Kimberlite indicator mineral and soil geochemical reconnaissance of the Canadian Prairie region

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INTRODUCTION

In 1988, kimberlite discoveries in central Saskatchewan were announced. The resulting private exploration was accompanied by the initiation of government surveys designed to provide systematic data that would permit industry to place its local, more detailed, surveys into the broader regional context. The survey summarized here was proposed in 1990 in order to map regional trends in indicator mineral frequency and chemistry, to demonstrate and compare various mineralogical and geochemical exploration methods, to map drift composition as an indicator of its transport history, to test for the presence of metallic mineral deposits, and to map regional soil geochemistry in order to aid both exploration and environmental applications. Work was initiated in 1991 under the 1990-1995 Canada-Saskatchewan Partnership Agreement on Mineral Development (PAMD). Subsequently in 1992, the survey was extended to southern Alberta under the 1992-1995 Canada-Alberta Agreement on Mineral Development, and across southern Manitoba as a co-operative effort with Manitoba Energy and Mines.

The survey was limited to areas underlain by Phanerozoic sedimentary rocks, between the Rocky Mountains and the Canadian Shield (Fig. 1). The area is underlain by Cretaceous and Tertiary shale, sandstone, and gravel west of the Manitoba Escarpment. East of this feature is subcrop of a Paleozoic carbonate sequence. Throughout most of the region, these pre-Quaternary deposits are deeply buried by glacial sediments, primarily multiple till sequences commonly exceeding 100 m in thickness. At surface, and to a lesser extent in the subsurface, other Quaternary deposits such as glaciolacustrine clay and glaciofluvial sand and gravel also occur.

Till was chosen as the indicator mineral sampling medium, rather than fluvial or glaciofluvial sediments, due to its simpler transport history, more uniform composition, and greater usefulness in the study of drift provenance. Soil geochemistry was mapped using A and C horizon samples collected on a random basis from all parent materials within the extent of contiguous farmland only. Soil sampling was extended 100 km south into the U.S.A. with the co-operation of the United States Geological Survey (USGS) to facilitate trans-border geochemical mapping.

In 1991, a test set of till and soil samples was collected at 40 to 50 km intervals along transects from both Edmonton and Calgary to Winnipeg. Processing of these samples led to refinement of laboratory procedures and indicated that well defined regional trends could be mapped by low density soil and till sampling (Garrett and Thorleifson, 1993).

SURVEY DESIGN

The project was initially designed as a low density soil geochemical reconnaissance meant to define broad regional trends in geochemical baselines. Similar surveys based on 100 x 100 km grids have been carried out by the USGS (Severson and Tidball, 1979; Severson and Wilson, 1990). Principles of low density survey design were discussed by Garrett (1983).

An 80 x 80 km grid was selected for the prairie survey, in conformance with IGCP 259 recommendations on low-density geochemical surveys (Darnley et al., 1995). These were subdivided into 40 x 40 km, 20 x 20 km and 10 x 10 km subcells and 1 x 1 km target cells were selected using a randomizing process for sampling (Garrett, 1994). This sampling design permits the spatial variability of the data to be quantified using Analysis of Variance. Rules specified procedures for selection of an alternative 1 x 1 km cell if the target could not be occupied. In each 80 x 80 km or 1600 km^2 cell, two sites were sampled for A horizon, C horizon, and till, if present at a nearby exposure such as a roadcut. Additional soil samples were selectively taken in order to characterize the spatial variability between more closely spaced samples.

FIELD AND LABORATORY METHODS

Sampling was completed in the summer and fall of 1992, by staff from the Alberta Research Council, the Saskatchewan Research Council (SRC), Manitoba Energy and Mines, and the GSC. At 734 sites, till samples were obtained at depths of 1 to 2 m below surface, in order to minimize the effects of surface weathering, from the area within farmland. An additional 82 till samples were collected along road traverses which extended to the Phanerozoic limit in Saskatchewan and Manitoba. At 1273 sites in Canada and the United States, A (averaging 3-18 cm below surface) and C (averaging 40-66 cm below surface) horizon soil samples were obtained. Details of the sampling procedures are described by Thorleifson and Garrett (1993). The field data provide information on the general sampling environment and observations on the colour, texture, moisture content, and composition of the soils and till.

