SEDIMENTOLOGY AND GEOCHEMISTRY OF SELECTED GLACIAL SEDIMENTS FROM CENTRAL MINNESOTA AS A METHOD FOR CORRELATION AND PROVENANCE STUDIES OF GLACIAL STRATIGRAPHIC UNITS

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ANGELA SUZANNE GOWAN

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ABSTRACT

The results of this investigation indicate that studies of the glacial stratigraphy and provenance of tills in Minnesota would be best served by using the geochemistry of the silt and clay fractions as the primary tool, regardless of expected local stratigraphy. Additional useful methods, in order of importance, are: rock magnetic properties, sand grain lithology, and grain size analysis.

This conclusion was obtained through the use of graphical and multivariate statistical comparisons of grain size, matrix carbonate content, rock magnetic properties, sand grain lithology, and silt and clay fraction geochemistry data from six groups of Minnesota tills of diverse provenance (the northwestern New Ulm, Granite Falls, and Browerville tills, the northeastern Brainerd and Independence (and underlying) tills, and the historically controversial Hewitt till). Only the geochemistry data was able to distinguish between the six till groups, and provide provenance information as well, designating the Hewitt till as of definitely northeastern provenance.

Additional statistical analysis of the geochemistry of carbonate pebbles from the till samples was unable to distinguish between carbonates from the Hudson Bay Lowland and the Winnipeg area.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

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Much needed and appreciated moral support has been provided by my family of friends: Sarah, Chris, Amy, and Elizabeth. And finally, without my parents this project might never have happened. They taught me that I could do anything and be anyone, no matter how big or how small.

Sedimentology and Geochemistry of Selected Glacial Sediments from Central Minnesota as a Method for Correlation and Provenance Studies of Glacial Stratigraphic Units

A.S. Gowan
Department of Geology, University of Minnesota-Duluth

INTRODUCTION

Many previous distinctions of glacial drifts in northern Minnesota have been based on the presence or absence of limestone. Limestone bearing drift presumably came from the Winnipeg area, it being the closest source region of Paleozoic limestone. The non-limestone bearing drifts were associated with a north-northeastern provenance from the Canadian Shield.

Recent investigations indicate that, in fact, all of the northern Minnesota drifts contain at least some carbonate, and thus limestone content cannot reliably be used as an indicator of provenance. The northeastern drifts contain limestone presumably derived from the Hudson Bay/James Bay Lowland or Hudson Bay itself. Therefore, previous stratigraphic works (Martin, *et al.*, 1988, 1989; Buchheit, *et al.*, 1989), based on carbonate lithologies may be suspect.

In the last few years mineral exploration in Minnesota has been extended to include drift prospecting. This technique, which has been successfully employed in Canada and Finland (Shilts, 1976; Kujansuu, 1976; Alley and Slatt, 1976; Drake, 1983; DiLabio and Coker, 1987), strives to locate ore deposits that are buried under glacial drift by tracing anomalously high geochemical signatures in the drift up glacier to their sources. However, without an accurate idea of glacial provenance, the usefulness of this technique will be limited. Additionally, if the geochemical anomaly is incorrectly assigned to the wrong glacier, because of inaccurate glacial stratigraphy, efforts to locate deposits are fruitless. Successful mineral exploration by drift prospecting methods in Minnesota can only be achieved through continued studies of glacial provenance and stratigraphy.

Numerous techniques have traditionally been used to describe and correlate tills (Dreimanis, 1971; Fenton and Dreimanis, 1976; Karrow, 1976; Raukas, *et al.*, 1978). Common methods include color, texture, carbonate content, sand and/or pebble lithologies, and, in recent years, rock magnetic properties.

For this investigation, it was decided to employ all the common traditional methods listed above plus geochemistry of the silt and clay fraction. This was done to evaluate which method, or methods, are most effective in discriminating among the groups of tills and to determine if there is a signature common to tills of similar provenance.

To accomplish this, three types of samples were analyzed using the methods specified above. The first group of samples were the control groups, from areas of known till stratigraphy, that were used to classify those in the second group, obtained from a rotosonic drill core stored at the Minnesota Department of Natural Resources Core Library in Hibbing, Minnesota. The third group was comprised of carbonate pebbles obtained from both groups of samples described above and from surface tills near Hudson Bay and the Winnipeg Lowland.

DESCRIPTION OF STUDY AREA

This investigation has two scales of interest, and hence two study areas. The bigger picture includes the source areas and the final resting places of the tills of central Minnesota. This area includes southern Manitoba, western Ontario south of Hudson Bay, eastern North Dakota, and northern and central Minnesota. The second study area is to the north of Lake Mille Lacs (Figure 1). The glacial stratigraphy of this area is based on a description of a 63 meter rotosonic core, OB-402.

Regional Bedrock Geology

The vast majority of the larger study area is comprised of outcrop and subcrop of Precambrian rocks of the Superior Province of the Canadian Shield as shown in Figure 2. A much smaller portion of the area is occupied by the Paleozoic platform deposits of the Hudson Bay Lowland, in the northeast, and the Williston Basin, in the northwest, and miscellaneous Phanerozoic deposits scattered through Minnesota.

Precambrian

The Superior Province of the Canadian Shield is comprised of bands of Archean igneous and metamorphic units, that are successively older to the south, surrounded by younger Proterozoic units of varying origin (Figure 3). The Archean units, or subprovinces, are grouped into four distinct types of terranes: plutonic, volcano-plutonic, metasedimentary, and high-grade gneiss (Card and Ciesielski, 1986)(Figure 4). Plutonic terranes include the Winnipeg River and Berens complexes, which are characterized by tonalitic gneisses intruded by dioritic to granitic plutons and by a combination of dioritic to granodioritic gneisses, folded sodic, and nonfoliated potassic plutons, respectively (Hoffman, 1989). The Abitibi, Uchi-Sachigo, Wabigoon, and Wawa subprovinces are all examples of volcano-plutonic terranes. These are the granite-greenstone terranes that are dominated by metavolcanic supracrustal sequences that are bordered and intruded by felsic plutonic rocks that include tonalitic gneisses and foliated to massive quartz diorite, granite, and syenite (Card and Ciesielski, 1986). The two metasedimentary units of interest, the English River and Quetico subprovinces, are composed of deformed felsic- to mixed felsic/mafic-derived turbidites, respectively, that have been intruded by felsic plutons (Hoffman, 1989). The last type of terrane, the high-grade gneiss subprovinces, are

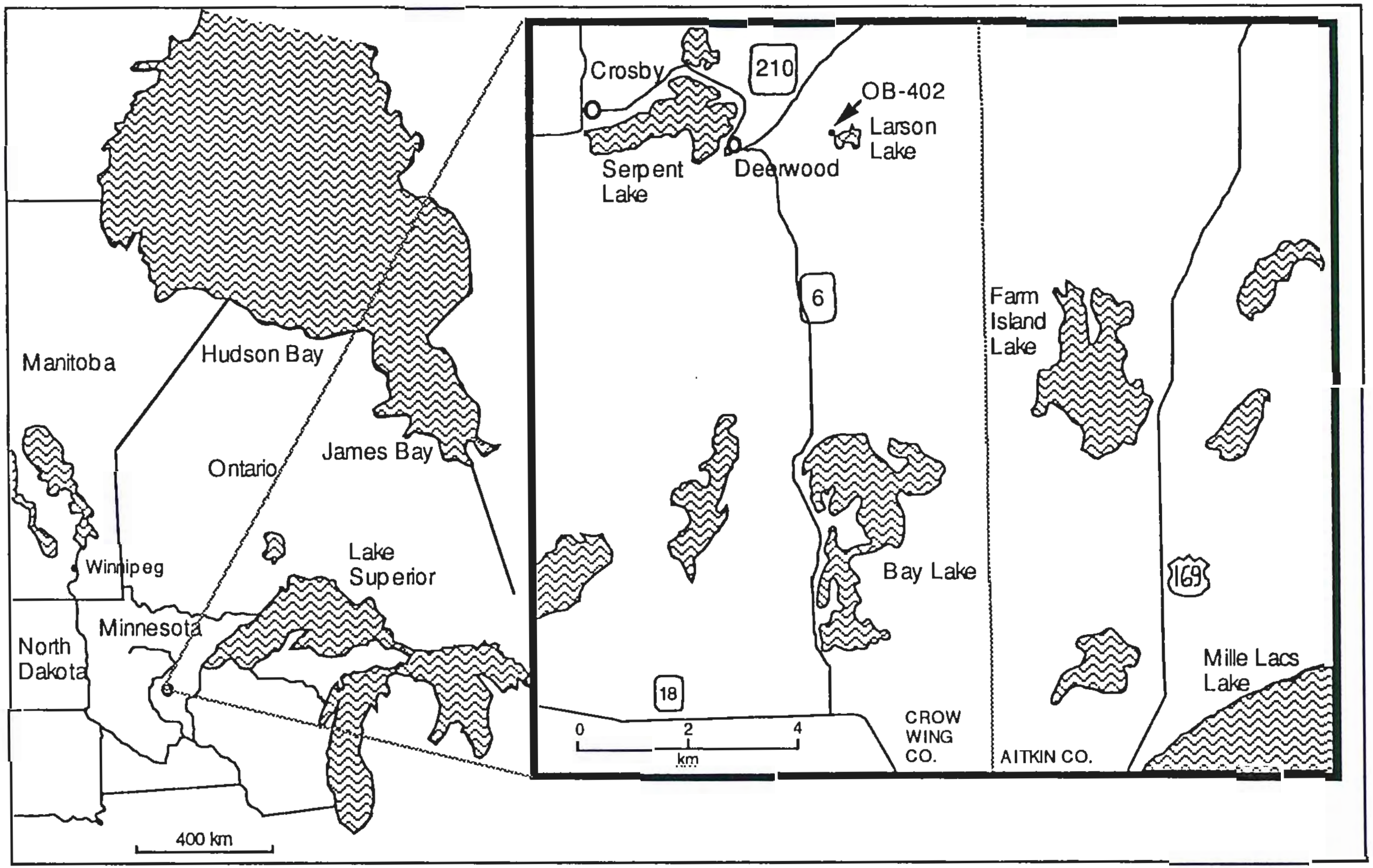

Figure 1. Location of study areas.

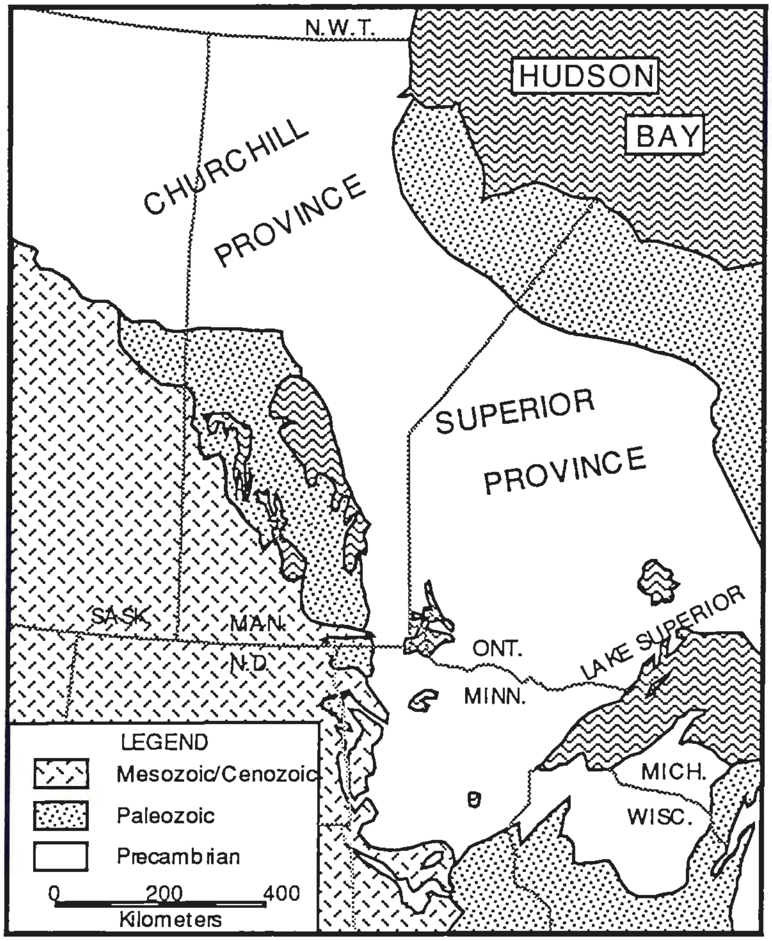

Figure 2. General bedrock geology of the study area (modified fromTeller and Bluemle, 1983).

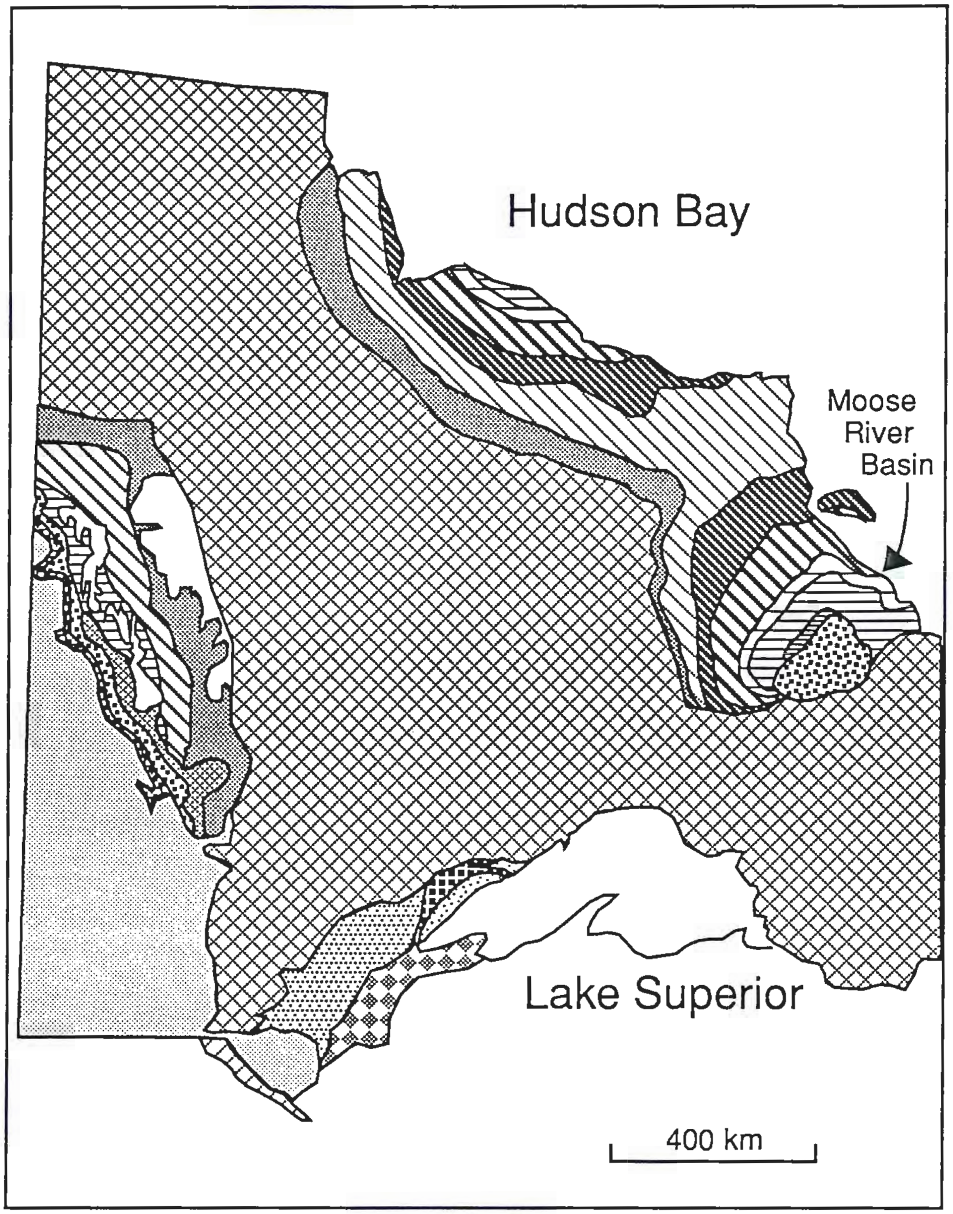

Figure 3. Regional bedrock geology (compiled from: Sanford, *et al.* (1967), McCabe (1971), Sims and Morey (1972), Bluemle, (1983), and Southwick, *et al.* (1988)).

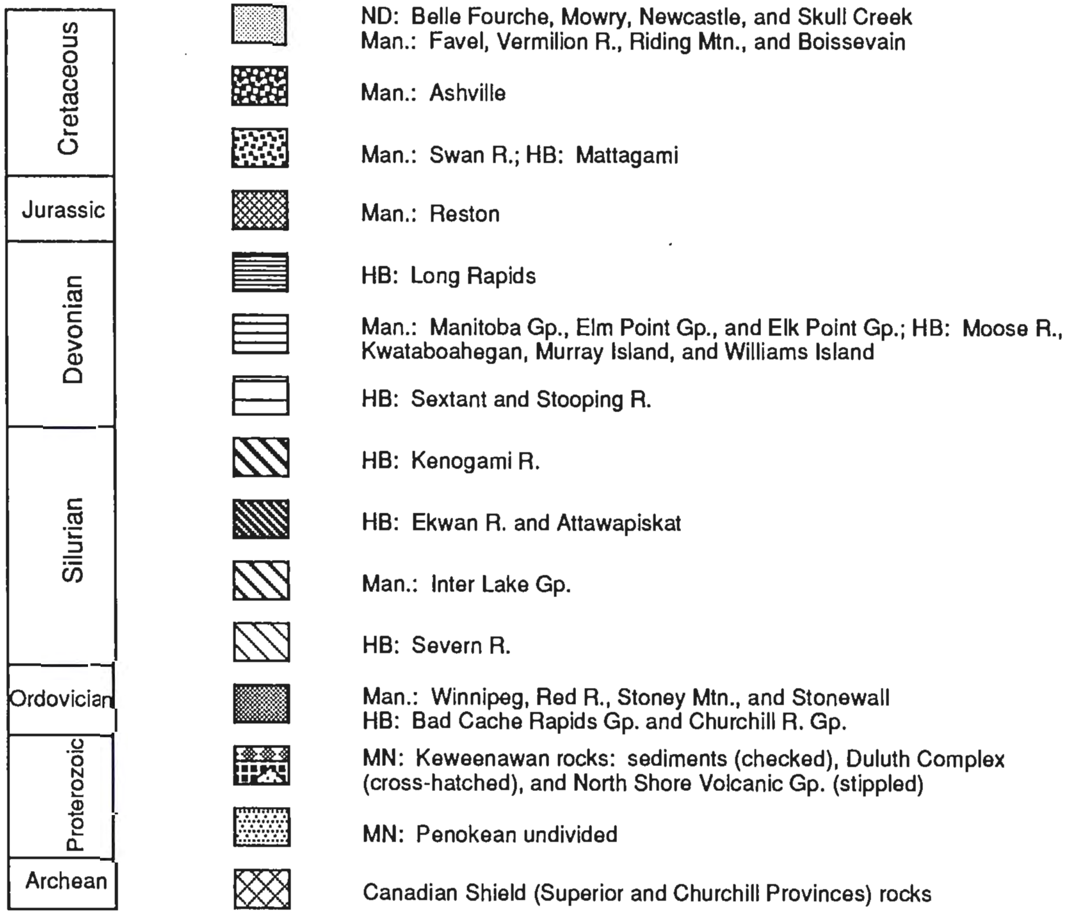

Figure 3 continued. All names refer to formations unless otherwise specified (HB=Hudson Bay, Man.=Manitoba, MN=Minnesota, ND=North Dakota).

