GS-30 Kimberlite potential in Manitoba: an update

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Summary

Numerous mineral dispositions were recorded in northern Manitoba in the past six years, partly in response to positive and widely spread kimberlite indicator-mineral (KIM) surveys by Manitoba Geological Survey (MGS) in the Superior Province. However, despite favourable bedrock geology, this activity has not translated into the discovery of kimberlite bodies. This lack of exploration success is due in part to the challenging, drift-covered terrain in many parts of Manitoba. Exploration models are evolving and will continue to mature until the first kimberlite is intersected and exploration can proceed on more actualistic grounds. The MGS is continuing with data compilation and interpretation to maximize the quantity, quality and digital distribution of public-sector information bearing on kimberlite potential in Manitoba. Initiatives include the downloadable KIM database (including a new standard classification of mantle garnets), Quaternary till stratigraphy in the Hudson Bay Lowland (HBL), a 3-D model of the Phanerozoic succession in the HBL, the web-enabled 'integrated anomaly map', and insights stemming from work on the bedrock geology of the Superior Boundary Zone and Trans-Hudson Orogen.

Introduction

Diamond exploration expenditures in Manitoba are projected to increase to \$3.8 million in 2004 (Natural Resources Canada, 2004a) from \$1.1 million in 2003 (Natural Resources Canada, 2004b). The major focus of exploration is situated in the Hayes River drainage basin between Knee Lake and Hudson Bay, where as of September 2004 there were 13,832 km^2 covered by mineral exploration licences. This is down 15% from the 16 246 km^2 in November 2003. Since 1999, exploration in the Hayes River drainage basin has met with little success, in part because of the challenging terrain characterizing northeast Manitoba. However, a number of junior and major mining companies are continuing to actively explore in the region.

The MGS continues to pursue a number of initiatives aimed at supporting exploration for kimberlites and diamonds in Manitoba. These initiatives are summarized below, with material taken from the MGS website and contributed by coauthors.

KIM Database

The Manitoba KIM Database brings together all existing published data, which were presented in different formats and media, into one coherent package (http://www.gov.mb.ca/itm/mrd/geo/kimdata/index.html), which can now be manipulated for use in a geographic information system (GIS). The KIM database, now at Version 3.0, has been upgraded since its initial release in early 2003 to include several new features and datasets.

The current database houses sample location, preparation and reference data, as well as microprobe analyses of heavy mineral grains. The current version of the KIM database features a customized query system providing advanced query options as well as the ability to directly create and view GIS shapefiles from queried data. Several data export options have also been added in order to extend the functionality of the database. Users can choose to save queried data as an Access table, Excel spreadsheet, dBASE compatible datafile (DBF), delimited text file or shapefile. Version 3.0 has a built in shapefile viewer to allow the user to directly view the results of queries.

KIM classifications

Each KIM survey uses a slightly different classification system for the naming of minerals. To level these surveys, the Manitoba KIM database applies standardized mineral classifications to published analyses, allowing comparison between samples. For example, a new garnet classification system (Grütter et al., 2004) is used that relies only on compositional microprobe data and is compatible with previous classifications.

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Mantle-derived garnets that are commonly recovered in diamond exploration surveys show variations in major element composition that reflect the chemical, physical and lithological environments in which they formed, occasionally together with diamond (e.g., Gurney et al., 1993). Based on variations in Cr, Ca, Mg, Fe and Ti, the seven distinct groups of mantle garnets classified in the KIM database can be summarized as follows: *peridotitic* (G10, G9, G12), *megacrystic, Ti-metasomatized* (G11), *pyroxenitic* (G4, G5) and *eclogitic* (G3) garnets (Figure GS-30-1). A 'D' suffix is added to the G10, G4, G5 and G3 categories to indicate a strong compositional and pressure-temperature association with diamond (Grütter et al., 2004). The G0 group encompasses any garnets unclassified by the above groups, and includes xenocrystic garnets derived from crustal-derived garnets or uncommon, unusual or 'polymict' mantle lithologies (Grütter et al., 2004).

Figure GS-30-1 presents the conventional Cr_2O_3 versus CaO classification (Gurney, 1984) for 621 garnets from five main geological domains in Manitoba:

1) Hudson Bay Lowland portion of the Hudson Bay Phanerozoic basin (n = 40),
2) Phanerozoic, subdivided into the Mesozoic (n = 73) and Paleozoic (n = 23) of southwest and southwest-central Manitoba, respectively,
3) Superior craton (n = 471), with the majority of samples from the Knee and Gods lakes area (n = 379),
4) Superior Boundary Zone (n = 8), and
5) Trans-Hudson Orogen (n = 6).

The majority of Manitoba mantle garnets plot in the fields of lherzolitic (G9) and pyroxenitic (G5) composition. The G5s are similar to G9s, but are richer in Fe and are separated from G9s by an Mg# less than 0.7 (Grütter et al., 2004).