Geochemical sample preparation and initial recovery of <2 mm heavy mineral concentrates from the 25 litre bulk till samples was completed at the SRC. To conform with agricultural and environmental protocols the <2 mm fraction of the soils were recovered, and the <63 μm fraction of the tills were recovered for geochemical studies. Heavy mineral separations were completed by Overburden Drilling Management Ltd. of Nepean, Ontario, using methylene iodide diluted with acetone to a specific gravity of 3.2. The concentrates were then returned to the SRC and were examined for potential indicator minerals under a stereoscopic microscope. The 0.5 to 2.0 mm non-ferromagnetic concentrates were picked without further processing. The 0.25 to 0.5 mm non-ferromagnetic fraction was sorted by magnetic susceptibility using a Frantz isodynamic separator into strongly, moderately, and weakly paramagnetic fractions. Selected grains were subsequently examined by the mineralogical staff of Consorminex Inc. of Gatineau, Quebec, and minerals such as staurolite and hornblende were removed prior to grain mounting and microprobe analysis. Full details of the procedures are presented in Thorleifson and Garrett (1993).

Electron microprobe data were used to classify the minerals. Garnets were classified using a simplified version of the Dawson and Stephens (1975, 1976) and Gurney (1984) classifications. Diopsides with >0.50% Cr_2O_3 (Deer et al., 1982; Fipke, 1989) were regarded as chrome-diopsides. Magnesian ilmenites in every case contained well in excess of 6% MgO. Cr-spinels exceeding 60% Cr_2O_3 and 12% MgO were regarded as compositions comparable to those reported for diamond inclusions (Gurney and Moore, 1993). Details of the classification were discussed by Thorleifson et al. (1994).

Subsequent to the initial microprobe analyses, a number of additional studies were undertaken. Eclogitic and near-eclogitic garnets were re-analyzed at reduced detection limits. These analyses were carried out to obtain acceptable sodium data, for diamond grade prediction (Gurney and Moore, 1993), and to enhance titanium data which were being used for definition of eclogitic garnets. The G7, G9, G10, and G11 pyropes and all Cr-spinels were analyzed by proton microprobe at the University of Guelph for Ni and several other elements in order to utilize classification methods developed by Griffin and Ryan (1993). Nickel temperatures were calculated for peridotitic garnets using the equation presented by Griffin et al. (1989).

The 8 to 16 mm fraction of till samples was classified with respect to lithology using a classification based on that of Shetsen (1984). Bulk mineralogy of the 63 to 250 μm-non-ferromagnetic heavy mineral fraction was determined on the basis of identification under a stereoscopic microscope of 300 grains in an araldite mount.

Following grinding of the <2 mm fraction of the soils to approximately <150 μm, duplicates and both internal GSC and international standards were inserted in the A and C horizon soil and till sample sequences. The three sequences were randomized and renumbered prior to analysis to destroy any relationship between analysis order and spatial context. All samples were submitted for a suite of trace element analyses using Instrumental Neutron Activation Analysis (INAA) and Atomic Absorption Spectrophotometry (AAS) procedures after a total acid decomposition. In addition, the till and C horizon soil samples were analyzed for major and minor elements by X-Ray Fluorescence (XRF), and carbonate determinations were performed on the tills by the Chittick procedure. Full details are provided in Thorleifson and Garrett (1993).

RESULTS

A total of 1253 kimberlite indicator minerals, 174 in the 0.5-2 mm fraction and 1079 in the 0.25 to 0.5 mm fraction, were reported by Garrett and Thorleifson (1993). The most abundant class consisted of 776 Cr-diopsides. A total of 206 Cr-pyropes (G7, G9, G10) including 12 G10 subcalcic Cr-pyropes, 136 titanian Cr-pyropes (G1, G2, G11), and 25 eclogitic garnets (titanian, calcic, magnesian almandines; G3, G4, G6) were initially identified. In excess of 76% of each of these mineral groups occurred in the finer 0.25 to 0.5 mm