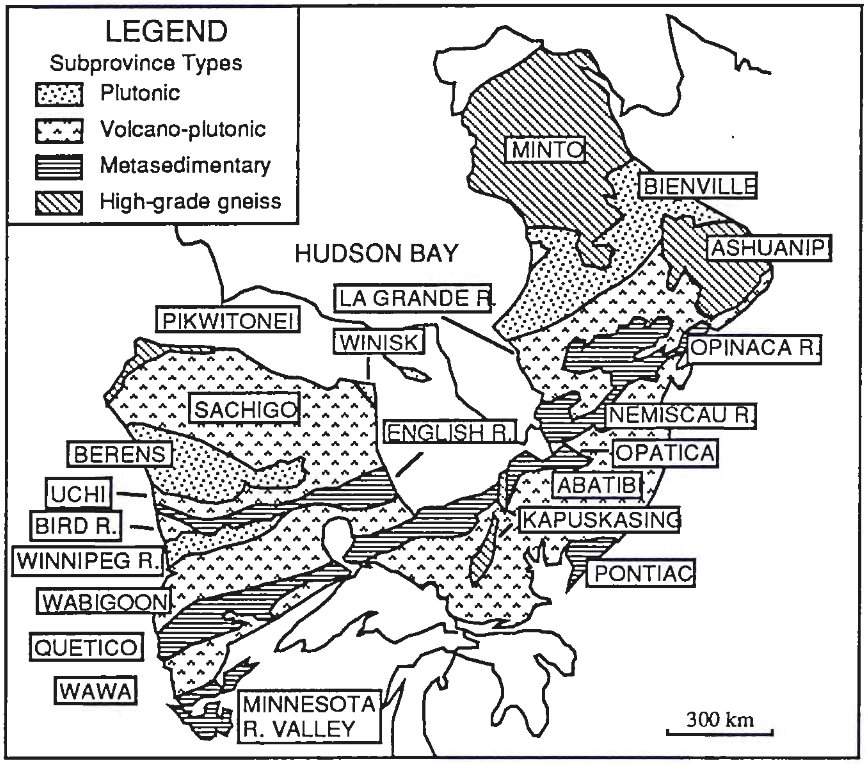

Figure 4. Archean geology of the Superior Province (modified from Card and Ciesielski, 1986).

typified by the Minnesota River Valley gneisses which are characteristically migmatitic gneisses and amphibolites; some of which are the oldest rocks in the Canadian Shield (Sims, 1991).

During the Early Proterozoic Penokean orogen the southern margin of what is now the Superior Province underwent an accretional event. In Minnesota the Penokean sequence is expressed by the Animikie basin, in the east central part of the state, and its subsidiary basins and fault panels shown in Figure 5. The bedrock within the basins is comprised of argillites, siltstones, and greywackes that have been metamorphosed at sub- to mid-greenschist facies levels. These include the Thompson, Trommald, and Virginia Formations. Along the northern margin of the Animikie basin is the Biwabik Iron Formation of the Mesabi range (Figure 5). The structural panels associated with the orogen contain folded and faulted rocks of various origins, including several iron formations, that become increasingly metamorphosed to the southeast (Southwick, *et al.*, 1988). At or near the end of this event, large masses of granite were intruded along the southern margin of the orogenic zone.

Shortly after the end of the Penokean event, the Midcontinent Rift system came into existence along the axis of what is now the Lake Superior basin and extending southward into Kansas. When the rift was active, lavas of dominantly basaltic composition, though intermediate and felsic chemistries are well represented (Figure 3), were extruded in subaerial environments, with the exception of some of the older flows which exhibit pillow structures (Green, 1972). Named the North Shore Volcanic Group, rock types range from olivine metabasalt to rhyolite, with olivine basalts and quartz tholeiites being most common (Sims and Morey, 1972). Flow tops are typically vesicular and/or amygdaloidal. Many of these amygdules were formed from periodic precipitation of iron-rich silica, providing the source of the Lake Superior agates.

Concurrent with the extrusion of the North Shore Volcanic Group was the intrusion of the Duluth Complex. Subsequent deformation and erosion has left the anorthosites, gabbros and granites of this body in the form of an arc (Figure 3). A wide range of plutonic rocks are found within the Duluth Complex, including troctolites, dunites and granophyre (Sims and Morey, 1972).

Phanerozoic

Southwestern Manitoba, eastern North Dakota and extreme northwestern Minnesota, adjacent to the Canadian Shield, are occupied by a wedge of Paleozoic and

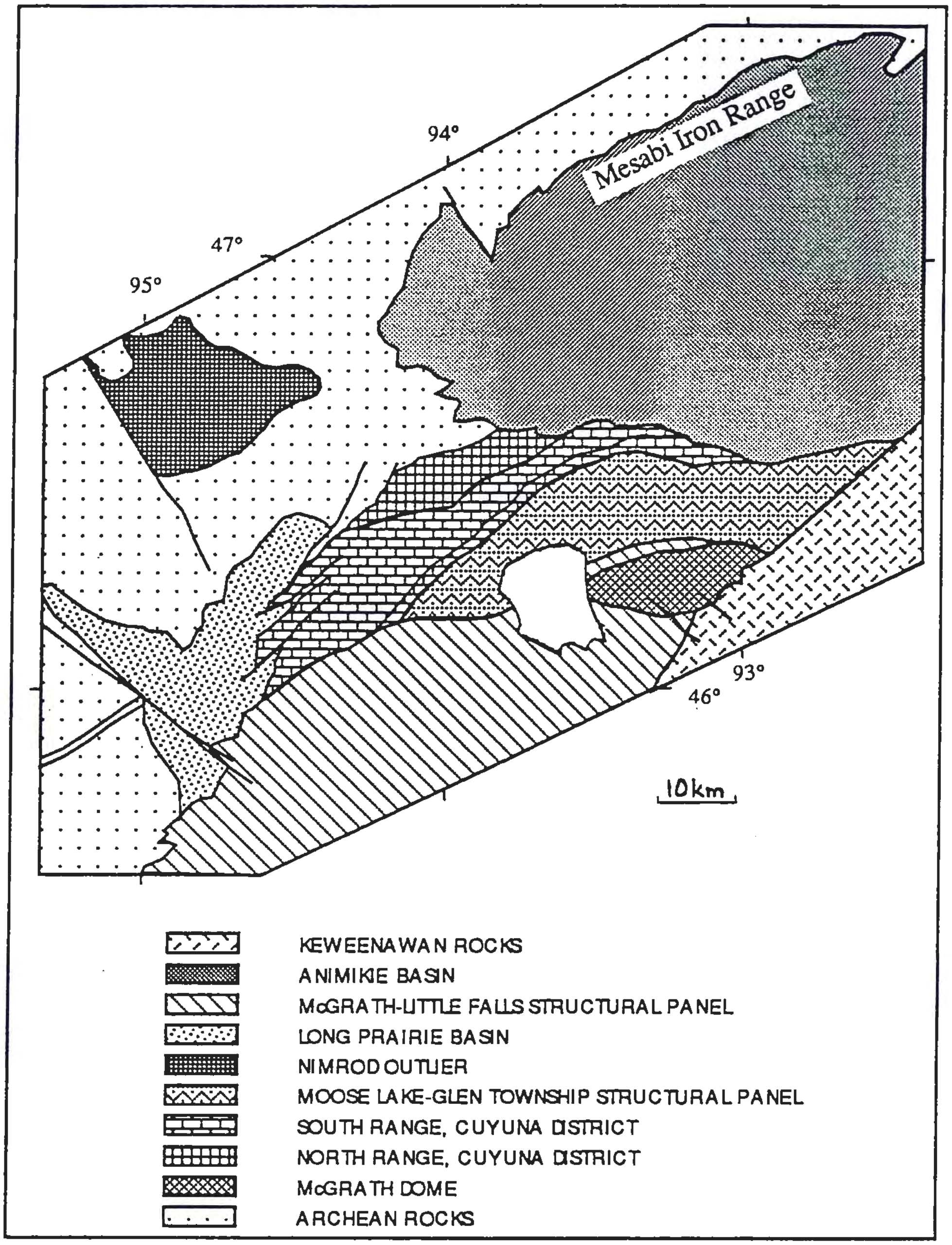

Figure 5. General geology of the Penokean orogeny in Minnesota (modified from Southwick, *et al.* (1988)).

Mesozoic sediments that form the northeastern flank of the Williston and Elk Point sedimentary basins (McCabe, 1971). In Manitoba, the Pennsylvanian through Triassic are the only periods not represented by sedimentary units (Figure 3). All formations except those from the later Devonian (Saskatchewan and Qu'Appelle Groups) and Mississippian outcrop somewhere in southwestern Manitoba. Of the remaining formations or groups, only 6 out of 24 have no calcareous units and 10 of the remaining 18 contain limestone and/or dolomite. Limestone is the main component of the Jurassic Reston Formation and the Devonian Manitoba Group and Elm Point Formation of the Elm Point Group. Dolomite is the main component of the Winnipegosis and Ashern Formations of the Devonian Elk Point Group, the Silurian Interlake Group, and all except the Winnipeg Formation in the Ordovician sequence. The Red River Valley in North Dakota and Minnesota is underlain by Cretaceous and very minor Jurassic units. These include the Belle Fourche, Mowry, Newcastle, and Skull Creek Formations, whose major components are grey shales and other marine sediments (Figure 3).

Across the Canadian Shield, the Hudson Bay Lowlands is the region to the south and west of Hudson Bay and James Bay that includes the Moose River Basin (Figure 3). This area is underlain by Phanerozoic rocks of Ordovician, Silurian, Devonian, and Cretaceous ages (Sanford, *et al.*, 1967). Ordovician rocks have been divided into the Bad Cache Rapids and Churchill River Groups and other undivided Ordovician units, all of which contain either limestone, dolomitic limestone, or dolomite. The Severn River, Ekwan River, Attawapiskat, and Kenogami River Formations represent the Silurian in this region. All four of these formations are made up of limestone and/or dolomite, with only the latter having a unit that is mostly non-calcareous. The Devonian is comprised of seven formations: the Stooping River, Sextant, Kwataboahegan, Moose River, Murray Island, Williams Island, and Long Rapids. The Sextant Formation contains no carbonate and the Long Rapids Formation contains only minor amounts. Brown or tan is a common color for the carbonates of this region.

Site of the Core

The small scale study area north of Lake Mille Lacs includes parts of the South Range, Cuyuna District and Moose Lake-Glen Township structural panels of the Penokean orogenic region in Minnesota, as shown in Figure 6 (Southwick, *et al.*, 1988). OB-402 itself is located in the South Range, Cuyuna District. The bedrock in this area consists of metasedimentary and metavolcanic rocks in the form of graphitic schist and slate, mafic to

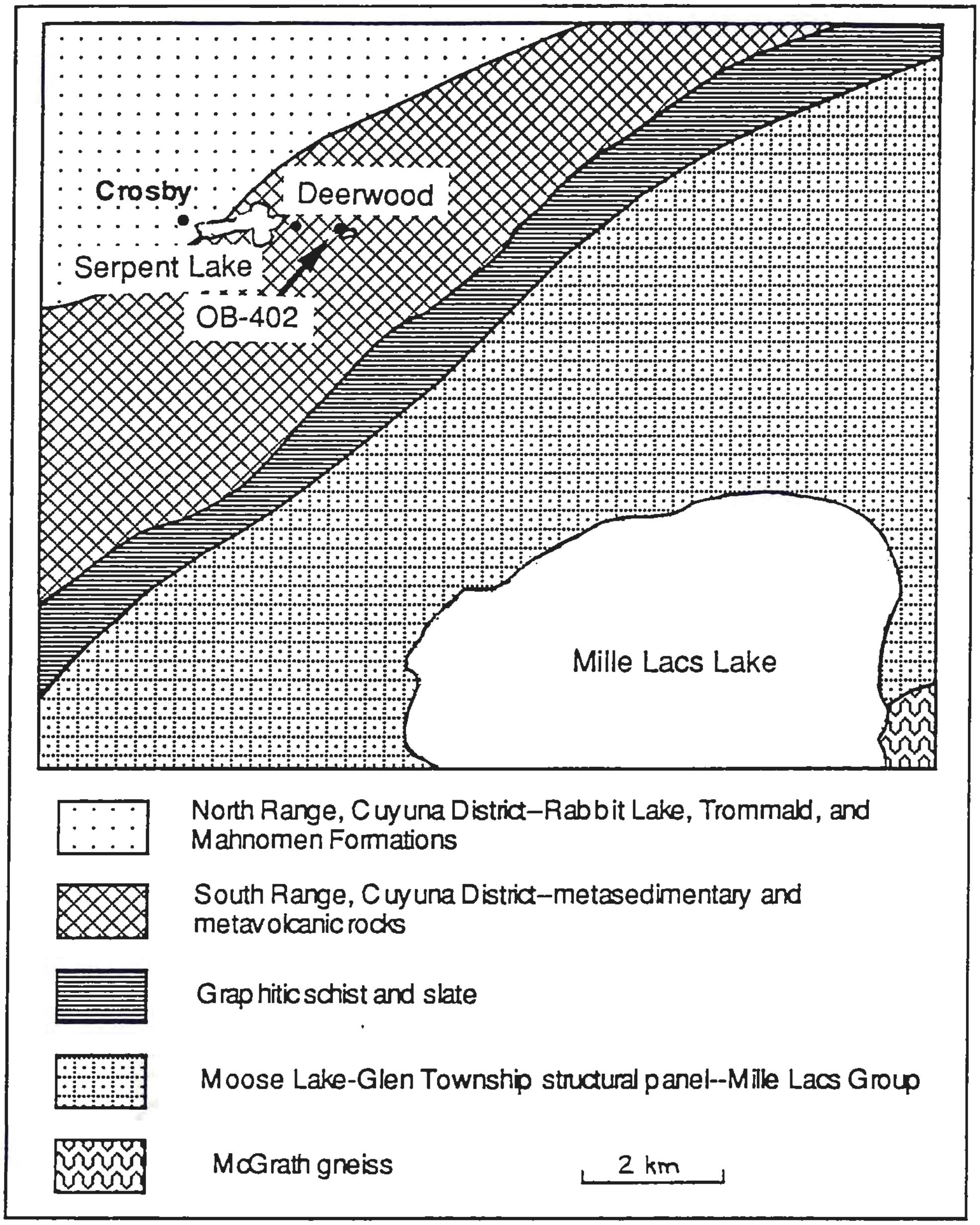

Figure 6. Local bedrock geology.

intermediate flows and volcaniclastics, and lean iron formation, in which the core was finished.

REGIONAL GLACIAL GEOLOGY

Previous Investigations

Source Regions

Prior to discussing studies on the glacial deposits of Minnesota, a brief mention will be made of the history of thought on the source regions for the various Laurentide glaciers that pertain to Minnesota, as summarized from Prest (1990).

The first recognition of more than one center of glacial ice was made by Dawson (1891). He named two separate glaciers: the Laurentide Glacier, which was the eastern center, and the Cordilleran Glacier, which was active in the west. Chamberlin (1894) produced a map showing three ice centers, one on the west side of the Rocky Mountains, one centered over the district of Keewatin to the northwest of Hudson Bay, and one centered in Labrador (Figure 7A). It was Tyrrell (1896, 1897, 1898) who finally named the Keewatin and Labradoran Glaciers. A fourth center of outflow was proposed by Tyrrell (1913) in the area west of James Bay, which he named the Patrician glacier (Figure 7B). The concept of ice dispersal centers is still under revision.

Glacial Deposits

A number of investigations have been made into the origin and classification of the drifts of Minnesota. Several of the most notable contributions to the knowledge of glacial geology in Minnesota are summarized below.

Winchell and Upham

The earliest comprehensive studies into the glacial geology of Minnesota were made by N.H. Winchell and Warren Upham, during the late 1800's (Winchell and Upham, 1884). Winchell (1884) in the Annual Report presented the surficial geology of each county in map form. In his general introduction, Winchell described the whole state as drift covered with the exception of the extreme southeastern and the extreme northeastern parts. He went on to say that the greater portion of till is blue or grey in color except for in the northeast and much of the east central where it is red or "has the color of non-hydrated iron-peroxide."