Harzburgitic, Ca-poor and Cr-rich G10 garnets (e.g., Dawson and Stephens, 1975) have a geochemical and statistical association with diamond and are therefore commonly used as key indicators in the search for diamondiferous kimberlites. The Cr_2O_3 versus CaO classification demonstrates that G10 garnets were sampled from all main geological

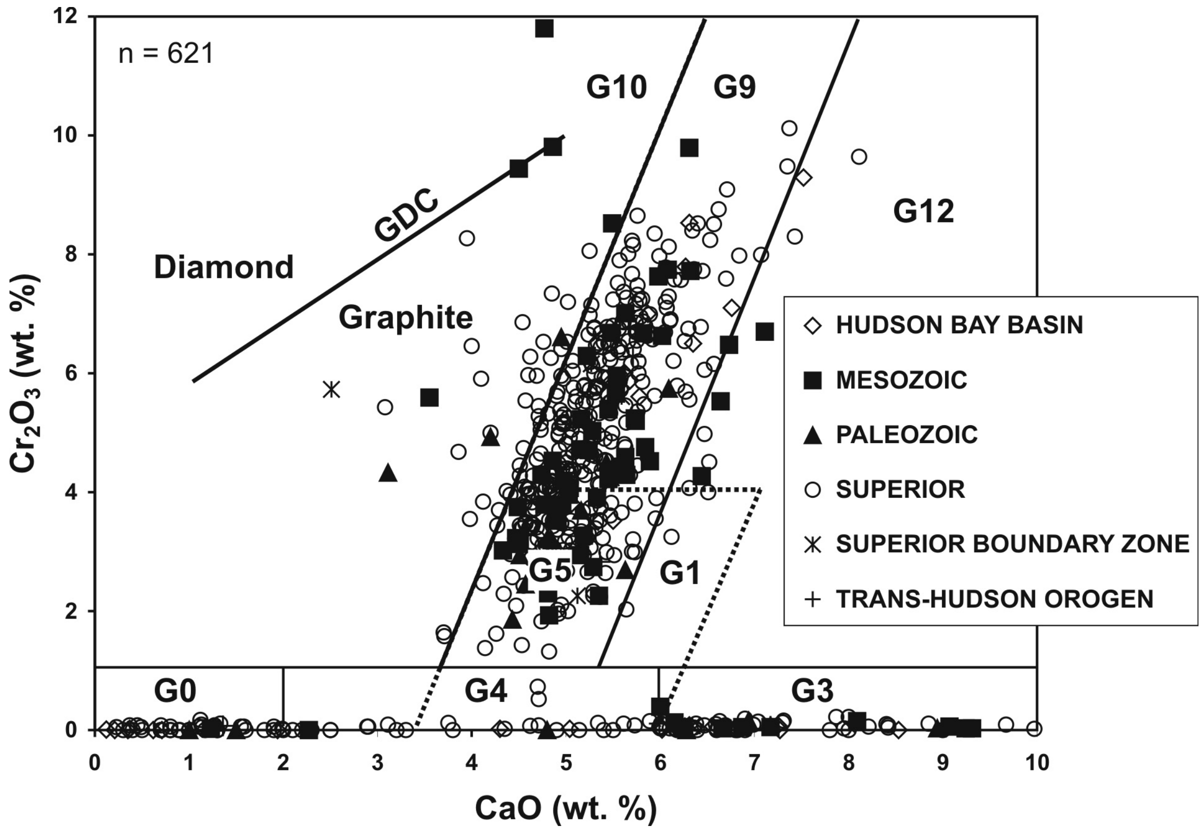


***Figure GS-30-1**: G-number nomenclature of the classification scheme of garnets viewed in a conventional Cr_2O_3 versus CaO diagram for garnets from surficial exploration surveys in Manitoba (*modified after *Gurney, 1984; Grütter et al., 2004). Megacryst group G1 (dotted outline) does not actually overlap groups G3, G4, G5, G9 or G12 since it occurs at higher TiO_2 content. The graphite–diamond constraint (GDC) of Grütter and Sweeney (2000) is also shown.*

domains except the Hudson Bay Basin and the Trans-Hudson Orogen, which might be due to the small sample numbers available from these areas (Figure GS-30-1).

In addition to the G10/G9 divide by Gurney (1984), the graphite–diamond constraint (GDC) of Grütter and Sweeney (2000) is also shown in Figure GS-30-1. The GDC represents a multiple constraint equilibrium feature of garnets in natural peridotites; G10 garnets with Cr contents above the GDC are derived from the diamond stability field (assuming a continental geotherm around 40 mWm^{-2}). Based on the GDC, only three G10 garnets—from the Mesozoic of southwest Manitoba—plot close or within the diamond stability field.

Ilmenite, another common KIM recovered during diamond exploration surveys, can be derived from kimberlitic rocks (e.g., kimberlite, lamproite, ultramafic lamprophyre) as well as other rock types (e.g., gabbro, norite, granites, anorthosite). Based on compositional fields and bounding reference lines for ilmenite derived from kimberlitic rocks worldwide, a classification scheme based on the Mg and Ti compositional variations has been applied to distinguish kimberlitic from non-kimberlitic ilmenite (Wyatt et al., 2004). The dataset for Manitoba ilmenites (n = 1292) reveals fields of low-Mg and high-Mg ilmenite that correspond with non-kimberlitic and kimberlitic ilmenite compositions, respectively (Figure GS-30-2).

A large percentage of ilmenite from the Northern Superior region falls into the kimberlitic classification field (Figure GS-30-2a). In contrast, ilmenite from southwest Manitoba (Mesozoic) and to a lesser degree southwest-central Manitoba (Paleozoic), dominantly show non-kimberlitic composition, whereas ilmenites from the HBL are dominantly kimberlitic, based on Mg and Ti concentrations (Figure GS-30-2b).

The GIS functionality of the current database facilitates comparison of KIM suites of different compositions and regions. As an example, mantle garnets classified using the method by Grütter et al. (2004) are plotted on a map of Manitoba subdivided by stippled lines into the main geological domains (Figure GS-30-3). Sampling sites that did not yield any mantle garnets are shown as small black dots. Large areas of Manitoba, including much of the Trans-Hudson Orogen, the southwest Superior craton, and the entire Far North, lack publicly available KIM data. Based on the existing garnet data, G10 garnets were recovered in southwest Manitoba and the northern Superior craton, the latter being shown in more detail in Figure GS-30-4. Here, a relatively large amount of KIM data exists from Operation Superior, a six-year multimedia geochemical sampling program that focused primarily on greenstone belt areas (e.g., Fedikow et al., 2002).