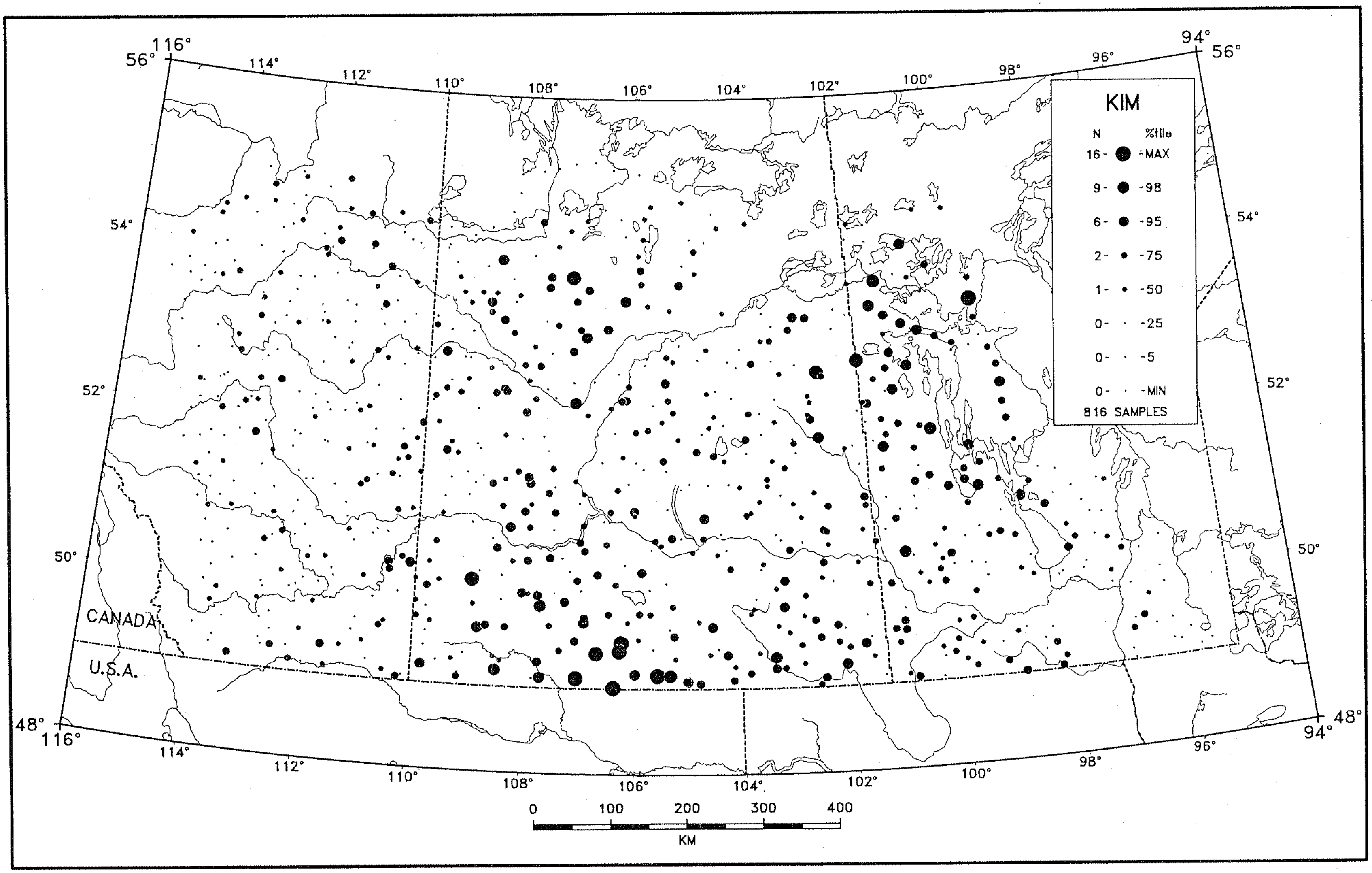

Figure 1. *Abundance of 0.25 to 2.0 mm kimberlite indicator minerals in 25 kg till samples.*

fraction. After the follow-up re-analysis, 76 garnets were re-classified as eclogitic using a lowered minimum TiO_2 value (>0.2%; Thorleifson et al., 1994). Magnesian ilmenite showed the greatest tendency to occur among the coarse grains, of a total of 110 Mg-ilmenites only 52% were obtained from the 0.25 to 0.5 mm fraction.