The blue till, which is described as occupying the western two-thirds of the state, is clayey, with the upper 5 - 50 feet oxidized to yellowish, and contains up to 50% limestone

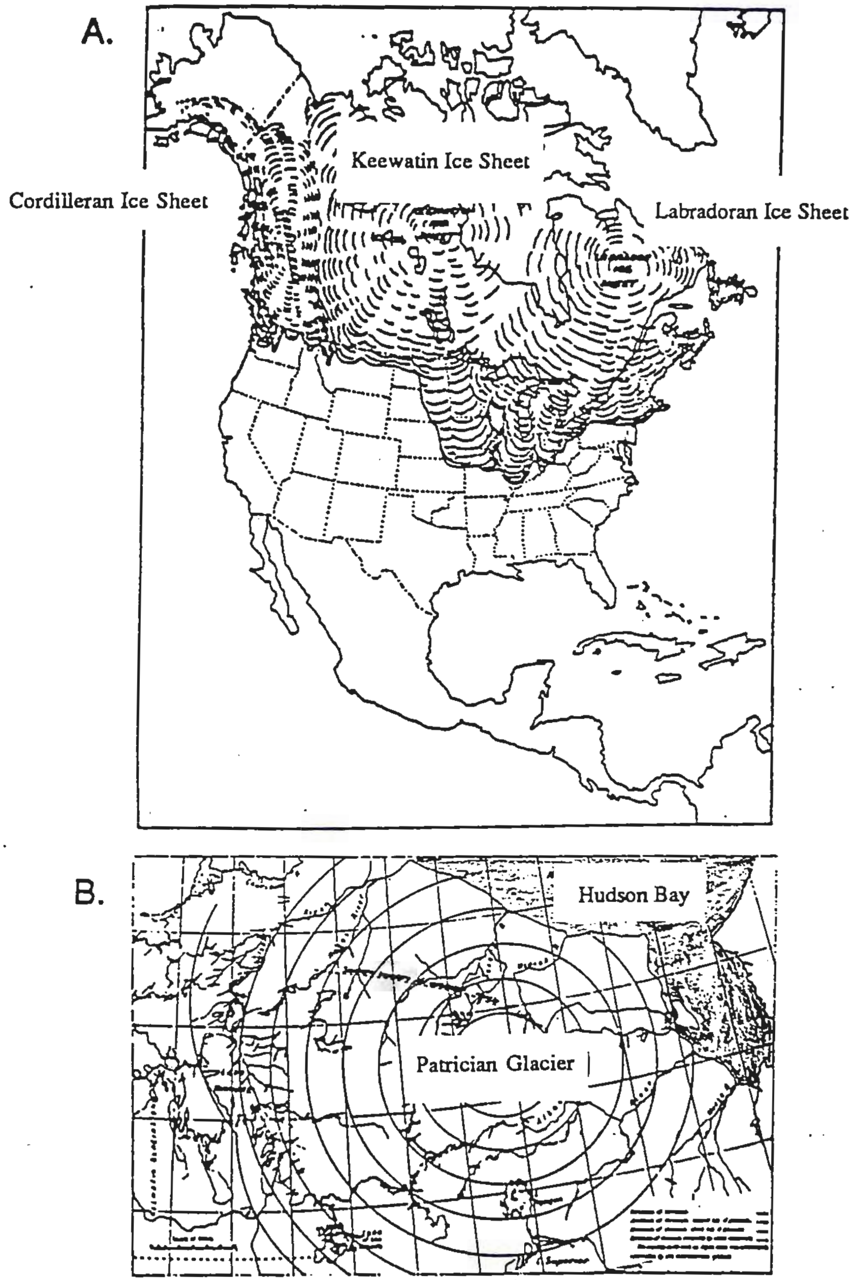

Figure 7. Ice center proposals: A. Cordilleran, Keewatin, and Labradoran (Chamberlin, 1894); B. Patrician (Tyrrell, 1913).

plus granite, syenite, schist, and quartzite. The limestone clasts were attributed to outcrops near Winnipeg based on glacier flow directions (Upham, in Winchell and Upham, 1884).

The northeast and east-central portions of the state are reportedly covered with the red drift, whose color was derived from the red sandstones, siltstones and volcanics near Lake Superior. Typical clasts include granite, gneiss, schist, gabbro, diabase, and, very rarely, limestone (Winchell, *et al.*, 1899).

Leverett

The next phase of investigations began in the early 1900's when Frank Leverett with the aid of F.W. Sardeson reconstructed the geologic history of Minnesota based on the surficial deposits (Leverett and Sardeson, 1932). In his discussion, Leverett described the "glacial gathering grounds" that supplied ice to Minnesota during the Wisconsin glaciation as: Keewatin, Labrador and Patricia. He also described each of the Pre-Wisconsinan (Nebraskan, Kansan, Illinoian and Iowan) drifts and their areal extents. However, during the Wisconsin only two drifts were specified: Wisconsinan red drift and Wisconsinan grey drift. Leverett's red drift had its origin in the district of Patricia. It is reddish in color, loose-textured, and contains clasts derived from the west end of Lake Superior (Leverett and Sardeson, 1932). The grey drift, which originated in the district of Keewatin, is yellow to grey, clayey, and its principal components are clasts of limestone and shale.

Wright

The most fundamental contributions to the glacial history of Minnesota have been made by Wright (Wright, 1962, 1972; Wright and Ruhe, 1965; Wright and Watts, 1969; Wright, *et al.*, 1970, 1973). In his studies, which have included both individual parts and the whole of Minnesota, the general framework for the glaciation of Minnesota was developed (Wright and Ruhe, 1965), and a variety of tills have been defined or summarized. The four major late Wisconsin glacial lobes were identified; two of northeastern provenance, the Rainy and Superior, and two of northwestern provenance, the Wadena and Des Moines. Figure 8 shows the sequence of events in the glaciation of Minnesota according to Wright (1972). All of the major surface tills have been considered in some way, including the Alborn, Barnum, Brainerd, Cromwell, Hewitt, and Independence, descriptions of which are given below.

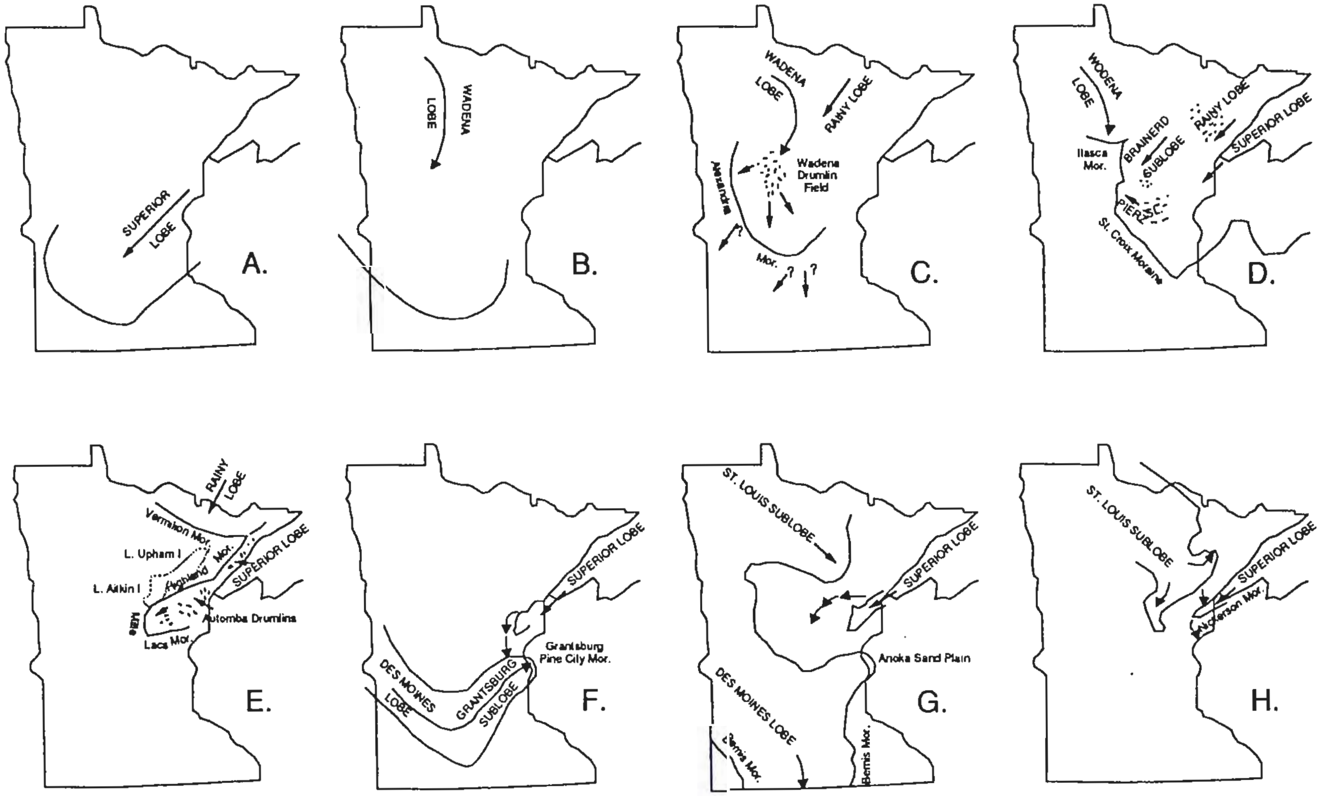

Figure 8. Sequence of glaciation in Minnesota according to Wright (1972). A, deposition of Hawk Creek till by Superior lobe; B, deposition of Granite Falls till by Wadena lobe; C, Hewitt phase of Wadena lobe; D, St. Croix phase of Superior, Rainy, and Wadena lobes; E, Automba phase of Superior and Rainy lobes; F, Split Rock-Pine City phase of Grantsburg sublobe and Superior lobe; G, Bemis phase of Des Moines lobe; H, Nickerson-Alborn phase of Superior lobe and St. Louis sublobe.

Others

Numerous individual studies have been made on portions of Minnesota. The central part of the state has been the focus of several notable studies (Schneider, 1961; Meyer, 1986; Mooers, 1988, 1989a, 1989b, 1990a, 1990b, 1990c; Goldstein, 1985, 1989). Schneider (1961) studied the Pleistocene geology of the Randall region. He described the Brainerd and Pierz tills, which he considered sedimentologically identical, along with the Superior and Wadena tills. All except the Wadena were interpreted as being of northeastern provenance.

Subsurface stratigraphy of the Todd County area of central Minnesota was described by Meyer (1986). In this study, numerous tills were identified. Major units include the Browerville, Pierz, and Wadena tills.

The Brainerd, Pierz, and Superior tills were the focus of a study by Mooers (1988) in his investigation of the Quaternary history of the Rainy and Superior lobes. Mooers (1990b) found the Pierz and Superior tills indistinguishable. Goldstein (1989) focused on the characteristics of the Wadena drumlin field, in which he described the subsurface Browerville and Hawk Creek tills.

The glacial history of the Mesabi-Vermilion Iron Range area was the focus of Winter's (1971) study. He used mine pit exposures to describe the glacial stratigraphy of the region, which is composed of three units. The first unit represents an advance placed as early or pre-Wisconsin and of northwestern provenance, because of the drift's calcareous nature. The second, a non-calcareous till, was deposited by an advance attributed to the Rainy lobe. The youngest drift, left by the St. Louis sublobe of the Des Moines lobe, is subdivided into two types. The western and north-central parts of the area were covered by a grey or brown, calcareous till, and the south-central portion was blanketed by a red to red-brownish, less calcareous till.

Matsch (1972) studied the Pleistocene stratigraphy of southwestern Minnesota. In this effort, three new tills were defined: the New Ulm and Granite Falls, of northwestern provenance, and Hawk Creek, of northeastern provenance.

Surface Deposits of Minnesota

This study is concerned with the physical characteristics of eight surface deposits in Minnesota. These drifts and their basic characteristics are presented in Table 1. Brief summaries are also given below from Schneider (unpublished).

Brainerd till

The Brainerd till (Schneider, 1956) was deposited in central Minnesota by the Rainy lobe during the late Wisconsin glaciation. Clasts include those derived from the Precambrian rocks of northeastern Minnesota, although red sandstones and siltstones from the Lake Superior basin are present because of contamination from underlying drift.

TABLE 1. 8 SURFACE TILLS OF MINNESOTA

TILL/LOBE	CARBONATE	COLOR	TEXTURE	LITHOLOGY	REFERENCE(S)
ALBORN / ST. LOUIS SUBLOBE	VARIABLE	5YR 4/4-2.5YR 4/3	SILTY-CLAYEY TO SILTY; SLIGHTLY STONEY	GRANITE, MINOR CARBONATE TO SHALE, CARBONATE, GRANITE	BAKER (1964)
BRAINERD / RAINY	NON-CALCAREOUS	7.5YR 4/4	3% GRANULES, 70% SAND, 18% SILT, 9% CLAY	PRECAMBRIAN ROCKS OF NE MINNESOTA (NOT RED SANDSTONES OR SILTSTONES)	SCHNEIDER (1956)
BROWERVILLE / ??	HIGHLY CALCAREOUS	10YR 5/1	CLAY LOAM	PALEOZOIC CARBONATES, NOT MUCH SHALE	MEYER (1986); GOLDSTEIN (1989)
GRANITE FALLS /WADENA??	HIGHLY CALCAREOUS	2.5Y 8/4-2.5Y 8/6	SANDY LOAM, LOAM TO CLAY LOAM	<=50% CARBONATE, 30% GRANITE, 0-5% K SHALE	MATSCH (1972)
HEWITT /WADENA	STRONGLY CALCAREOUS	10YR 5/4-10YR 5/6	SANDY LOAM	~40% CARBONATE, NO K SHALE	WRIGHT AND RUHE (1965)
INDEPENDENCE /RAINY	NON-CALCAREOUS	GREY-BROWN	STONY, SANDY	GABBRO SOME GRANITE, BASALT	WRIGHT, *ET AL.* (1970)
NEW ULM / DES MOINES	STRONGLY CALCAREOUS	2.5Y 7/4-2.5Y 5/4	LOAM TO CLAY LOAM	10-40% PALEO CARBONATE, HIGH % K SHALE AND GRANITE	MATSCH (1972)
CROMWELL FORMATION / SUPERIOR	LOW CARBONATE CONTENT	5YR 4/4-5YR 4/3	3% GRANULES, 6% SAND, 25% SILT, 11% CLAY	RED SANDSTONE AND SILTSTONE, BASALT, LAKE SUPERIOR AGATE	WRIGHT, *ET AL.* (1970)

Hewitt till

The Hewitt till was defined by Wright and Ruhe (1965), and it was the basis for the definition of the Hewitt phase of the Wadena lobe during late Wisconsin glaciation (Wright, 1972). Approximately 40% of the clasts are limestone and dolomite, with the rest being granite, basalt, gabbro, felsite, greywacke, greenstone, and quartzite. No Cretaceous shale is present.

New Ulm till

The New Ulm till was defined by Matsch (1972). It was deposited during the Bemis and subsequent phases of the Des Moines lobe during Late Wisconsinan glaciation. It typically has a high percentage of Cretaceous shale fragments, 10-40% Paleozoic carbonate pebbles, and granitic clasts as well.

Granite Falls till

The Granite Falls till is interpreted to be a pre-Late Wisconsin age Wadena lobe deposit (Matsch, 1972). It is composed of up to 50% carbonate clasts and 30% granitic clasts, with 0-5% Cretaceous shale fragments.

Browerville till

The Browerville till, as described by Meyer (1986) and Goldstein (1989), has abundant Paleozoic carbonate clasts and only a few percent Cretaceous shale fragments.

Independence till

Wright, et al. (1970) defined the Independence till as deposited by the Rainy Lobe during the Late Wisconsinan. It contains high percentages of gabbro, with lesser amounts of granite, basalt, felsite, slate, and greywacke. Red sandstones and carbonate clasts are rare.

Tills of the Superior lobe

There are at least three tills that have been attributed to the Superior lobe in Minnesota: the Hawk Creek till (Matsch, 1972), the Cromwell Formation (Wright, *et al.*, 1970), and the Barnum till (Baker, 1964). This study is concerned with that till left by the Superior lobe in the Lake Mille Lacs region: the Cromwell Formation. The till of this formation is characterized by its low but variable carbonate content and high proportions of red sandstone and siltstone and basalt, with attendant felsite, acidic intrusives, greywacke, and iron formation (Wright, *et al.*, 1970).

Alborn till

The till deposited by the St. Louis sublobe of the late Wisconsin Des Moines Lobe has been named the Alborn till (Baker, 1964). Baker originally attributed two tills to this glacier: a red-brown (5YR 4/4) when wet, silty-clayey, and slightly stoney till, whose average lithologies include 21% granitics, 2% carbonate, and 1% chert (the original Alborn till), and a slightly younger olive-brown (2.5YR 4/3), silty, and slightly stoney till possessing pebble lithologies typical of the Des Moines lobe: shale, carbonate, and granite (his Prairie Lake till). Subsequent authors (Wright, 1972, Wright, *et al.*, 1973, Matsch and Schneider, 1986) have lumped both groups together under the name Alborn till, with the disclaimer that it varies in color, texture, and lithology as stated previously.

Stratigraphy

Glacial stratigraphy in Minnesota is at best not very well known for the pre-Late Wisconsin drift, though there are a few exceptions. In almost every case the surface tills have been assigned to a time and glacial parent lobe, except perhaps the southeastern part of the state that was unglaciated during the Wisconsinan Stage. Subsurface glacial deposits tend to be very poorly defined as to source region and age. Investigators typically assign subsurface deposits to the Late Wisconsin glacier that is most appropriate as a parent lobe. Other authors define new lobes as the sources for these tills, for example the Winnipeg and Old Rainy lobes of Meyer (in Martin, *et al.*, 1989). Figure 9 shows the surface, and in some cases subsurface, deposits of the glacial lobes and sublobes of Wisconsinan stage in parts of Minnesota. Also included are typical stratigraphic columns for various areas, as defined by the authors mentioned above, and some others of interest.

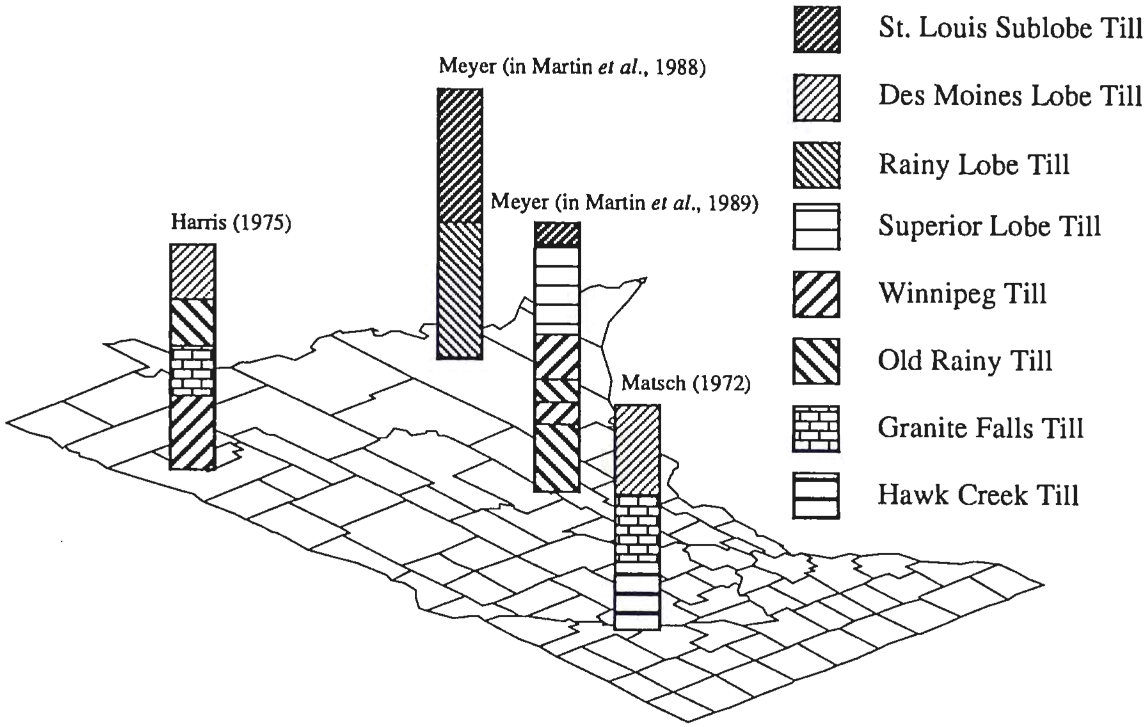

Figure 9. Generalized glacial stratigraphy of Minnesota. Units in columns are not to scale, nor are they an accurate protrayal of relative thicknesses in the area.