The distribution and spacing of sampling locations of publicly available surveys in the northern Superior craton only allows limited prediction of the location of potential kimberlite sources, in part because large, dominantly granitic areas between the greenstone belts were not sampled during surveys. To predict regional diamond potential, the geochemical classification and regional distribution of the available KIM data should be used in conjunction with geophysical, structural and ‘young’ igneous features—all of which may control the occurrence and distribution of kimberlitic rocks (*see* section on Integrated anomaly map).

Hudson Bay Lowland

Three-dimensional model

In the HBL, an anomalously thick Quaternary succession composed of interbedded sand, clay and silt diamicton was encountered in recent drilling by Foran Mining Corporation in the Bouchard Lake area (NTS 54B). The Foran drillhole is situated within the ‘Kaskattama highlands’, an area of higher elevation (clearly identified on a digital elevation model [DEM] of Manitoba). Coincidentally, this region is also the location of the ‘Kaskattama trough’—a structural feature in the Precambrian basement oriented parallel to the Kaskattama River and perpendicular to the Hudson Bay shoreline. This structure was proposed in 1964 by James Barron (Barron, 1964) to explain seismic data from the HBL.

Two topographic cross-sections through the HBL highlands suggest that the highlands contain an additional 150 m of as of yet unexplained stratigraphy, possibly Quaternary in age (Figure GS-30-5). The upper cross-section (A-A’) is drawn to the north of the highland and shows a gradual slope into Hudson Bay, while the lower cross-section (B-B’) is drawn over the highland depicting an additional 150 m of sediments of unknown age.

Till stratigraphy in the Hudson Bay Lowland

Quaternary stratigraphy in the HBL comprises four glacial till units interbedded with a variety of glaciofluvial and interglacial sediments and overlain by glaciolacustrine, glaciomarine and fluvial sediments (Nielsen et al., 1986; Nielsen, 2002; Nielsen and Fedikow, 2002). The four tills from oldest to youngest are Sundance, a grey sandy till; Amery, a grey clayey till; Long Spruce, a grey blocky till and the only regionally pervasive till in the area; and Sky Pilot, a reddish brown silty till (Figure GS-30-6).