The indicator minerals are concentrated in southwestern Saskatchewan, west-central Manitoba, and central Saskatchewan (Fig. 1). Five of the G10 garnets, the best known predictor of diamond, were obtained in southern Manitoba. Additional occurrences of G10 garnets are scattered across southern Saskatchewan to the Alberta border. Indicator minerals in southwestern Saskatchewan show a spatial relationship to the outcrop of the Miocene Wood Mountain Formation. Therefore, the possibility of at least one stage of preglacial fluvial transport has to be considered in determining the ultimate provenance of these minerals.

After re-analysis of the 156 eclogitic and near-eclogitic garnet grains, 4 were found to contain marginally anomalous Na concentrations, >0.06% Na_2O. Three are from western Manitoba and adjacent Saskatchewan, and the remaining grain is from southwestern Saskatchewan.

The Ni determinations by proton microprobe on the kimberlitic garnets were used in a geothermometry study. Using the assumption of a 40 mW/m^2 geotherm (Griffin et al., 1989) and assuming acceptable calibration to other instruments, 13% of the garnets, mostly G11s, report temperatures above the diamond stability field (>1250 C°, >75 ppm Ni), 31% are in the diamond stability field (32-75 ppm Ni), and 56% are cooler (<950 C°, <32 ppm Ni). Of the grains in the Griffin diamond window (950-1250 C°, 32-75 ppm Ni), 80% contain <50 ppm Zr, a positive sign regarding diamond grade (Griffin and Ryan, 1993). These grains occur in Alberta, Saskatchewan, and Manitoba, with clusters around Diefenbaker Lake and Prince Albert.

Indicator minerals obtained from the till samples were transported by the continental ice sheet during the Pleistocene. Hence they were carried to the sampling sites by at least the final ice flow in the region. The dominant ice flow was towards the west and southwest, as indicated by drift composition in the region (e.g. Shetsen, 1984). This was overprinted in many areas by southeastward flow in late glacial time (Prest et al., 1968; Dyke and Prest, 1987). In most cases, the grains are likely to have undergone a complex transport history involving repeated glacial transport, and possibly interglacial and/or preglacial fluvial transport.

Useful evidence for interpreting glacial transport history was provided by lithological classification of the 8-16 mm fraction and the bulk mineralogy of the 63 to 250 μm non-ferromagnetic heavy mineral fraction. These patterns include abundant brown carbonate pebbles in southern Manitoba and southeastern Saskatchewan, a high concentration of shale clasts in southwestern Manitoba, the highest concentration of Precambrian Shield pebbles in Saskatchewan north of the Saskatchewan River, and Cordilleran-derived pebbles in the western half of southern Alberta. Heavy mineral counts indicate abundant garnet and hornblende in central Saskatchewan, as well as relatively more epidote and titanite near Winnipeg.

Geochemical data from till reveal broad-scale patterns that can be related to provenance. In addition, a number of elements exhibit single element patterns that, even though they are of low geochemical contrast, may be related to mineral occurrences.

The most notable feature in the data is a high carbonate, low As (Fig. 2), zone in the vicinity of southern Manitoba Paleozoic carbonate occurrences. However, of greater interest is the rapid dilution of the high carbonate till with Cretaceous shale material immediately to the west and southwest on the Manitoba Escarpment, and the persistence of an elevated carbonate pattern as far west as the Missouri Coteau, a northwest-trending escarpment lying west of Estevan-Regina-Saskatoon. In addition, the western carbonate domain of Shetsen (1984) is clearly visible in the data in the form of elevated carbonate values in the Calgary region. The majority of the data for the remaining elements show an inverse response, i.e., the carbonate terrain of eastern and central Manitoba are reflected by trace-element lows.