ANALYTICAL METHODS

Core Description

Core OB-402 was described visually using such methods as Munsell color notations of the wetted samples when viewed under fluorescent light, qualitative textural analysis by rubbing between fingers, and relative carbonate content, by way of degree of effervescence (none, low, medium, high) under the application of dilute HCl, also noted were distinctive clast lithologies.

Sample Collection

Seventy-seven till samples were collected from both the surface and subsurface at various locations around Minnesota, and from core OB-402 (Figure 10). Each sample was approximately one quart in volume. Surface samples, obtained from beneath the soil horizon using a shovel, were taken from areas where the occurrence of Brainerd, Browerville, Granite Falls, Hewitt, and New Ulm tills is uncontested in the literature. Subsurface samples of tills associated with the Rainy lobe were collected from a rotosonic core through one of the Toimi drumlins drilled by the Minnesota Geological Survey (core CDC-33). As three separate till units were sampled, including the surficial Independence till, an informal label of "Toimi" was given to this sample group.

Carbonate pebbles were obtained from the >1 mm size fraction from all the till samples in which they were present. Carbonate pebbles were also obtained from the archives of the Geological Survey of Canada. These samples were collected from till in and around the Hudson Bay Lowland and the Winnipeg area. Locations of the original till samples from which these pebbles came are also shown in Figure 10.

Basic Sample Preparation

Till samples were split into two unequal portions. A subsample of the smaller split was collected for grain size analysis. The 1-2 mm fraction was saved for determination of lithologic composition by point counts. The larger portion was run through standard sieves to obtain two size fractions: >1 mm and <62 µm. The >1 mm portion was visually inspected for carbonate pebbles. All carbonate pebbles were washed in a bath of dilute HCl to remove any contamination from the metal sieves. The silt and clay fraction (<62 µm) was utilized in several of the procedures described below.

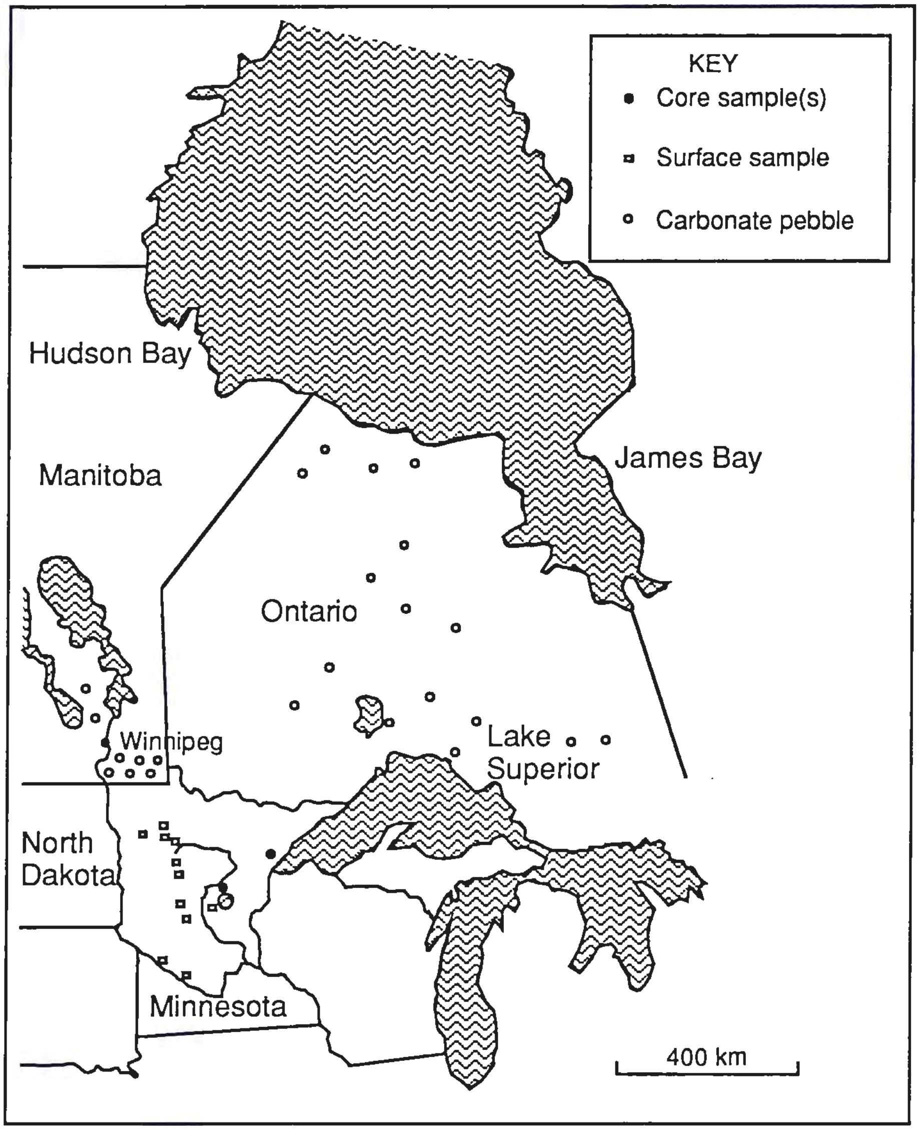

Figure 10. Sample Locations

Choice of analytical techniques

The following procedures were chosen for this study based on their widespread use by other investigators (Dreimanis, 1971; Raukas, *et al.*, 1978). Grain size analyses, in one form or another, are used in a large portion of the studies on till (Dreimanis and Vagners, 1971; Boulton, 1978; Gross and Moran, 1971; Karrow, 1976; Fenton and Dreimanis, 1976; Teller and Fenton, 1980).

Carbonate content of the till is of particular importance in Minnesota, especially when utilizing the traditional method of carbonate content as a provenance indicator. Numerous authors have used this parameter in their studies (Winter, 1971; Matsch, 1972; Leverett and Sardeson, 1932; Winchell, *et al.*, 1899; Chernicoff, 1980, 1983; Teller and Fenton, 1980; Wright, *et al.*, 1973; Goldstein, 1985; Norton, 1983). Two methods of determination were utilized, loss on ignition and carbon coulometry.

Rock magnetic properties are a fairly recent addition to the suite of methods used to describe tills. Low frequency magnetic susceptibility (χ) measurements have, in some instances, taken the place of heavy mineral studies as it is a measure of the ferromagnetic mineral content (Gravenor and Stupavsky, 1974; King, *et al*, 1982). Banerjee, *et al.* (1981) outlined the use of plots of anhysteretic remanent magnetization (ARM) versus χ to show changes in the grain size of magnetite in sediments. Small slope values for ARM/χ indicate the dominance of coarser grained magnetite in the sediment, as ARM is sensitive to fine grained magnetite and χ responds strongest to coarse grained magnetite. Several studies have used one or both of these magnetic properties in their characterizations (Gravenor and Stupavsky, 1974; Goldstein, 1989; Chernicoff, 1983; Mooers, 1988, 1990b).

Another technique commonly used to describe tills is clast lithology of the pebble or sand fraction. This information has been used for both classification and provenance purposes (Arneman and Wright, 1959; Gwyn and Dreimanis, 1979; Gross and Moran, 1971; Horberg and Potter, 1955; Teller and Fenton, 1980; Wright, *et al.*, 1973; Chernicoff, 1983; Goldstein, 1985, 1989; Mooers, 1988, 1990; Norton, 1983; to name but a few).

To further characterize the samples, elemental analyses of the silt and clay fraction of the tills were undertaken. The use of till geochemistry is not widespread in glacial geological studies largely because of cost, however, it was viewed as appropriate for inclusion in this study. May and Dreimanis (1973) used a four element suite in their study of southern Ontario.

Grain Size

Grain size analysis was carried out using a modified method after Folk (1974). Forty to sixty grams of sample were dispersed in a small amount of Calgon solution (2.55 g Calgon/liter water). The dispersed sample was washed with Calgon solution through a 1.4 mm sieve into a settling tube. Additional solution was added to total one liter and the >1.4 mm fraction was set aside to be recombined with the sand fraction later. The sediment in the settling tube was agitated and samples were withdrawn using a pipette at appropriate intervals based on solution temperature to obtain one phi increments of the silt and clay fraction. Remaining sediment was washed through a <62 mm sieve to remove the silt and clay, combined with the >1.4 mm fraction, and dried at 100° C. The dried sand was then sieved to obtain one phi intervals from -1 to 4 phi.

Loss On Ignition

A small portion (2-3 g) of the silt and clay fraction from each till was analyzed for total inorganic carbon (TIC) by Loss on Ignition (LOI) as described in Dean (1974). In this method, the sample is weighed four times: moist weight, dry weight (105° C), total organic carbon (550° C), and TIC carbon (1000° C). Between 550° and 1000° C, the carbonate minerals evolve CO_2. The percent carbonate for the sample is computed by conversion from the percent weight loss as CO_2.

Carbon Coulometry

Total carbonate content of the till matrix was also determined by carbon coulometry. About 10 g of the silt and clay fraction from each till sample were sent to the University of Minnesota Limnological Research Center Core Laboratory in Minneapolis for this analysis. In this procedure, the samples were treated with acid to release CO_2 from the carbonates. This carbon dioxide is then swept into the coulometer, with carbon dioxide-free air, where it is automatically titrated, and the weight of inorganic carbon is displayed. Percent total inorganic carbon is obtained from division by the original sample weight, from which percent carbonate is computed.

Rock Magnetic Properties

Rock magnetic measurements were performed on the silt and clay fraction of each till sample. Approximately 2.5 cc from each sample was tightly packed, to eliminate shifting by individual grains, into magnetically inert plastic cubes designed for this purpose.

Low frequency susceptibility (χ)

Low frequency magnetic susceptibility of the silt and clay fraction for each till sample was measured on a Bartington Dual Frequency Bridge at the University of Minnesota Limnological Research Center Core Laboratory in Minneapolis.

Anhysteretic remanent magnetization (ARM)

Anhysteretic remanent magnetization of the silt and clay fractions was measured at the University of Minnesota Institute for Rock Magnetism. An ARM was given to each sample by subjecting them to a peak alternating field of 99 millitesla (mT) with a biasing DC field of 50 mT. A superconducting magnetometer was then used to measure the imposed ARM for each sample.

Geochemistry

Approximately 10 g of the silt and clay fraction from each till sample and up to 10 g (depending on availability) of powdered carbonate pebbles, from till samples and from the carbonate pebbles obtained from the GSC, were sent out for a 34 element geochemical analysis by Inductively Coupled Plasma-Atomic Emission Spectroscopy (Lichte, *et al.*, 1987). Analyses were performed by Bondar-Clegg & Company, Ltd., Ottawa, Ontario.

Point counting

Lithologies of the 1-2 mm sand grains were determined from point counts of thin sections using a petrographic microscope. Thin sections of the sand grains were made from hardened epoxy blocks with the grains embedded in the bottom. Blocks were made by utilizing a rectangular seven-section pill container, available in drug stores, as molds. The plastic pill container allowed easy removal of the epoxy blocks and was reusable.

Thirteen lithologic categories were chosen to represent a wide range of rock types. The large number of categories was utilized in an attempt to determine if there were any minor lithologic component signatures that can be used to identify any of the tills. The thirteen categories are: granite, perthite, volcanic, basalt, gabbro, schist, greenstone, quartzite, chert, carbonate, sandstone, hematite, and opaques. Individual grains of quartz and orthoclase were assigned to the granite category, plagioclase was grouped with the gabbro, shale was grouped with sandstone, and gneiss was grouped with schist. The 1-2 mm fraction was chosen so that the majority of grains would be polymineralic (Dreimanis and Vagners, 1971).

STATISTICAL METHODS

Descriptive Statistics

Grain size data for the tills were run through descriptive statistical analyses to determine the mean grain size, expressed in ϕ units, standard deviation, skewness, and kurtosis for each sample. These calculated values then became variables that were added to the basic data set as shown in Appendix A.

Principal Components Analysis

Principal components analyses (PCA) were run, using SYSTAT 5.0 for the Macintosh, on combinations of variable groups from the basic data set (normalized to means of zero and standard deviations of one, shown in Appendix A) in order to determine which combination of information best differentiates between the groups of samples. PCA creates a number (not exceeding the number of input variables) of linear combinations of the input variables called components. These components, which are all orthogonal to each other in n-dimensional space, describe successively smaller amounts of the total variance in the samples (Davis, 1986). Each individual component can be described by its loadings of the input variables, which are simply the magnitudes of the variables in that component. The loadings (whose absolute values never exceed 1) describe the importance of each variable in the component. The absolute magnitude of the loading must be greater than 0.5 for its variable to be considered significant (Davis, 1986). Projections from the samples onto the various components, in the n-dimensional component space where n is the number of input variables, yield component scores that are utilized in biaxial plots to examine trends in the samples. As the goal of PCA is not to group samples, but to simply describe the variance among them, the clustering of like samples in discrete groups in a particular biaxial plot enables a description of the group based on the component loadings. Only those components with eigen values greater than one were initially considered (R.R. Regal, pers. comm.). Oblique Varimax rotation of the components was done to minimize inconsequential variance (noise) in the samples. Nine subsets of the data were analyzed using PCA as shown in Table 2. PCA of the carbonate pebble geochemistries was run on the data from Appendix C, normalized in the same way as described above.

Discriminant Function Analysis

Discriminant function analyses (DFA) were performed, using SYSTAT 5.0 for the Macintosh, on the same data sets as above. In discriminant analysis, group membership of the samples must be specified before the data are processed, as the goal is to compute a series of functions that describe the separation of the groups. These discriminant functions are linear combinations of the input variables that can later be used to predict group membership for unknown samples (Tabachnick and Fidell, 1983; Klovan and Billings, 1967; May and Dreimanis, 1973). As with the components in PCA, each subsequent discriminant function describes a smaller amount of separation in the n-dimensional variable space occupied by the sample groups, however, the number of discriminant functions obtained is now one less than the number of groups being analyzed. Discriminant analysis, like PCA, produces function scores for each sample that are the result of projecting from the sample onto the respective discriminant function.

TABLE 2. Principal Components Analyses

ANALYSIS	GRAIN SIZE	LOI	MAGNETICS	POINT COUNT	GEOCHEMISTRY	PEBBLES
1st RUN	X					
2nd RUN	X	X				
3rd RUN	X		X			
4th RUN	X	X	X			
5th RUN				X		
6th RUN	X	X	X	X		
7th RUN					X	
8th RUN	X	X	X	X	X	
9th RUN						X

Specified sample groups for input to the DFA were chosen according to known till types (Brainerd, Browerville, Granite Falls, Hewitt, New Ulm, and Toimi). Only those samples that were known to belong to one of these groups could be used to compute the discriminant functions. As a result, only seven of the combinations of data analyzed with

PCA could be run with DFA (Table 3) because of the limited number of sample knowns relative to variables. The DFA of the geochemistry data was done by using the component scores from the PCA. The DFA of the carbonate pebbles data was run using only two specified groups, northeastern and northwestern provenance. Once again only those samples of known provenance were used in computing the discriminant functions.

TABLE 3. Discriminant Function Analyses

ANALYSIS	GRAIN SIZE	LOI	MAGNETICS	POINT COUNT	GEOCHEMISTRY	PEBBLES
1st RUN	X					
2nd RUN	X	X				
3rd RUN	X		X			
4th RUN	X	X	X			
5th RUN				X		
6th RUN					X	
7th RUN						X

RESULTS AND DISCUSSION

Core OB-402 Description

A stratigraphic column representing core OB-402 is shown in Figure 11. Included are sample locations and designations. Further discussion of this column will occur later.

Till Samples

Appendix A contains a complete listing of results from each analysis for the till samples. Seven columns are derived from the one ϕ grain size percentage data. They are: %gravel, %sand, %silt, %clay, and the matrix compositions (%sand SSC, %silt SSC, and %clay SSC). This was done to enable rapid comparison with other grain size data formats. Average values for the basic grain size information, LOI, magnetics, and lithologic information for each till type are shown in Table 4 below. Five of the elements (Mo, Cd, Sn, Te, and W) from the geochemistry results were eliminated from the original data set before input to the multivariate statistics because a majority of their values were below detectable limits.

The ternary plot of the grain size of the matrix for the samples (Figure 12A) shows clustering of the data points for groups of till samples, however, many of the groups overlap, especially the Hewitt and Brainerd tills. The small number of sample points makes it difficult to state with any degree of confidence where the complete fields for these groups might lie. It also precludes serious use of this plot to classify unknown samples for the same reason. Because of this difficulty, a larger number of data points is plotted in Figure 12B using data from previous investigations (Mooers, 1988; Matsch, unpub.). The greater number of points in this graph, however, show the same clustering and overlapping of groups seen in the previous plot, even though the groups are better defined. It would still be difficult to predict group membership of unknowns using this technique alone.