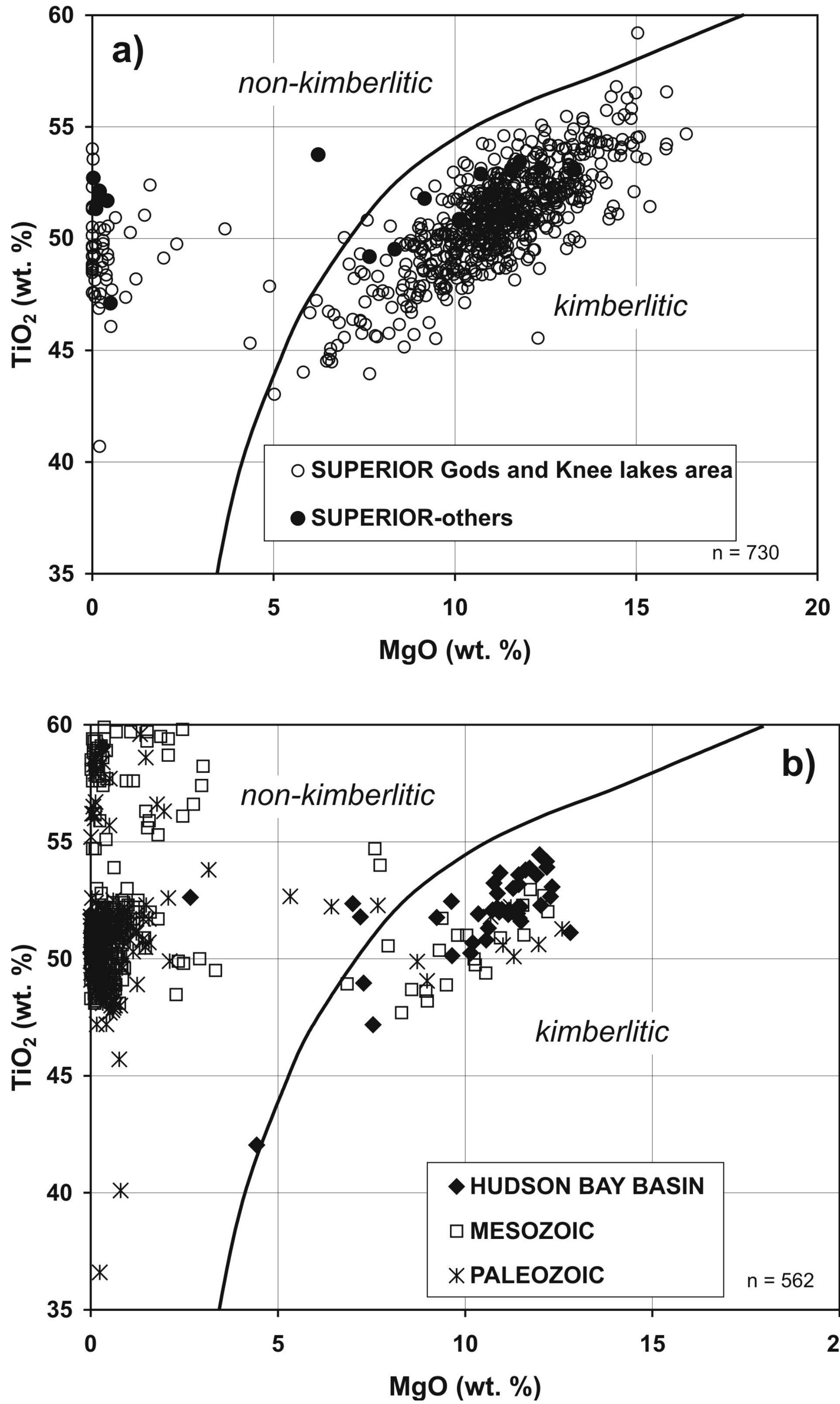


***Figure GS-30-2**: Classification diagram using MgO and TiO_2 to separate kimberlitic from non-kimberlitic ilmenite recovered from diamond exploration surveys in **a)** the Superior craton (n = 730; open symbols for Knee and Gods lakes area only) and **b)** the Phanerozoic basins (n = 562) in Manitoba. The black curve represents the bounding reference curve of the kimberlitic ilmenite field (*after *Wyatt et al., 2004).*

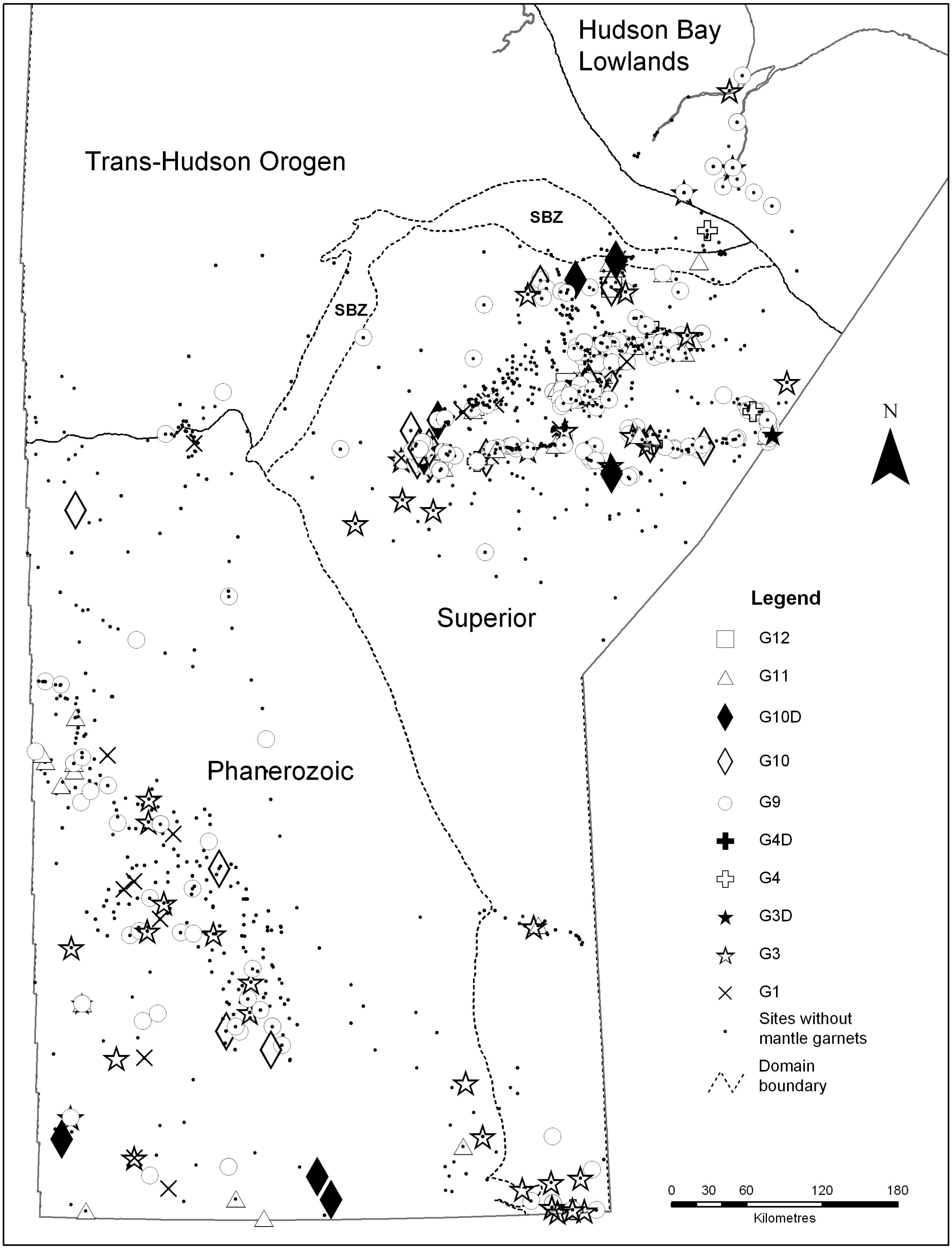


***Figure GS-30-3**: Mantle garnets from the Manitoba KIM database (classified after Grütter et al. [2004]) plotted on a map of Manitoba, showing the main geological domains.*

