, 1986).

Till in the region contains carbonate pebbles, and calcite and dolomite in the matrix that are derived from the Paleozoic outlier at New Liskeard. Carbonate-rich debris has been dispersed southward, in some cases for at least 50 km. Carbonate concentration in till varies across the area (Figs. 11 and 12). In general, it is highest just down-ice of the outlier (near Cobalt), is very low near Latchford, and then increases further south near Temagami. Further sampling of till will be conducted to reconcile carbonate distribution patterns reported here with those reported by Veillette (1996). The distribution of carbonate pebbles down-ice of the Paleozoic outlier at New Liskeard may provide some insight into the source of KIM anomalies further south. Till just down-ice of the Peddie, Gravel, Bucke, Seed and Opap kimberlites is carbonate- and KIM-rich. This positive correlation would be expected in till further south if the KIM anomalies further south were derived from the known kimberlites near New Liskeard.

This reconnaissance-scale till sampling survey in the New Liskeard to Marten River area, provides information on the regional background content of KIMs in till; the nature of KIM signatures in till just down-ice of known kimberlites; and the presence of several KIM anomalies that warrant further investigation. Suggested ice-flows paths for the various KIM anomalies are presented in Figure 10, based on the relative abundance of the various KIM in the till samples and the trends of the three phases of ice flow. However, these interpretations are speculative because the relative abundance of KIM in most of the known kimberlites is not known. Some of these anomalies coincide with anomalies identified by the OGS in their recent stream sediment survey (Allan, 2001). Detailed examination of the pebble lithology data for these anomalous till samples (Appendix F), combined with additional till sampling and geophysical surveys should be conducted to determine the extent of the KIM anomalies and trace them to their bedrock source. Till sample spacing should be much smaller (<500 m) than that used in this reconnaissance-scale survey.

All three phases of ice flow are associated with erosion, transportation and deposition of till in the region. The main carriers of glacial debris, however, were the two oldest ice flows. A large dispersal train of Paleozoic limestone, derived from upper Lake Timiskaming, trends south-southwest across the area but has been truncated in its proximal part (Latchford area) by the last southeast ice flow (Veillette, 1989, 1996), indicating that in this area, southeast ice flow was a major carrier of debris. These situations must be taken into consideration in the interpretation of dispersal trains formed by the three major ice flows.

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