Average till lithological compositions in the 1-2 mm fraction (Figure 13) appear to be much better at discrimination than the grain size information. The Toimi samples (Figure 13F) are distinctly different than the other tills, with their high percentages of sandstone, volcanics, and mafic igneous rock types. The Brainerd and Hewitt tills (Figures 13A and B) differ mainly in the amount of carbonate present; remove the carbonate from the Hewitt till and it is indistinguishable from the Brainerd (Mooers, 1988). The remaining three tills, the Browerville, Granite Falls, and New Ulm (Figures 13C, D,

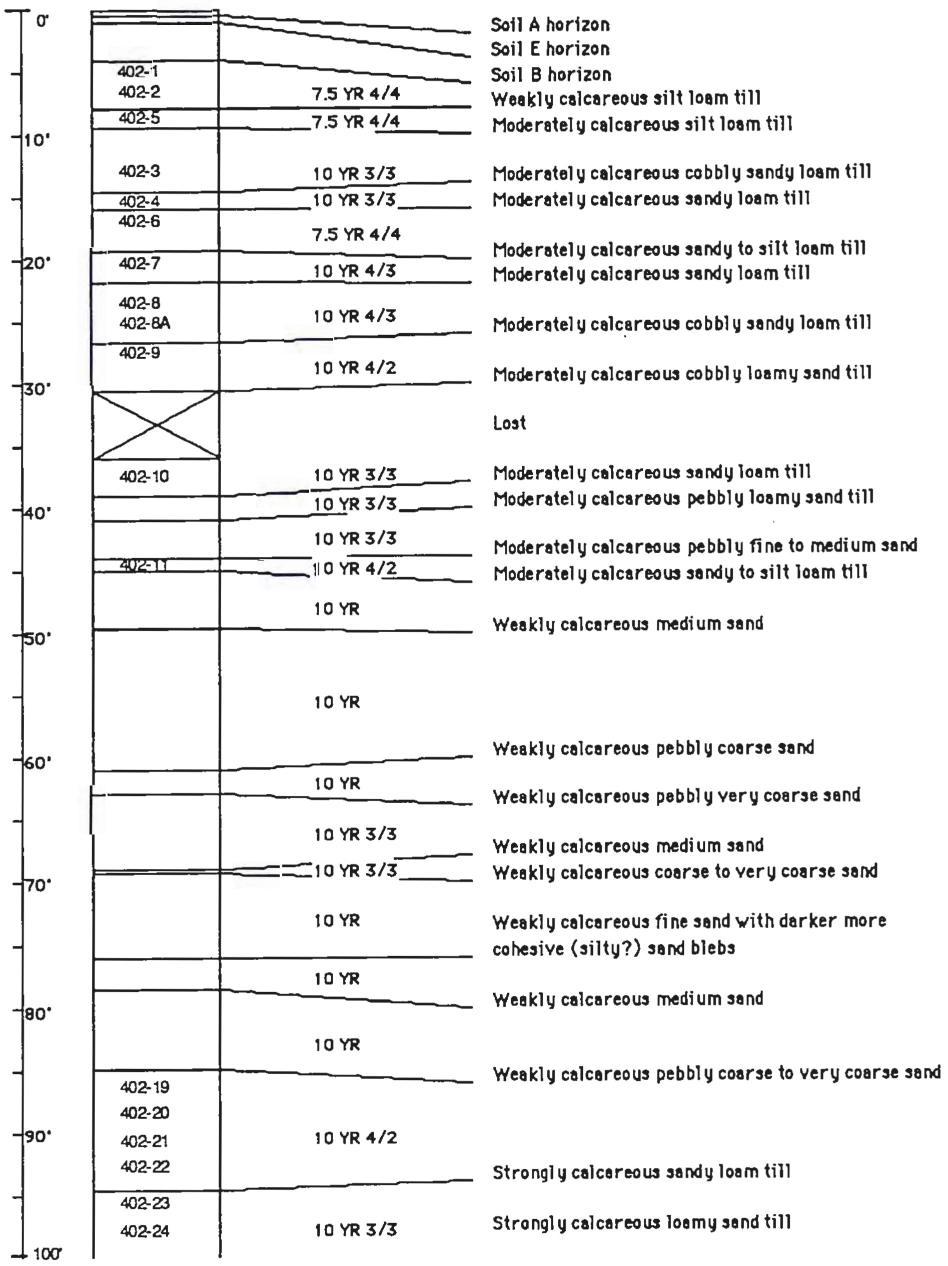

Figure 11. Visual description of core OB-402 with sample locations labeled.

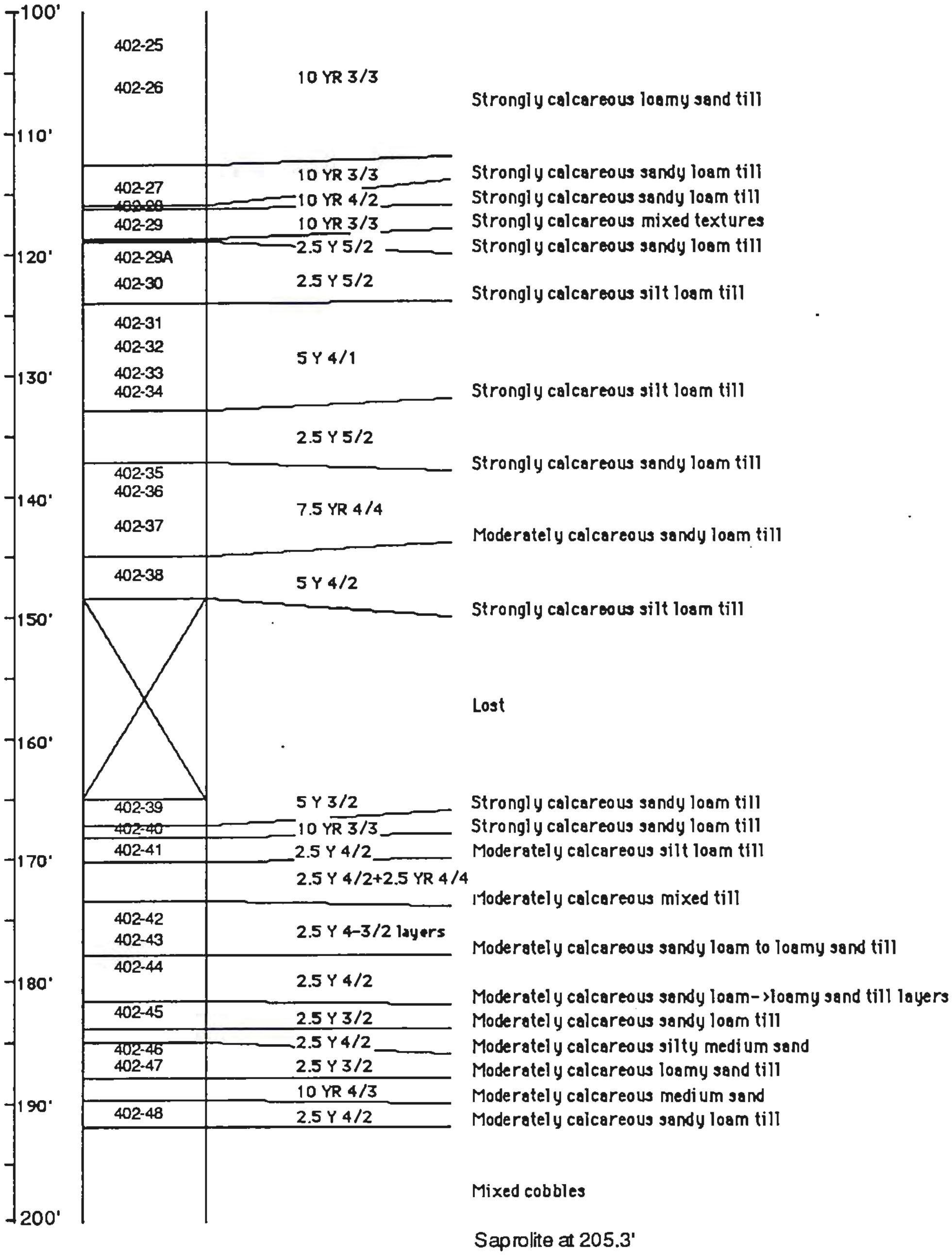

Figure 11 continued.

TABLE 4. GENERAL DATA AVERAGES

sample	% gravel	%sand	%silt	%clay	%clay SSC	%sand SSC	%silt SSC	mean	Std. Dev.	skewness	kurtosis	LOI	ARM
HEWITT SAMPLES													
HT NoS	14.26	58.83	18.52	8.39	9.79	68.61	21.60	2.46	3.21	0.84	2.83	21.45	0.13
L A	6.77	59.51	28.20	5.52	5.92	63.83	30.25	3.02	2.91	0.59	2.64	20.93	0.15
LS	2.92	35.23	49.05	12.80	13.18	36.29	50.52	4.79	2.94	-0.07	2.27	25.92	0.21
Z	3.88	52.77	34.88	8.46	8.80	54.91	36.29	3.67	2.95	0.41	2.40	22.31	0.11
average	**6.96**	**51.59**	**32.66**	**8.79**	**9.42**	**55.91**	**34.67**	**3.49**	**3.00**	**0.44**	**2.54**	**22.65**	**0.15**
stdev	5.77	13.83	15.60	3.67	3.63	17.44	14.84	1.22	0.17	0.47	0.28	2.74	0.04
BRAINERD SAMPLES													
HT SoM	4.46	58.90	24.65	11.99	12.55	61.65	25.80	3.51	3.10	0.63	2.49	1.94	0.10
92-1	10.68	66.32	19.41	3.59	4.02	74.25	21.73	2.39	2.69	0.81	3.38	1.41	0.52
92-2	3.31	66.04	27.47	3.18	3.29	68.30	28.41	3.01	2.43	0.68	3.26	1.08	0.44
average	**6.15**	**63.75**	**23.84**	**6.25**	**6.62**	**68.07**	**25.31**	**2.97**	**2.74**	**0.71**	**3.04**	**1.48**	**0.35**
stdev	3.97	4.21	4.09	4.97	5.15	6.30	3.37	0.56	0.34	0.09	0.48	0.43	0.22
GRANITE FALLS SAMPLES													
92-4	2.53	36.13	46.27	15.07	15.46	37.07	47.47	4.82	3.06	-0.06	2.14	45.47	0.02
92-5	6.44	37.39	43.87	12.30	13.15	39.96	46.89	4.28	3.32	-0.05	2.03	46.90	0.01
average	**4.49**	**36.76**	**45.07**	**13.69**	**14.31**	**38.52**	**47.18**	**4.55**	**3.19**	**-0.06**	**2.09**	**46.19**	**0.02**
stdev	2.76	0.89	1.70	1.96	1.63	2.04	0.41	0.38	0.18	0.01	0.08	1.01	0.01
NEW ULM SAMPLES													
92-7	6.20	36.71	42.39	14.70	15.67	39.14	45.19	4.56	3.19	-0.05	2.19	20.25	0.02
MI	5.58	30.09	43.76	20.57	21.79	31.87	46.35	5.21	3.23	-0.27	2.21	37.98	0.11
average	**5.89**	**33.40**	**43.08**	**17.64**	**18.73**	**35.51**	**45.77**	**4.89**	**3.21**	**-0.16**	**2.20**	**29.12**	**0.07**
stdev	0.44	4.68	0.97	4.15	4.33	5.14	0.82	0.46	0.03	0.16	0.01	12.54	0.06
BROWERVILLE SAMPLES													
92-8A	4.26	47.01	34.49	14.24	14.87	49.10	36.02	4.17	3.16	0.27	2.14	24.55	0.02
92-8B	4.71	45.20	35.34	14.75	15.48	47.43	37.09	4.25	3.18	0.22	2.13	24.79	0.01
92-9A	3.99	34.83	38.41	22.78	23.72	36.27	40.00	5.09	3.34	-0.14	1.90	28.30	0.01
92-9B	4.27	40.73	38.88	16.12	16.84	42.55	40.61	4.54	3.22	0.07	2.04	27.14	0.01
average	**4.31**	**41.94**	**36.78**	**16.97**	**17.73**	**43.84**	**38.43**	**4.51**	**3.23**	**0.11**	**2.05**	**26.20**	**0.01**
stdev	0.30	5.43	2.19	3.95	4.08	5.76	2.22	0.42	0.08	0.18	0.11	1.83	0.01
TOIMI SAMPLES													
33 105-7	25.20	47.39	24.01	3.39	4.53	63.36	32.10	2.03	3.08	0.59	2.51	6.40	1.20
33 164	10.54	48.90	35.05	5.50	6.15	54.67	39.18	3.27	3.05	0.24	2.32	4.23	1.40
33 207	37.99	37.54	22.03	2.43	3.92	60.55	35.53	1.49	3.16	0.79	2.56	2.92	1.24
average	**24.58**	**44.61**	**27.03**	**3.77**	**4.87**	**59.53**	**35.60**	**2.26**	**3.10**	**0.54**	**2.46**	**4.52**	**1.28**
stdev	13.74	6.17	7.02	1.57	1.15	4.43	3.54	0.91	0.06	0.28	0.13	1.76	0.11

TABLE 4. GENERAL DATA AVERAGES (CONT.)

X lf	granite	perthite	volcanic	basalt	gabbro	schist	greenstone	quartzite	chert	carbonate	sandstone	hematite	opaques
42.00	62.00	0.00	0.00	1.00	0.00	0.00	0.00	2.00	0.00	20.00	15.00	0.00	0.00
57.60	49.00	0.00	10.00	1.00	0.00	5.00	0.00	7.00	1.00	18.00	7.00	0.00	0.00
67.50	52.00	0.00	4.00	1.00	0.00	1.00	0.00	2.00	0.00	26.00	15.00	0.00	0.00
65.30	53.00	2.00	3.00	7.00	0.00	1.00	0.00	6.00	0.00	1.00	24.00	0.00	0.00
58.10	**54.00**	**0.50**	**4.25**	**2.50**	**0.00**	**1.75**	**0.00**	**4.25**	**0.25**	**16.25**	**15.25**	**0.00**	**0.00**
12.86	5.60	1.00	4.19	3.00	0.00	2.22	0.00	2.63	0.50	10.72	6.95	0.00	0.00
39.00	80.00	0.00	2.00	0.00	0.00	1.00	1.00	6.00	0.00	0.00	9.00	0.00	0.00
160.00	56.00	0.00	4.00	7.00	0.00	2.00	0.00	9.00	1.00	13.00	8.00	0.00	0.00
127.00	57.00	1.00	1.00	10.00	3.00	2.00	0.00	4.00	0.00	0.00	21.00	1.00	0.00
108.67	**64.33**	**0.33**	**2.33**	**5.67**	**1.00**	**1.67**	**0.33**	**6.33**	**0.33**	**4.33**	**12.67**	**0.33**	**0.00**
62.55	13.58	0.58	1.53	5.13	1.73	0.58	0.58	2.52	0.58	7.51	7.23	0.58	0.00
30.60	33.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	53.00	12.00	0.00	0.00
25.40	22.00	0.00	1.00	0.00	1.00	1.00	0.00	2.00	0.00	57.00	18.00	0.00	0.00
28.00	**27.50**	**0.00**	**0.50**	**0.00**	**0.50**	**1.00**	**0.00**	**1.50**	**0.00**	**55.00**	**15.00**	**0.00**	**0.00**
3.68	7.78	0.00	0.71	0.00	0.71	0.00	0.00	0.71	0.00	2.83	4.24	0.00	0.00
19.40	46.00	0.00	1.00	1.00	0.00	1.00	2.00	0.00	0.00	39.00	9.00	1.00	0.00
45.70	43.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	44.00	10.00	0.00	0.00
32.55	**44.50**	**0.00**	**0.50**	**0.50**	**0.00**	**1.50**	**1.00**	**0.00**	**0.00**	**41.50**	**9.50**	**0.50**	**0.00**
18.60	2.12	0.00	0.71	0.71	0.00	0.71	1.41	0.00	0.00	3.54	0.71	0.71	0.00
29.50	45.00	0.00	1.00	0.00	1.00	3.00	0.00	4.00	0.00	33.00	13.00	0.00	0.00
24.40	25.00	0.00	1.00	0.00	0.00	0.00	0.00	6.00	0.00	59.00	8.00	0.00	0.00
20.80	48.00	0.00	1.00	1.00	1.00	2.00	0.00	1.00	1.00	36.00	10.00	0.00	0.00
12.20	46.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	39.00	13.00	0.00	1.00
21.73	**41.00**	**0.00**	**0.75**	**0.25**	**0.50**	**1.25**	**0.00**	**3.00**	**0.25**	**41.75**	**11.00**	**0.00**	**0.25**
7.28	10.74	0.00	0.50	0.50	0.58	1.50	0.00	2.45	0.50	11.76	2.45	0.00	0.50
317.00	15.00	2.00	7.00	9.00	24.00	0.00	0.00	1.00	0.00	2.00	37.00	0.00	2.00
308.00	21.00	9.00	1.00	15.00	24.00	0.00	1.00	0.00	0.00	0.00	26.00	0.00	1.00
465.00	14.00	5.00	5.00	12.00	22.00	0.00	1.00	1.00	0.00	1.00	37.00	0.00	0.00
363.33	**16.67**	**5.33**	**4.33**	**12.00**	**23.33**	**0.00**	**0.67**	**0.67**	**0.00**	**1.00**	**33.33**	**0.00**	**1.00**
88.16	3.79	3.51	3.06	3.00	1.15	0.00	0.58	0.58	0.00	1.00	6.35	0.00	1.00

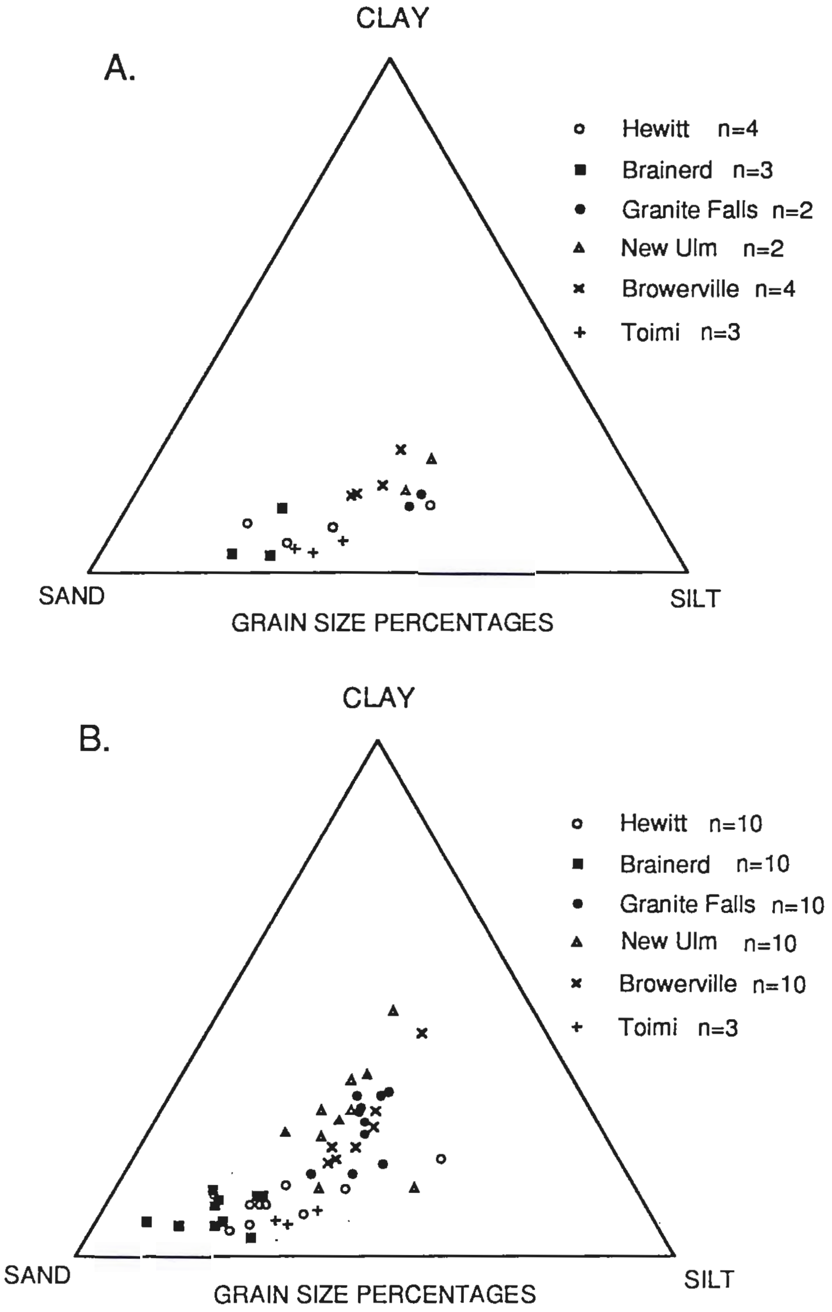

Figure 12. Till Matrix Textures.