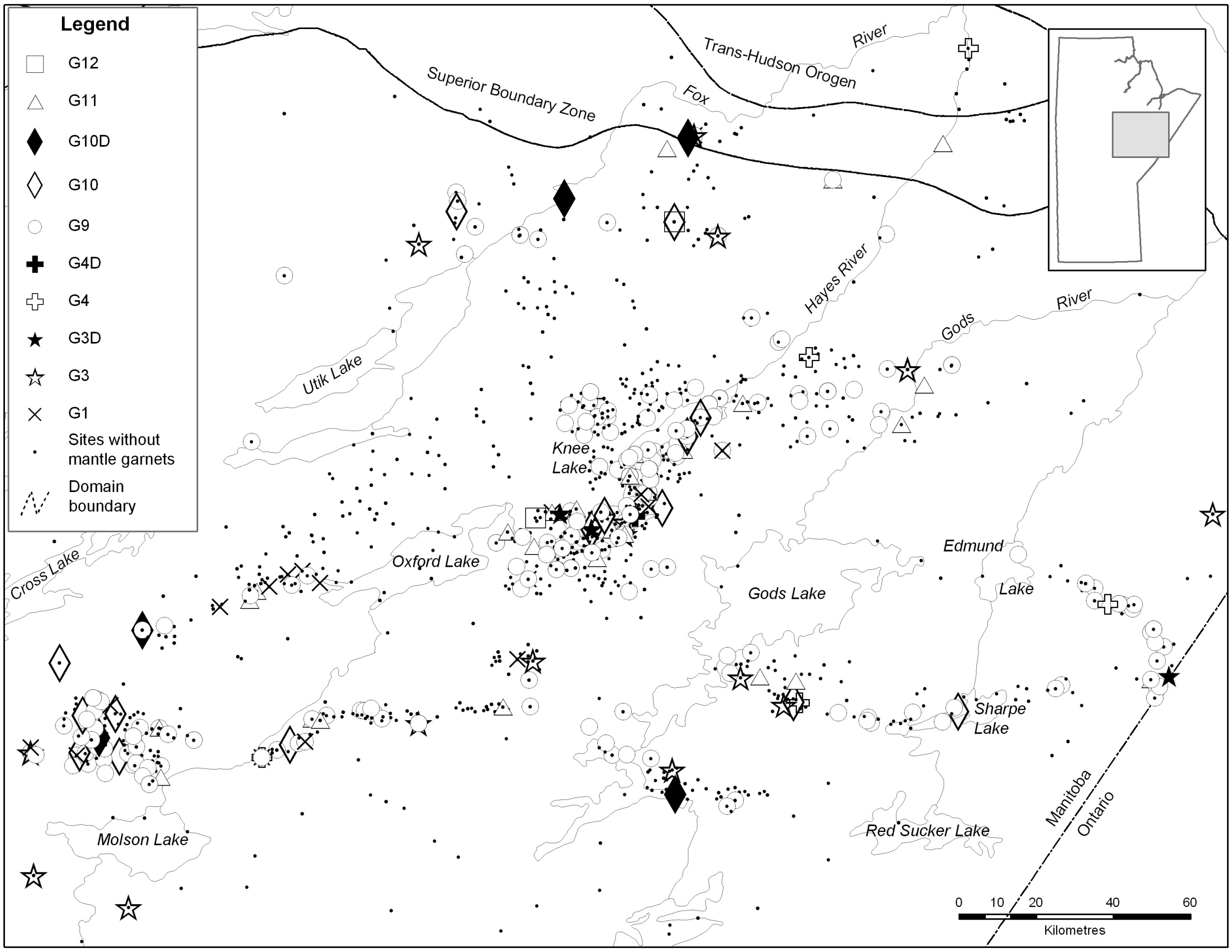


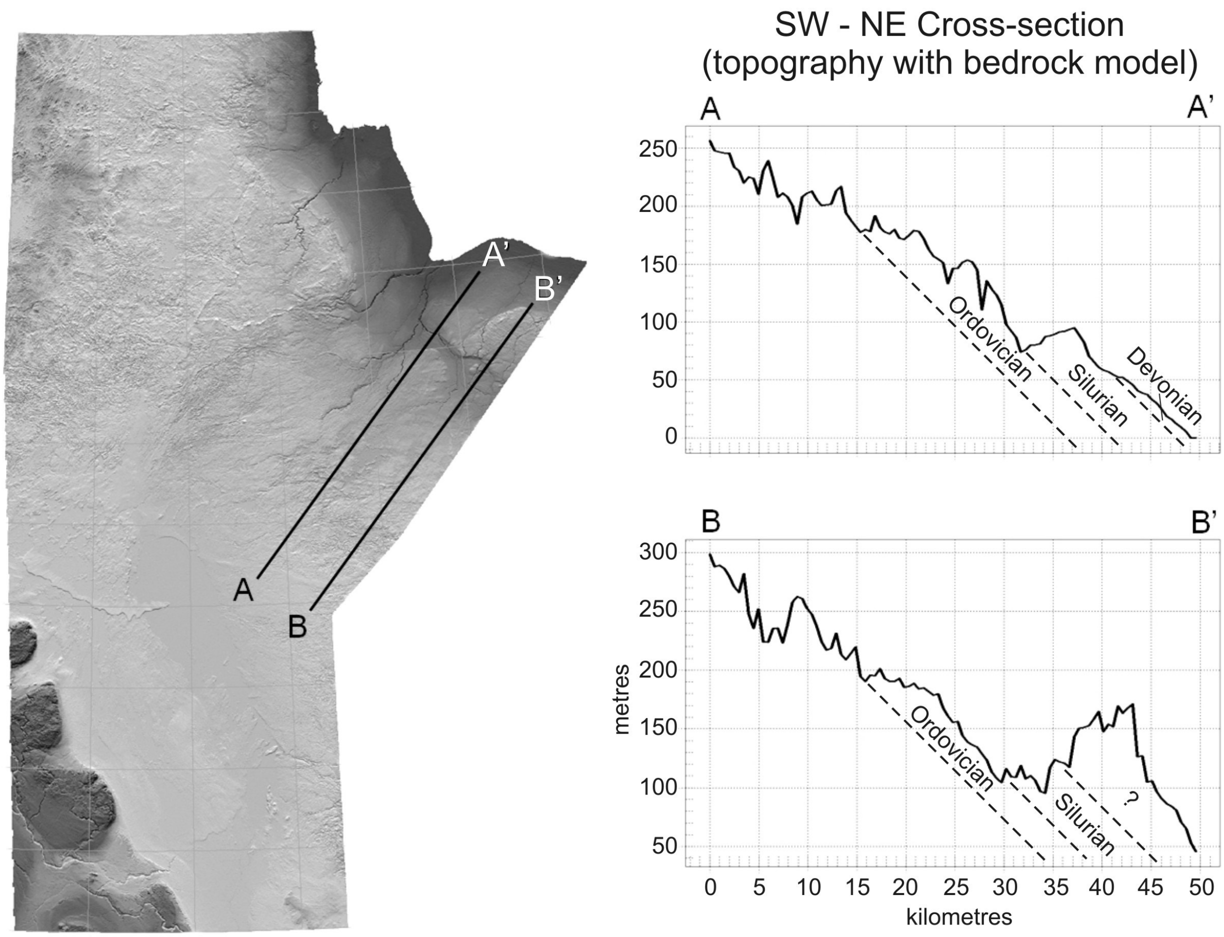
***Figure GS-30-4**: Mantle garnets from the Manitoba KIM database (classified after Grütter et al. [2004]) plotted on a map of the northern Superior craton of Manitoba.*