Tills down ice flow from Cretaceous shales of the Manitoba Escarpment are characterized by higher levels of Fe, Mn, V, Mo, As (Fig. 2), Sb and Zn, and to a lesser extent Cu and Ni, than the tills to the east or west. The Cd pattern is slightly different, whilst following the same general pattern, the highest values are concentrated in the northern tills in the Duck Mountain and Tisdale areas.

The line of the Missouri Coteau west of Estevan-Regina-Saskatoon appears to mark the boundary between tills of different regional geochemical compositions. The transition is most clearly seen in the data for Total Carbonate, Fe, V, As (Fig. 2), Rb, Ba and Br, and to a lesser extent with Pb, Zn and Cr. The Br data are of interest as the area east of this lineament is characterized by a zone of elevated levels.

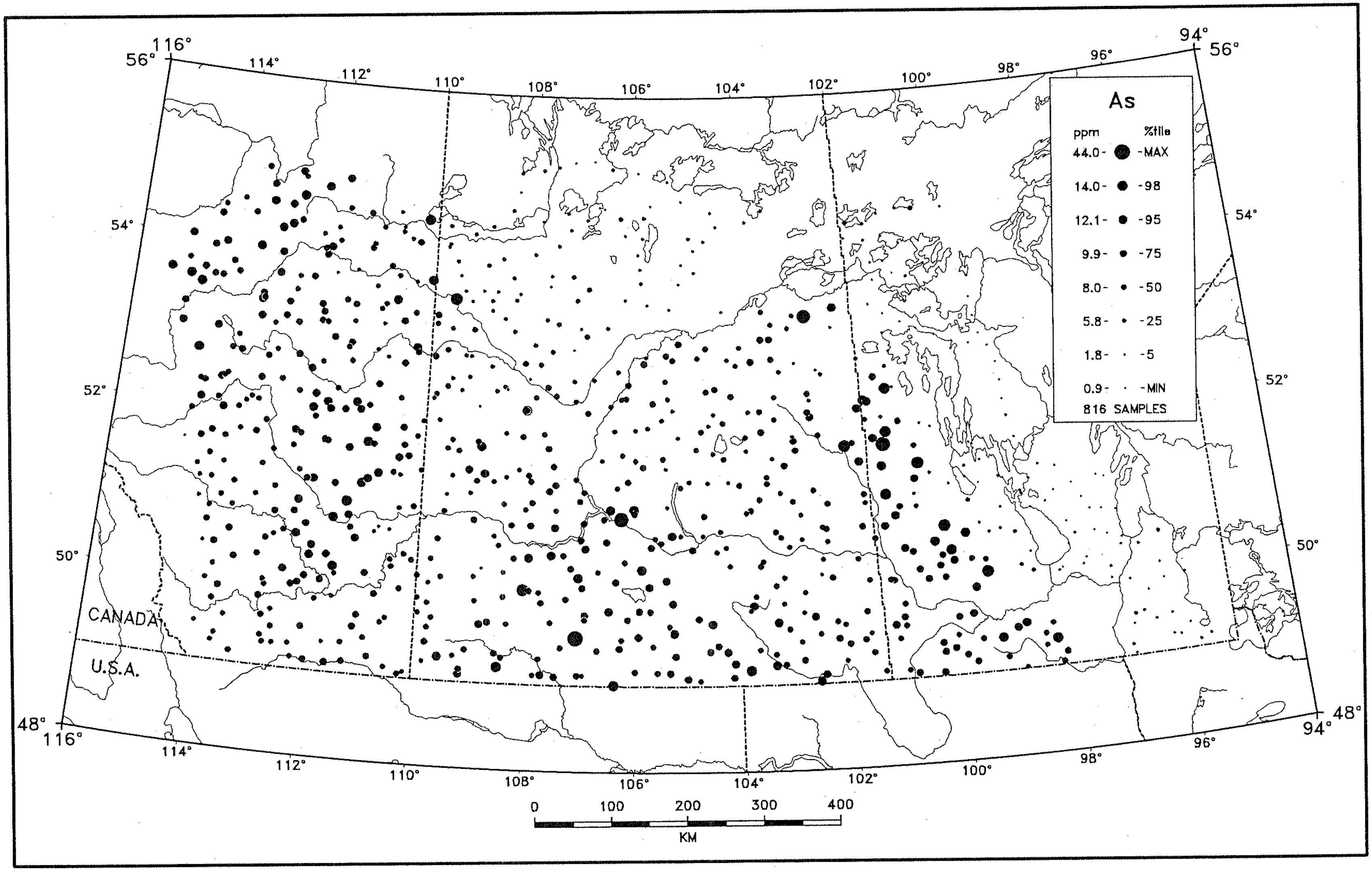

Figure 2. *As (ppm) in the < 63 μm fraction of till samples.*

Till north of the Saskatchewan River is characteristically low in a number of trace-elements in comparison with areas immediately to the south and/or west, e.g., V, Mo, U, Br, As (Fig. 2) and Zn. In contrast, Na and Th show the opposite, and are locally enriched; it is postulated that this may be due to the tills of the area containing a large proportion of Cretaceous Manville sediments or Precambrian Shield derived material. It is noteworthy that this area is also characterized by the highest amphibole contents in the heavy mineral separates.

A number of elements increase in level to the northwest in Alberta relative to the area to the south, e.g., Fe, V, Cu, Ni, Cr, Th, Sc, Rb and As (Fig. 2). This is likely a lithological control being exerted on the till composition. Shales are more widespread to the north and northwest, in comparison to the likely trace element poorer Tertiary sandstones and Foothills carbonates in the west.

The major task ahead is the interpretation of the chemical, mineralogical and lithological data for the tills. These data provide evidence for multiple ice advances from the northeast and east, and later advances from the north. There is also a suggestion that many of the surface tills east of the Missouri Coteau, except along the Manitoba Escarpment and in parts of the Interlakes region, have been transported long distances prior to deposition. In contrast, west of the Missouri Coteau, and particularly in the southern part of the survey area the surface tills may be of more local provenance.