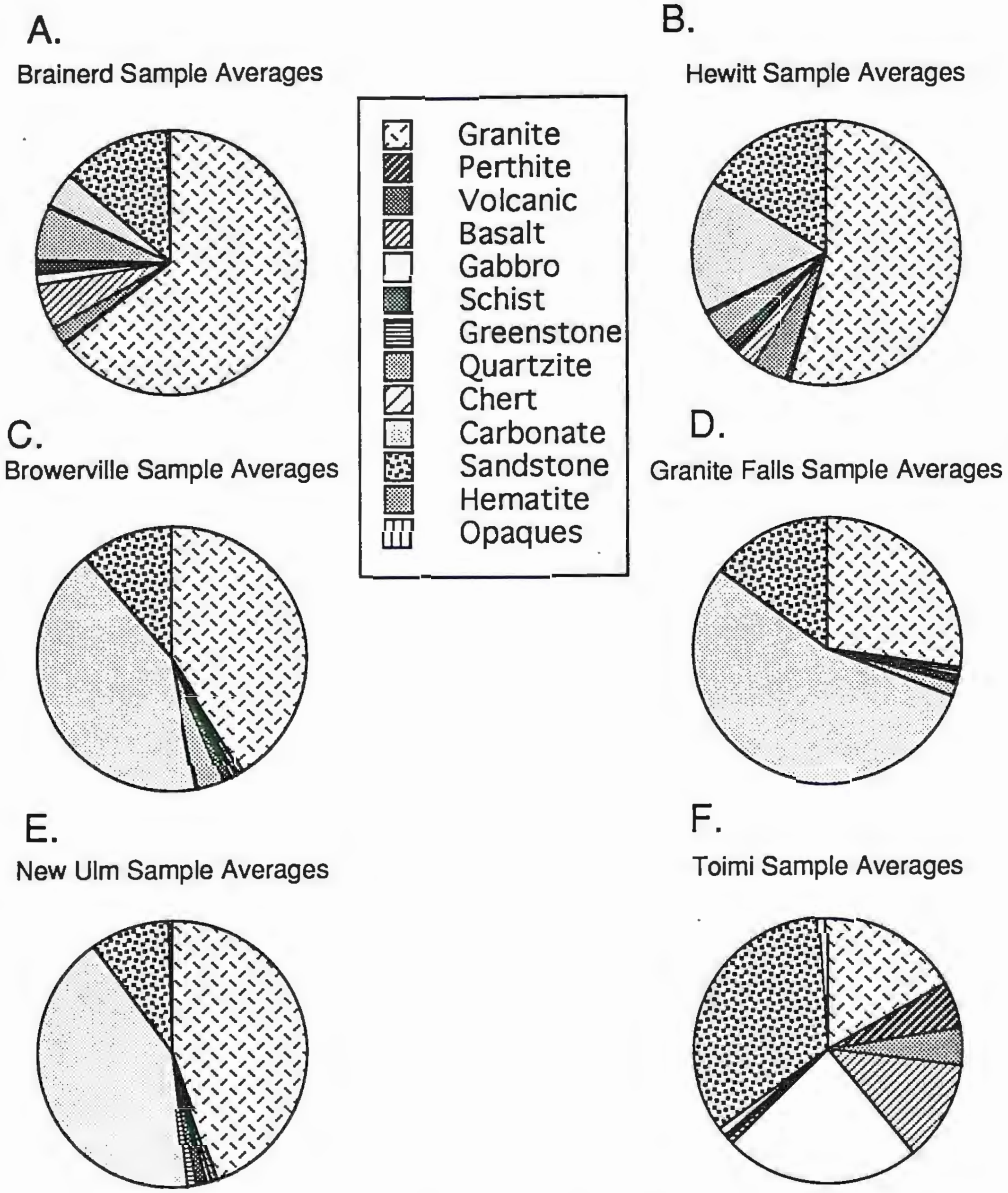

Figure 13. Average till lithologies.

and E) are similar in that their major constituents, which are granite, carbonate, and sandstone. The New Ulm and Browerville tills closely resemble each other, possessing roughly equal amounts of granite and carbonate. The Granite Falls till has approximately 15% more carbonate than either the Browerville or New Ulm till.

A further representation of the basic data is shown in Figure 14. The Toimi samples are easily recognized from their high values of ARM and χ values (Figure 14A and B). Likewise, the Granite Falls samples can be recognized by their very high carbonate contents (Figure 14B).

Carbonate Pebbles

The results of the geochemical analysis of the carbonate pebbles (from all tills that had carbonate clasts over 1 mm in diameter and the Geological Survey of Canada) are shown in Appendix B. In this case, ten elements (Ti, Sc, Y, Mo, Ag, Sn, Te, La, Ta, and W) were eliminated from the multivariate statistical analyses because the values were near or below detectable limits. Calcium was also eliminated because it was constantly >10%.

Principal Components Analysis

From the nine principal components analyses, a varying number of significant components (eigen values >1) were obtained. Table 5 lists the total amount of variance described by the components for each run. Brackets have been placed around the values for those components that account for less than 10% of the total variance. As these components describe such small portions of the total variance among the samples, they will not be considered in the following sections.

Till Samples

The component loadings from the eighth run of the principal components analyses, that considered all available data, clearly show within them all the patterns found in those of the previous seven analyses that are significant in till group discrimination. As an example, Figure 15A shows the loadings on the second component (which describes the second largest amount of variance among all the till samples) from this eighth run (bar graphs of the component loadings are used to enable their rapid visual evaluation). The loadings for the first component (which describes the largest amount of variance) of the first run (Figure 15B), which only considered grain size data, is visible as the left-most loadings in Figure

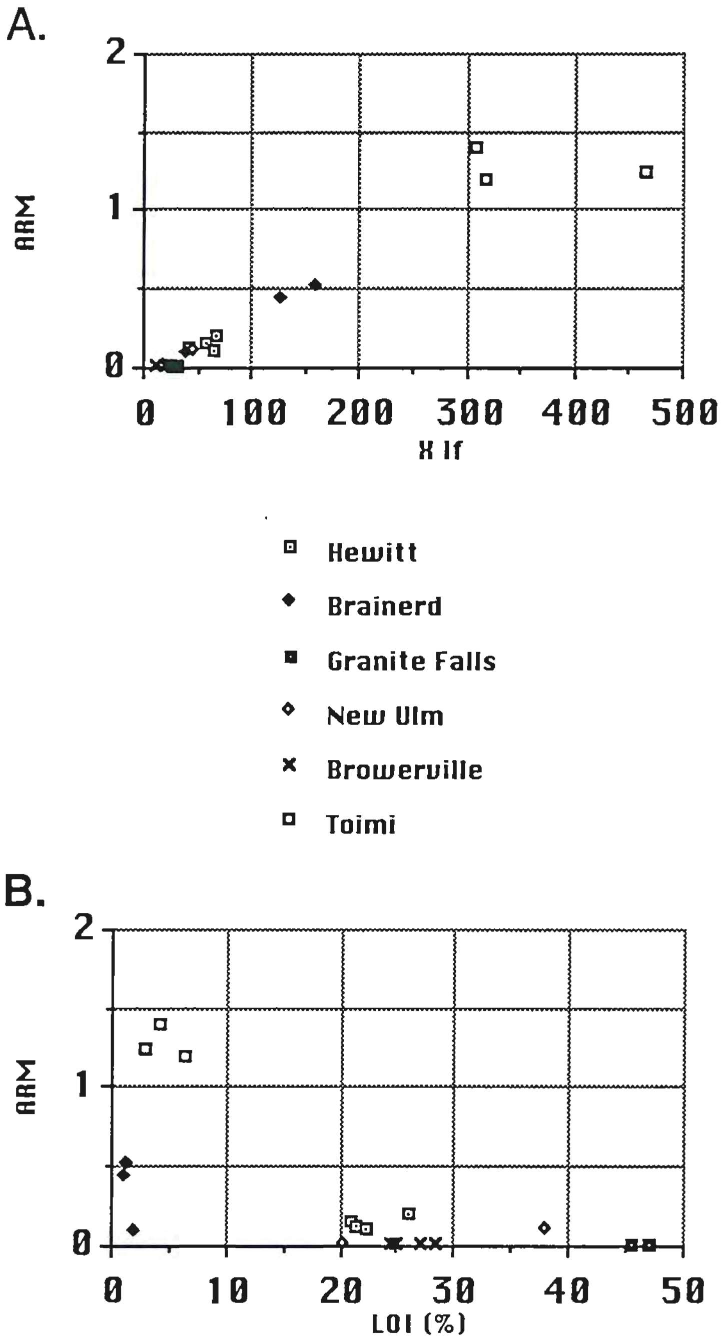

Figure 14. Graphical representations of till magnetics and LOI data.

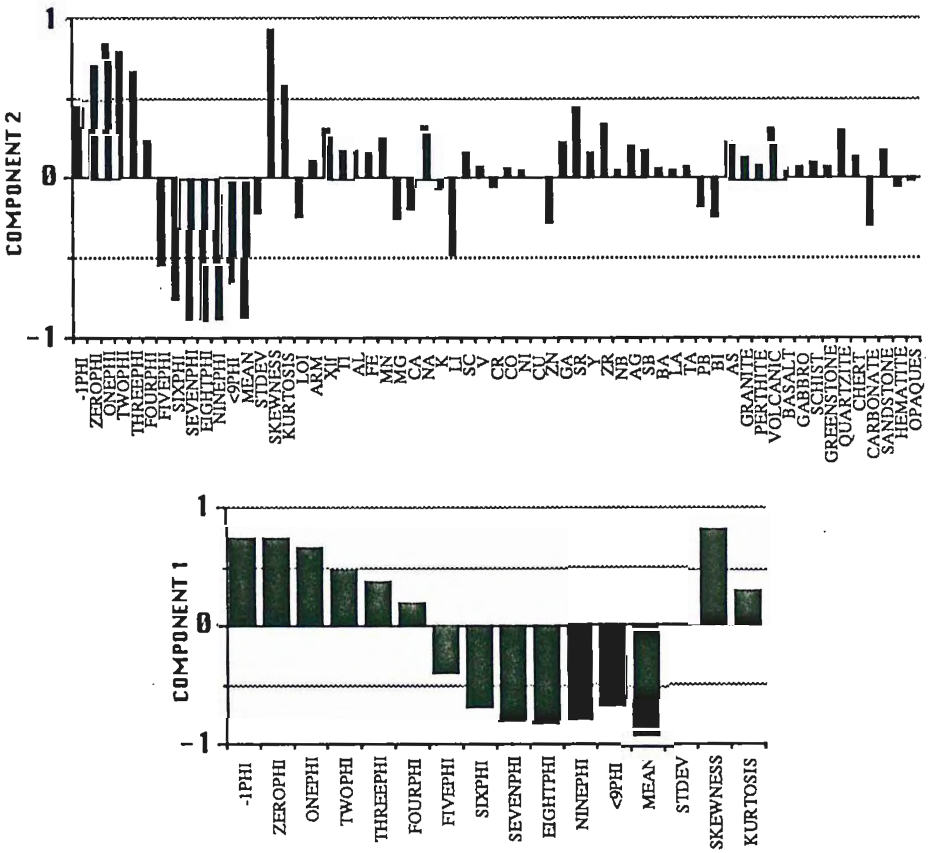

Figure 15. Comparison of 8th run loadings (all data) with 1st run loadings (grain size data). Notice that the pattern from the 1st run appears as the most significant information in the 8th run graph.

15A. Both of these components only describe variation from coarse textured samples, that have a skewed grain size distribution almost by definition, compared to those that are fine textured, and thus have high mean phi sizes, as seen by the inverse relationship between the coarse phi sizes (-1ϕ through 4ϕ) and skewness with the finer sizes (5ϕ through clay) and mean. All of the other categories of variables in Figure 15A do not contribute significantly to the variance (silt and clay geochemistry is only weakly represented with the appearance of lithium covarying with the fine textures). Therefore, in the interest of clarity and brevity, the eighth run component loadings will be discussed with reference to previous run component loadings to examine details of the variance structure.

TABLE 5. PCA COMPONENTS AND THE AMOUNT OF SAMPLE VARIANCE DESCRIBED BY EACH

ANALYSIS	SIGNIFICANT COMPONENTS	COMPONENT VARIANCE %
1st RUN	3	41.8; 26.4; 15.0
2nd RUN	3	41.8; 24.4; 13.7
3rd RUN	4	40.2; 18.9; 15.4; 11.3
4th RUN	4	35.5; 21.1; 16.1; 11.2
5th RUN	4	22.1; 20.0; 16.2; [9.3]
6th RUN	8	28.0; 18.1; [8.3; 7.5; 6.9; 6.0; 4.6; 4.6]
7th RUN	6	27.6; 21.8; 12.9; 11.7; [5.2; 4.8]
8th RUN	12	19.2; 16.3; 15.4; [6.0; 5.0; 5.0; 4.7; 4.1; 3.5; 3.1; 2.8; 2.2]
9th RUN	6	27.6; 12.8; 12.5; 11.2; 10.5; [5.9]

The loadings on the three components from Run 1 (grain size only) are shown in Figure 16. The variance on the first component is discussed above. The second component represents the inverse relationship between fine and very fine sand, which covaries with skewness and kurtosis, and the bimodal granule, silt, and clay rich samples with high standard deviations. This loading suggests that as sand percentage decreases, the

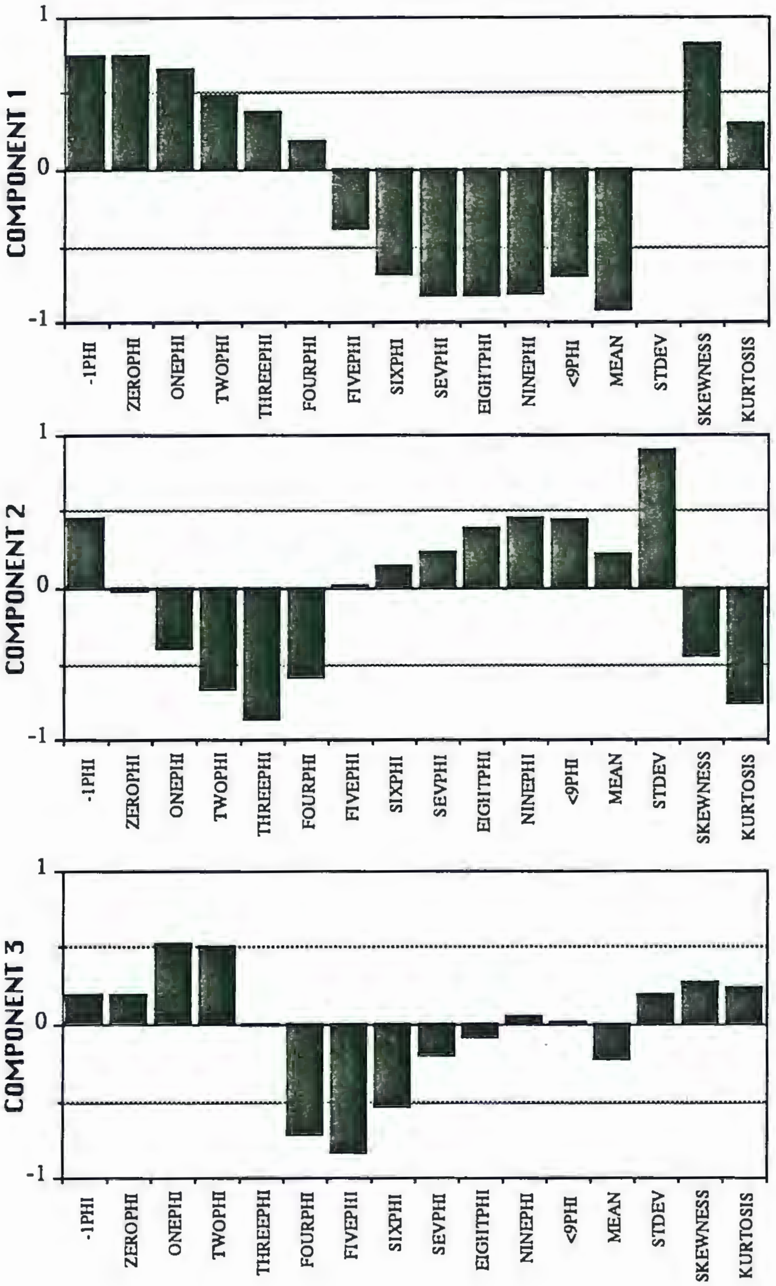

Figure 16. PCA grain size data component loadings.

standard deviation increases, and that the addition of fines results in poorer sorting. The variation explained by the Component 3 loadings is the medium sand versus very fine sand and silt ratio of the tills.