Composite till fabrics, from 23 HBL river sections for each till unit, are shown on Figure GS-30-6, with the exception of the Sundance till. Measurements of the striations on the rocks underlying the Sundance till are relied on for an indication of ice-flow direction. Striations indicate that the ice flow was towards the south-southeast during the deposition of the Sundance till. Fabrics in the Amery till are highly variable but suggest an initial ice-flow direction of southwest, followed by south-southeast. This is supported by pebble lithologies and striations measured from underlying rocks (Nielsen and Fedikow, 2002). In contrast, fabrics in the overlying Long Spruce till indicate that the ice-flow direction shifted from southeast to southwest. The ice-flow direction indicated in the Sky Pilot till is towards the southwest, which is supported by the orientation of surface drumlins.

The distribution of KIM in the HBL river sections is not uniform (Figure GS-30-6). As a result of till sampling along the lower Nelson, Hayes, Gods and Pennycutaway rivers by Nielsen in 2002, it was determined that the bulk of the KIM were in the Long Spruce till and, more precisely, the lower portion of the unit (Nielsen, 2002; Figure GS-30-7).

In plan view, the distribution of KIM suggests a significant concentration around the confluence of the Gods and Hayes rivers (Figure GS-30-8). This signal is most evident in those KIM that originated in the Long Spruce till, but nevertheless is also present in the KIM that originated in the Sky Pilot till.

The Sky Pilot till is best recognized in stratigraphic context in the sections along the deeply incised rivers of the HBL. On the Precambrian Shield terrain to the southwest (i.e., down-ice from the HBL) the Sky Pilot till becomes less carbonate rich and the characteristic drumlinized surface less common. Down-ice till sampling by Nielsen and Fedikow prior to 2002 became futile as the survey area moved towards the HBL and the drumlinized Sky Pilot became the dominant surface material. The drumlins were found to have anomalously low concentrations of KIM (Fedikow et al., 2002).



Source: United States Geological Survey, 2002.

***Figure GS-30-5**: Topographic sections (A-A' and B-B') from the Canadian Shield to Hudson Bay through portions of the Hudson Bay Lowland. The 'Kaskattama highlands' attain an anomalous elevation and are underlain by an unknown thickness of Quaternary sediments and Phanerozoic bedrock units (?) (*see *B-B').*

Integrated anomaly map

Kimberlite intrusions or fields worldwide are commonly associated with a set of geological associations or controls, including thick (typically old and cold) lithosphere; locations on cratonic margins; association with extension structures such as grabens, mafic dike swarms and crustal-scale faulting; and spatial association with alkaline intrusions, syenites and carbonatites. Based on known occurrences near Manitoba, the likely age of kimberlite intrusions in the province would be Jurassic to Cretaceous (e.g., Heaman et al., 2004).

Because portions of Manitoba are covered with a thick cover of Quaternary deposits, the identification of both kimberlites and associated features in Manitoba has proven difficult. To address this problem, the MGS has undertaken a program of compiling and synthesizing data that may help identify regions of the province with the potential to host kimberlites.

The 'integrated anomaly map', created from the compilation of diverse datasets in a GIS, is an attempt to identify structural and petrological anomalies that may have some bearing on kimberlite exploration (http://www.gov.mb.ca/itm/mrd/geo/gis/geoscimaps.html). The data types include geophysical maps, structural and lineament studies and the compilation of documented anomalous occurrences, such as carbonatite and syenite intrusions and structures that involve both the Precambrian and the overlying Phanerozoic rocks. The information layers included in this compilation were chosen to help identify associations between these features. Included are

- provincial-scale gravity data;
- aeromagnetic trends and breaklines;
- major faults;