The geochemical patterns in the C horizon soil data closely follow those observed for the tills. However, as soils were collected at all sites some patterns relate to the fluvial derivatives of the tills, e.g., coarser grained quartz-rich fluvial and eolian sands, etc., and clay-sized material of glaciolacustrine sediments. These two groups are characterized by generally lower trace-element levels in the coarser, quartz-rich, sediments and higher values for many elements in fine-grained parent materials. The A horizon samples have been influenced by pedological processes that have led to a modification of the C horizon patterns through concentration and depletion for different elements in different areas and soil regimes. These data are of particular interest to agricultural and environmental scientists, e.g., Cd (Garrett, 1994) and Hg (Garrett and Thorleifson, 1994).

CONCLUSIONS

The prairie-wide kimberlite mineral reconnaissance project has provided the first systematic data on the distribution of kimberlitic and lamproitic indicator minerals, and till and soil geochemistry in the region. These demonstrate:

1) That indicator minerals are widespread across the prairie region. Local concentrations in the Prince Albert area of north-central Saskatchewan and southwestern Saskatchewan were previously known. This project brought to light the abundance of favourable indicator minerals in north-central and southern Manitoba as well as several areas of southern Alberta.

2) The till matrix geochemical, 8 to 6 mm fraction lithological classification, and bulk 63 to 250 μm non-ferromagnetic heavy mineral fraction geochemical and mineralogical data vary systematically and can be related to the bedrock provenance of the tills. These data will assist in identifying glacial flow history for the surface tills sampled in this project, the most important factor in determining the bedrock source areas of the kimberlitic indicator minerals identified in the survey.

3) Soil geochemical data from the A horizon have proven useful to baseline studies for at least Cd and Hg, and will be of future use in a variety of environmental and agricultural investigations. Availability of C horizon data paired to samples of overlying A horizon permits regional mapping of apparent surface enrichment. Further work will quantify carbonate loss from hand-augured samples, but it is apparent that many patterns indicated by the till samples collected below 1 m depth are also revealed in C horizon samples more easily collected from depths of approximately 0.5 m, which would also be suitable for refractory heavy mineral separation.

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