When the scores for the three components are plotted against each other (Figure 17), the groups show a fair amount of overlap. The only exception to this is shown in Figure 17B in which the Toimi samples are somewhat distinct from the rest. Given the variable loading on Component 1 this placement of the Toimi samples indicates that they are generally very coarse textured. However, overall these graphs emphasize the unreliability of grain size information as an independent classifier for the tills in this study, as was seen in Figure 12.

The majority of the variance between the samples is a function of the geochemistry of the till matrices, represented by the combinations of elements seen in the loadings on Component 1 (Figure 18). An interpretation of this combination of elements is Canadian Shield type lithologies (granite/greenstone/mafic igneous) versus platform lithologies (limestone and dolomite), especially given the covariance of LOI and carbonate grains with the elements magnesium, calcium, lead, and bismuth. The loadings of the elements on this component are virtually identical to those on Component 1 from the preceding seventh run, using geochemistry alone (Figure 19).

The loadings from the four relevant components from the analysis of the matrix geochemistries are shown in Figure 19. The variation on the first component is loaded by the inverse relationship between magnesium, calcium, lead, and bismuth and most everything else, the pattern of which is also seen in Figure 18. Component 2 shows a similar grouping of the majority of the elements contributing to the variance, however, there is no inverse relation. Component 3 represents the combination of sodium and strontium versus lithium and lanthanum. The fourth component shows a covariance of aluminum, antimony, nickel, cobalt, and scandium.

The geologic interpretation for the loadings on Component 1 were already given to be Canadian Shield versus platform derived lithologies. Component 2 would seem to represent simply the presence or absence of Canadian Shield chemistries. The combination of sodium and strontium in the third factor is interpreted to represent an intermediate chemistry, while lithium and lanthanum are found in felsic assemblages. The geological meaning of the fourth component is obscure.

Plots of the component scores for the geochemistry data are shown in Figure 20. Immediately apparent is the clustering of like samples with relatively little overlap of the

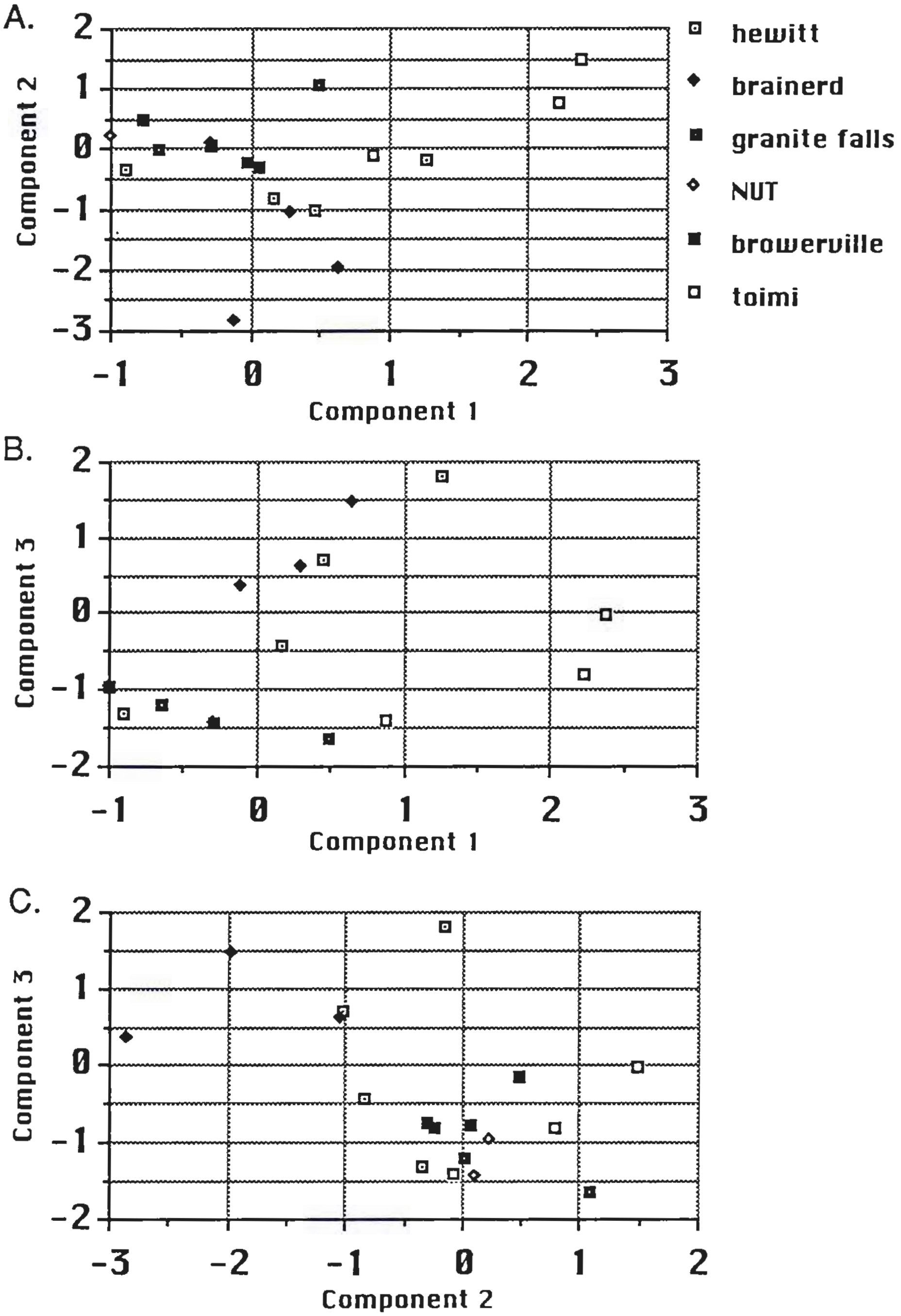

Figure 17. PCA grain size data component score plots.

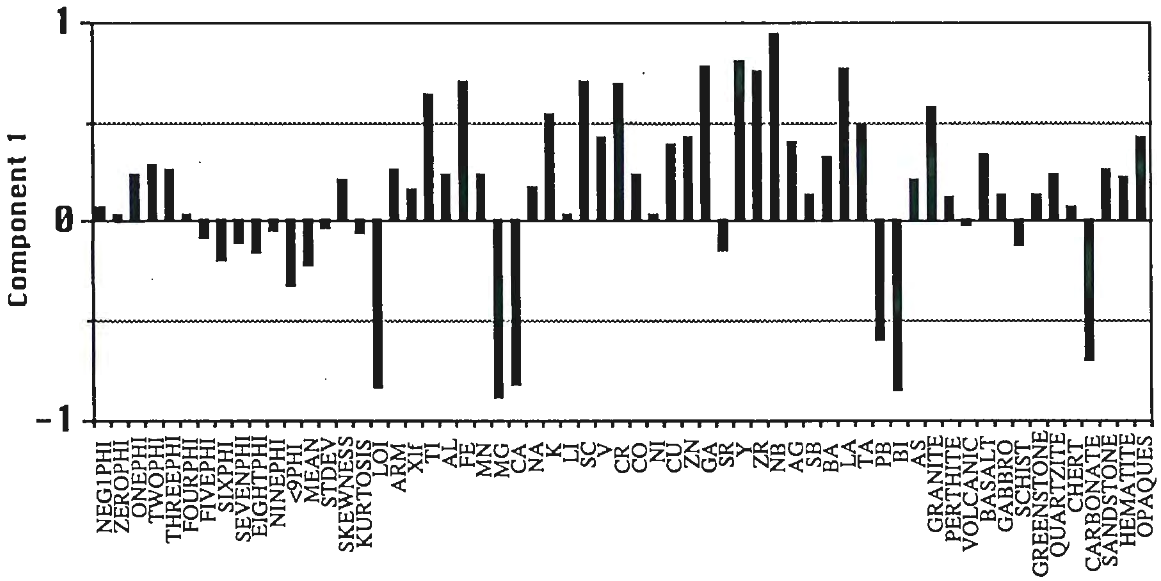

Figure 18. PCA all data Component 1 loadings.

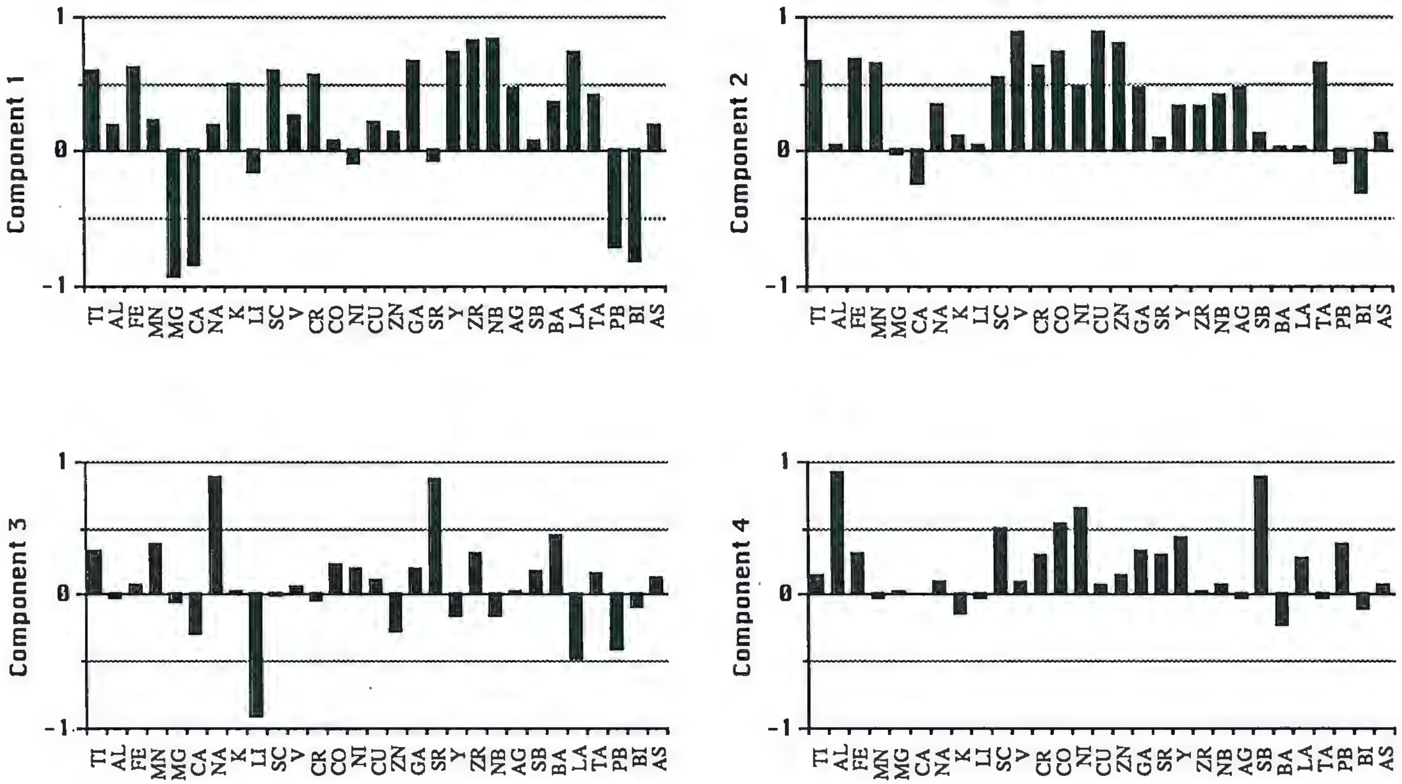

Figure 19. PCA geochemistry data component loadings.

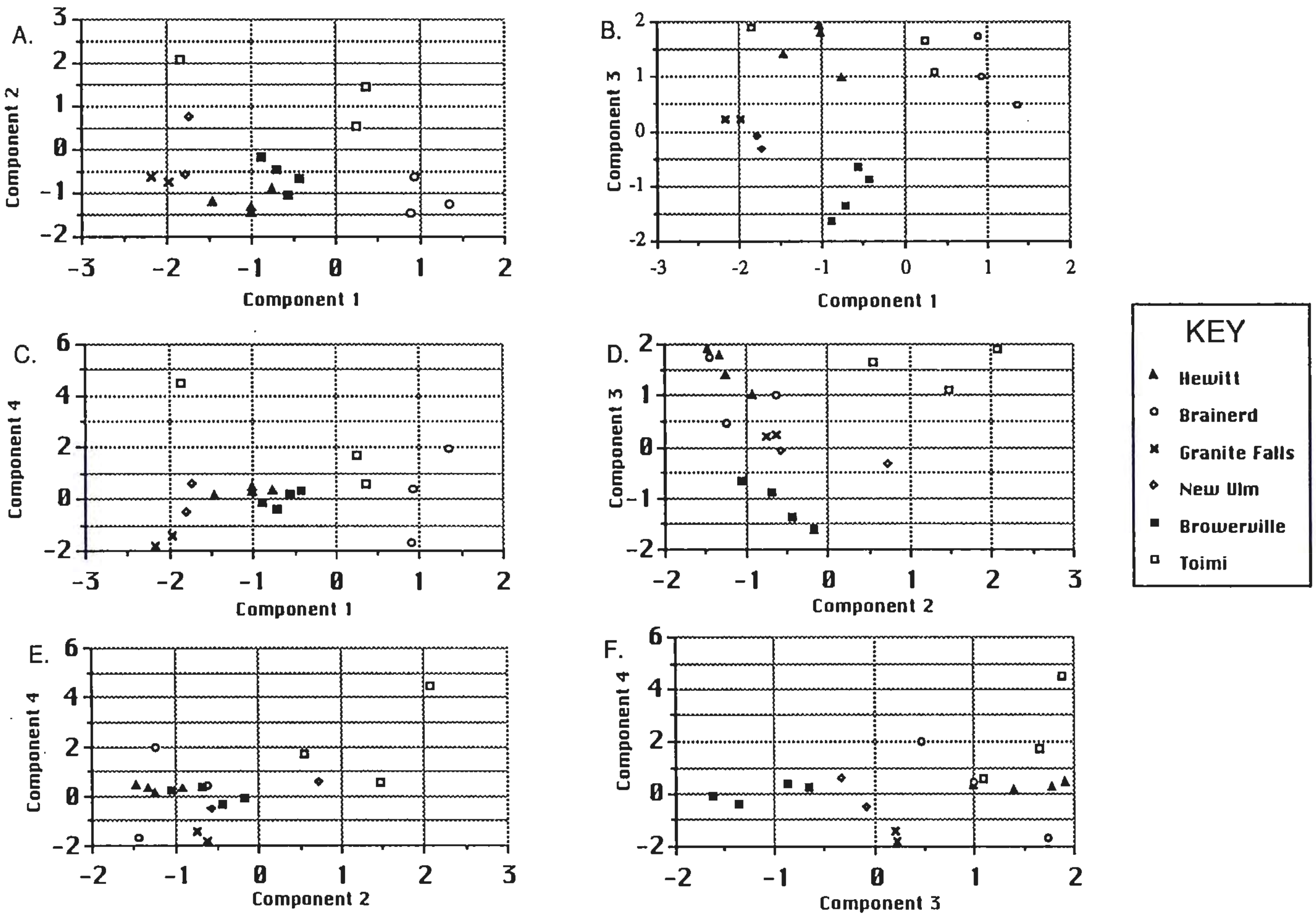

Figure 20. PCA geochemistry data component score plots.

groups, indicating that the various groups are distinct geochemically. Also evident is the inability of Component 4 to separate the samples, except for a few that appear to be either enriched or depleted in aluminum, antimony, nickel, cobalt, and/or scandium relative to the other samples (Figures 20C, D, and F). Component 4 will not be discussed further.

Another item of interest is the placement of one of the Toimi samples relative to the other two on Component 1 (Figures 20A, B, and C). This particular sample (33 207) plots extremely negative on the first component. The negative field of this component is interpreted to be occupied by platform chemistries, indicated by the elements calcium, sodium, lead, and bismuth, compared to the Canadian Shield chemistries on the positive side. A possible explanation for this is the location of 33 207 in core CDC-33. This sample, from a depth of 207 feet, is immediately above bedrock of the Duluth Complex which is high in calcium plagioclase and magnesian olivine and pyroxene. A look at the raw geochemistry data for this sample (Appendix A) reveals that it has higher calcium, magnesium, and lead concentrations than the samples from higher up in the core (33 105-7 and 33 164), suggesting a strong local bedrock signature.

The best separation of the groups is accomplished by Component 1 (Figure 20A, B, and C). Disregarding the Toimi outlier, the only overlapping occurs between the Hewitt and Browerville samples. The problem of this overlap is eliminated by plotting Component 1 against Component 3 (Figure 20B). In this plot, all the sample groups are widely separated, with the exception of the Granite Falls and New Ulm tills, which plot very close together (as is the case in all graphs). Besides producing the best separation of the sample groups, this plot is further characterized by the diagonal separation between the upper and lower sample groups, which appears to be a function of Component 3 and its interpretation of felsic versus intermediate composition. The three groups below this gap are all of widely acknowledged northwestern provenance, while the Brainerd and Toimi tills on the upper side of the gap are of undisputably northeastern provenance, leading to an interpretation that the gap separates the northwestern and northeastern tills.

The third largest amount of variance among the samples, as seen in Component 3 from the eighth run of the PCA (Figure 21), is described by a combination of three signatures, magnetics, geochemistry, and sand grain lithology. Each of these signatures will be discussed separately below.