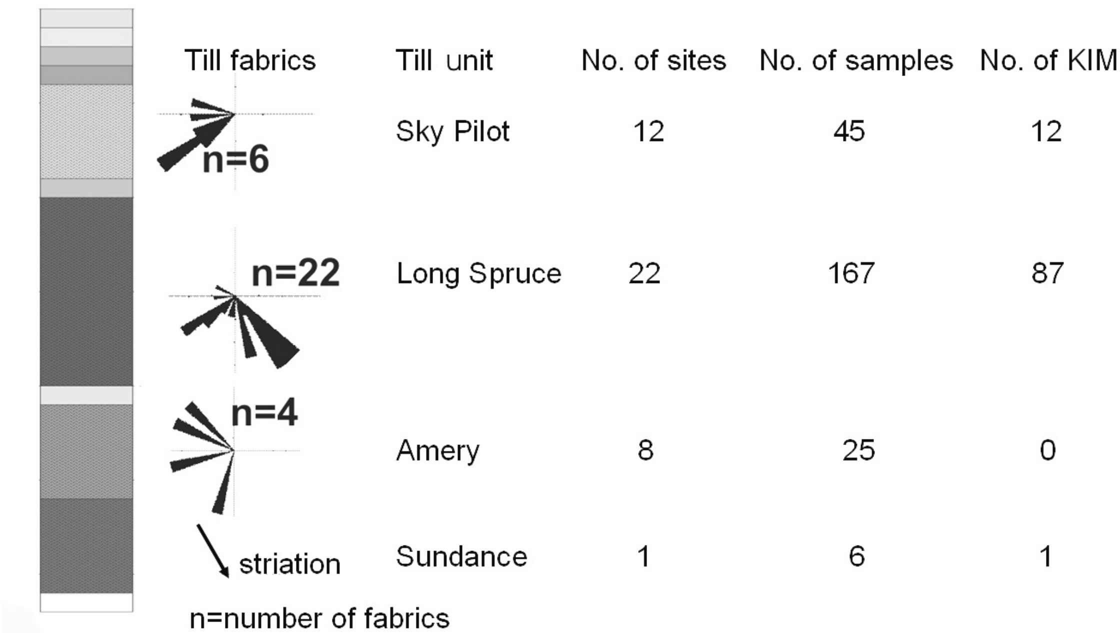


***Figure GS-30-6**: Composite stratigraphic column of 23 Hudson Bay Lowland river sections.*

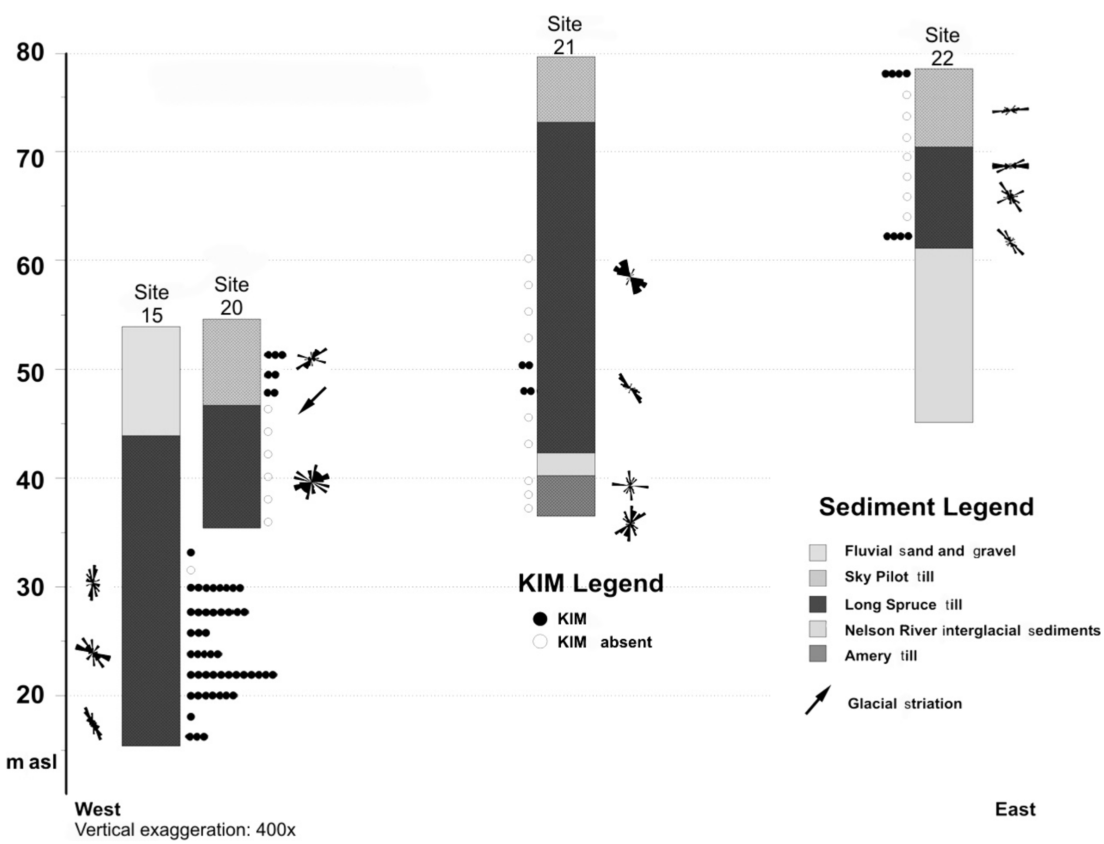


***Figure GS-30-7**: KIM distribution in a section profile along the Gods River (Transect A in Figure GS-30-8).*

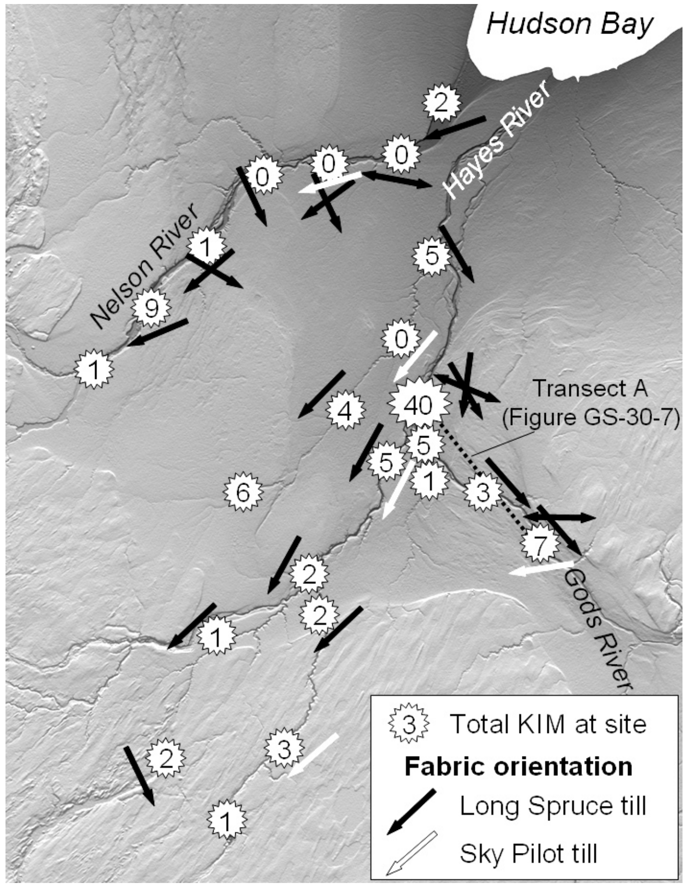


***Figure GS-30-8**: Plan view distribution of KIM in the vicinity of the confluence of the Gods and Hayes rivers.*

- surface lineaments;
- mafic dike swarms;
- point locations of a unique geological character such as the Wekusko kimberlite, Eden Lake carbonatite and Cinder Lake nepheline syenite; and
- results of KIM surveys.

Magnetic trend lines on the map were derived from careful examination of the total field data and represent three basic types: 1) breaklines that mark a transition from one type of magnetic pattern to a visually different pattern (terrane boundaries and major lithostratigraphic breaks); 2) narrow linear traces that can represent faults or mafic dikes; and 3) linear magnetic lows that cross all other features.

Surface lineaments were identified using a 90 m pixel digital elevation model (DEM). Elevation shadowgrams were produced with three different illumination directions to ensure that all possible lineaments were identified.

For both the magnetic linear and surface lineament studies, slope aspect analysis was used to help separate linear from curvilinear trends. It is assumed that long, straight, linear trends are likely related to young structures.

The locations of major faults and mafic dikes (Mackenzie and Molson swarms) were derived from existing geologic maps. The dike swarms were also extrapolated using aeromagnetic maps.

The process of identifying anomalous locations has only begun and a representative selection is included on the map. These locations include both unique rock occurrences (e.g., kimberlite, syenite, Cretaceous volcanism) and structural anomalies (e.g., faulting in the Paleozoic). The KIM distribution database can also be displayed on top of the anomaly map.

Development of this compilation map will continue with the addition of further datasets, such as updated geochronology information and additional geophysical and interpreted data, that may help delineate areas of crustal thickening.

Bedrock controls on potential kimberlite distribution

Manitoba possesses bedrock geology containing Precambrian elements similar to those of neighbouring jurisdictions (Saskatchewan and Ontario) that have proven and potentially economic kimberlite fields. Recent work has advanced a regional appraisal of kimberlite potential in Manitoba:

- The Archean granulitic rocks of the Nejanilini Domain form part of a stable cratonic crust that may have developed a deep lithospheric keel; moreover, the Nejanilini and adjacent crustal domains form the margin of the large Archean Rae-Hearne craton, making the study area a prime target for kimberlite exploration (e.g., Böhm et al., GS-19, this volume).
- The Archean Superior Province in Manitoba is internally complex and contains at its northwest margin a distinct terrane comprising ancient (>3.0 Ga) supracrustal and intrusive rocks (e.g., Bowerman et al., GS-14, this volume).
- The tectonic configuration along the Superior craton margin, where thick Archean lithosphere is bounded by major sutures against the Paleoproterozoic Trans-Hudson Orogen (e.g., Downey et al., GS-15, this volume; Kuiper et al., GS-18, this volume), is favourable for kimberlite emplacement.
- The Superior-Trans-Hudson boundary in Manitoba is a first-order crustal-scale feature that is implicated in anomalous features in the overlying Phanerozoic succession, suggesting post-Precambrian reactivation.
- The Paleoproterozoic Trans-Hudson Orogen is characterized by buried ca. 2.4 Ga 'Sask craton' at depth, suggesting that Archean lithosphere may be present beneath at least part of the Orogen.
- Late structures identified in the Precambrian are associated with documented alkaline intrusions and Phanerozoic deformation.

Economic considerations

The presence of a locally thick and complex till stratigraphy has proved to be a significant factor complicating effective diamond exploration in the province. However, recent work in the HBL has demonstrated that KIM are distributed in a non-random manner through the various till sheets documented in the region. KIM are most abundant in the lower part of the Long Spruce till, which was emplaced during a southeasterly ice advance. These data support an interpretation that the kimberlitic source rocks of these minerals occur on land to the northwest, and not to the northeast under the waters of Hudson Bay.

Compilation of existing data from a number of surveys and agencies into a single database has provided explorationists with a comprehensive view of public-sector survey results. The garnet and ilmenite compositional data have been levelled within a common classification scheme, providing for the first time a comprehensive view of the distribution of these key indicator minerals. These, combined with new information from the bedrock of the Superior craton, Superior Boundary Zone and Trans-Hudson Orogen, provide important additional constraints in the search for Manitoba's kimberlites.

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