Magnetics

The component loadings for the third run, which included only grain size and magnetics data are shown in Figure 22. The combination of variables, ARM and χ,

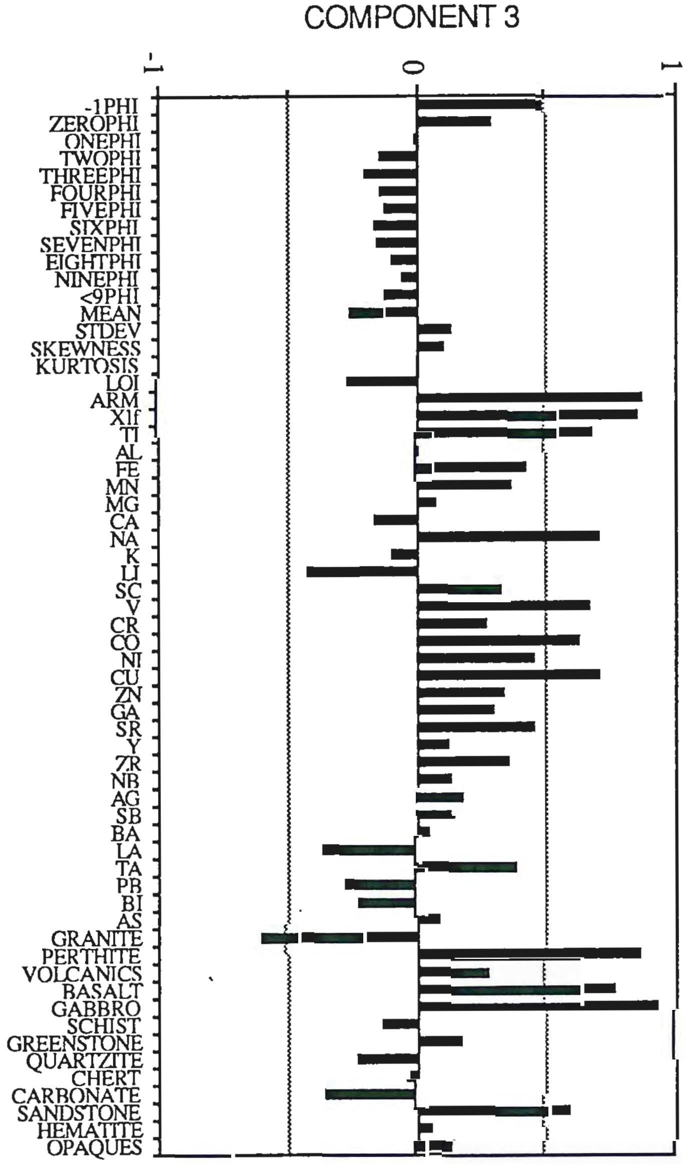

Figure 21. PCA all data Component 3 loadings.

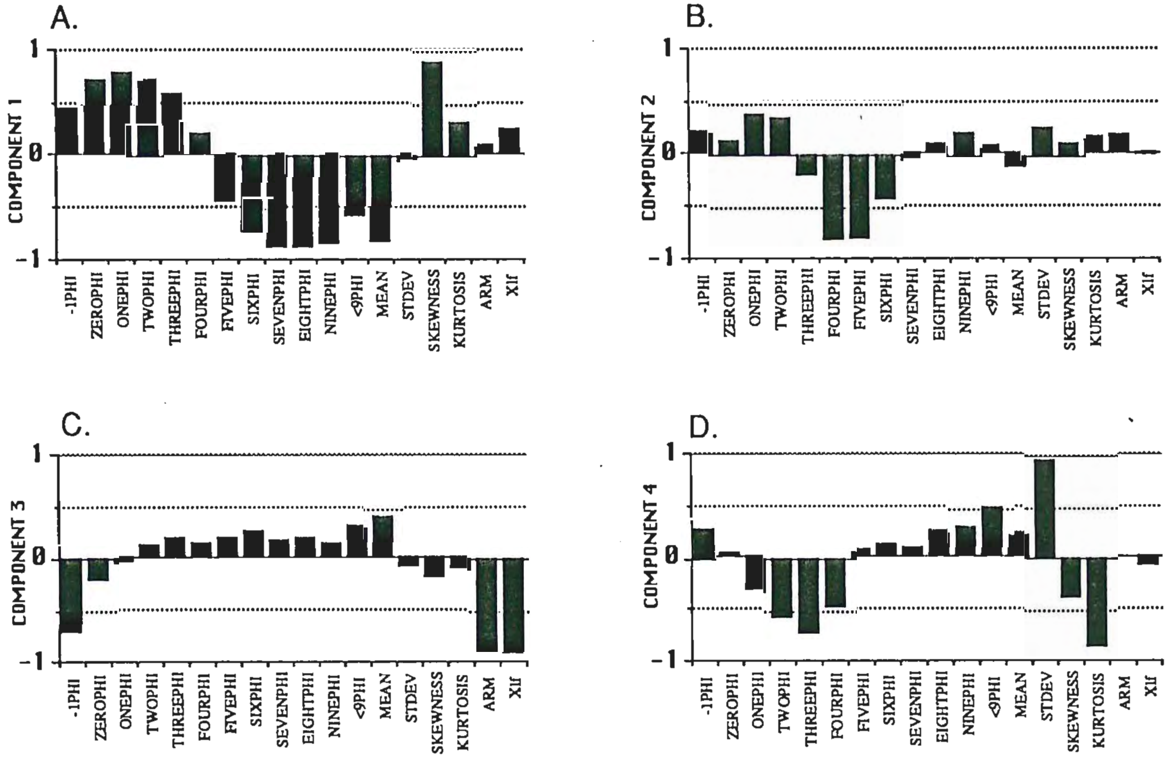

Figure 22. PCA grain size & magnetics data component loadings.

contribute significantly to the variance on the third component (Figure 22C), and links the presence of granules with high rock magnetic properties. The other three components have loadings that are virtually identical to those from the grain size only run (Figure 16). Plots of the component scores (Figure 23) show a similar lack of discrete grouping seen in the plots from the first run of grain size only (Figure 17). The only exception is once again the Toimi samples, whose strong negative placement on Component 3 (Figures 23B, C, and F) is indicative of a highly magnetic coarse grained nature.

Geochemistry

The second signature indicated by the third component in Run 8 is geochemical. This pattern of the elements corresponds to a combination of the second and third component loadings from the geochemistry only run (Figure 19), in which the third component appears as a weaker signal. The second component is interpreted to again represent Shield lithologies, except there are no elements representing platform lithologies on the opposite side of the graph. The elements loading Component 3 are the inverse pairs Na/Sr and Li/La, which would represent intermediate versus felsic compositions. The combination of these two geochemical loadings would produce an intermediate to mafic versus felsic interpretation for this signature.

Lithology

The last signature is of a lithologic nature. This pattern of loadings is similar to that seen in the first component from the PCA run of point count data. The component loadings from this run are shown in Figure 24. The variation on Component 1 is loaded by the inverse relationship between granite and perthite, basalt, gabbro, and sandstone, which might be interpreted as granitic versus northeastern Minnesota lithologies. The second component is loaded by a covariance among volcanics, schist, and hematite. Component 3 represents an inverse relationship between basalt, gabbro, greenstone, and sandstone and carbonate. Interpretations of the geologic meanings of the last two components are rather unclear, especially for Component 2. Component 3 might represent another Canadian Shield versus platform indicator, though the absence of granite would indicate a more northeasterly source region.

Plots of the component scores from the fifth run show that the Toimi samples are easily distinguishable based on the first component (Figure 25A and B), having large amounts of northeastern Canadian Shield lithologies. Figure 25C has an interesting negatively-sloping gap between two groups of the samples. Both the Toimi and Brainerd sample groups plot above this gap, but the Hewitt samples split on either side of it.

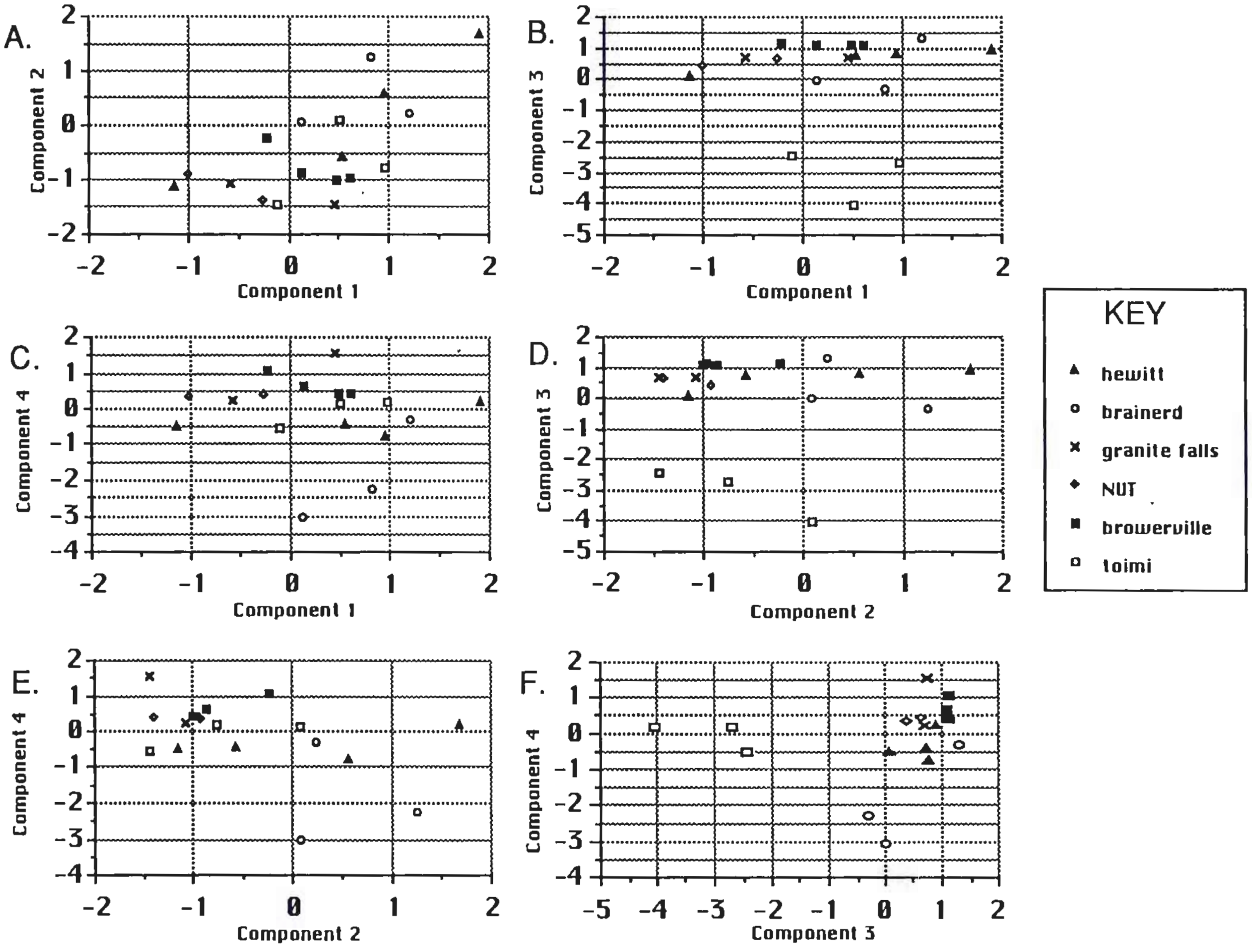

Figure 23. PCA grain size & magnetics component score plots.

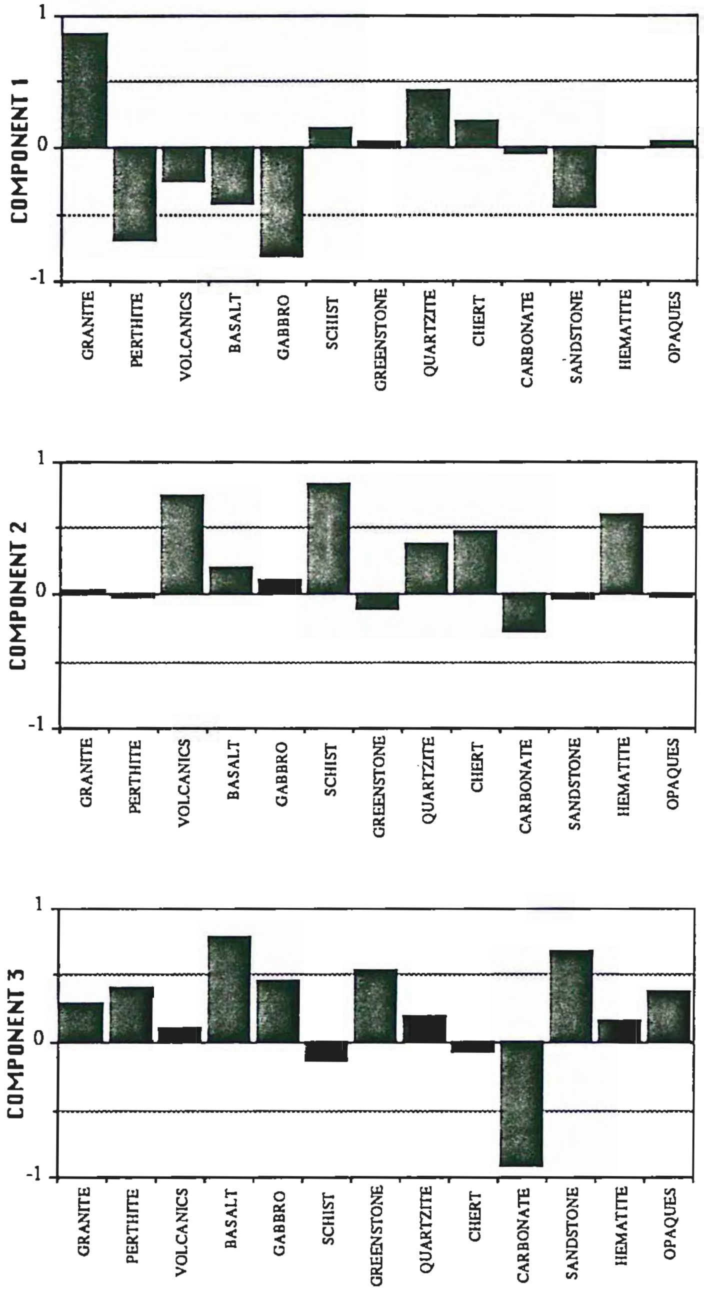

Figure 24. PCA point count data component loadings.

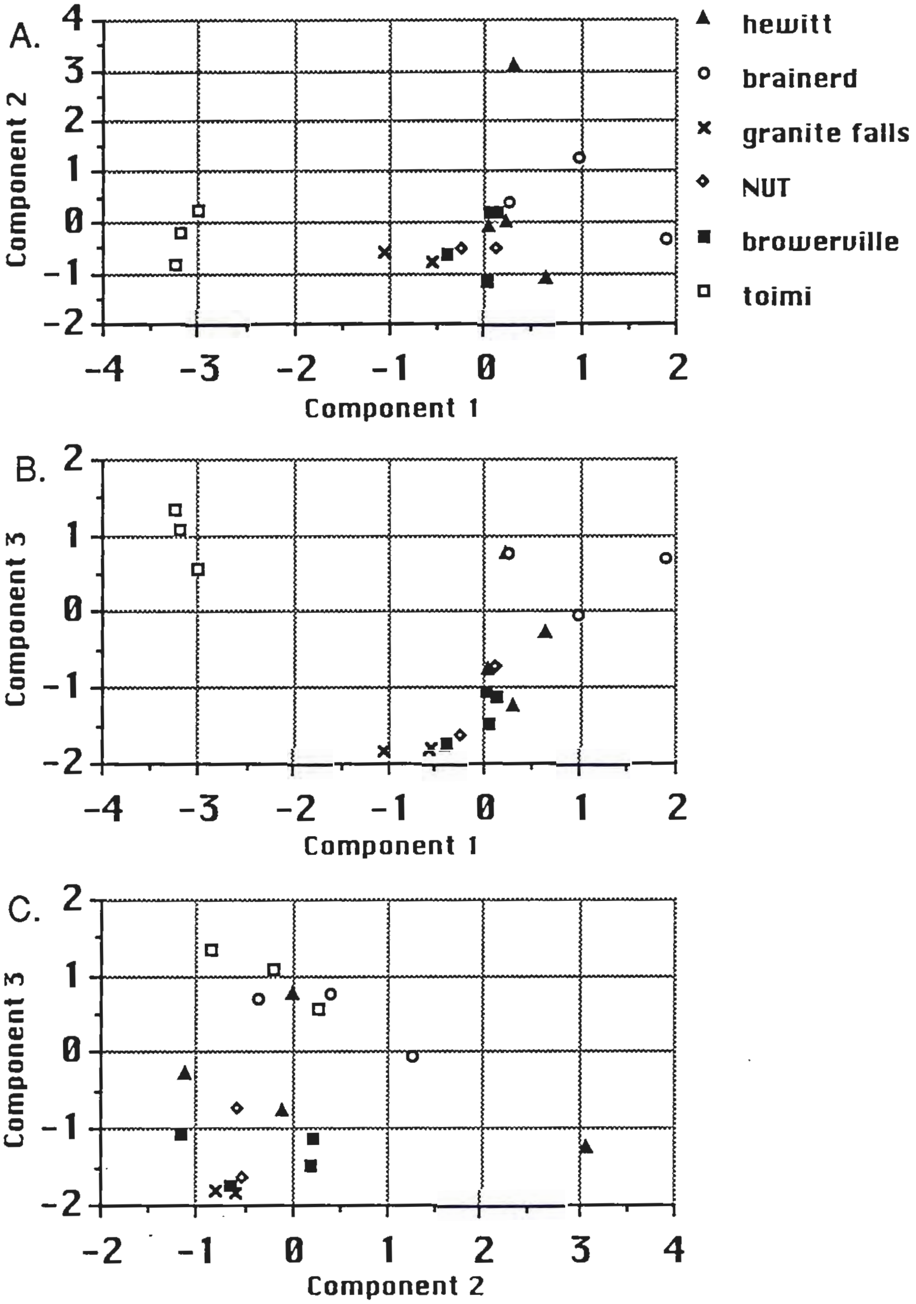

Figure 25. PCA point count component score plots.

The combination of the interpretations of these signatures produces the conclusion that the third largest amount of variance in the samples, as described by the loadings on Component 3 for the eighth run, is from highly magnetic tills with intermediate to mafic chemistries compared to those that are felsic and relatively non-magnetic.

The plots of the component scores for the eighth run (Figure 26) show discrete grouping of the samples. Only Figure 26C has no overlapping of the groups, however, four of the groups are nearly overlapping. In all three plots, the Toimi and Brainerd sample groups are clearly defined.

Three of the PCA runs have not been mentioned. The second run, on grain size and LOI data, produced component loadings that are virtually identical to those from the first run (Figure 27). LOI covaries with the fine grain sizes in the first component, indicating that fine grained tills are generally higher in carbonate. The second and third components have loading patterns identical to those for just the grain size data (Figure 16). Biaxial plots of the component scores, shown in Figure 28, reveal a lack of discrete groups, though the Brainerd samples plot strongly negative on Component 2, and the Toimi samples occupy the lower left quadrant in Figure 28B.

The loadings from the combination of grain size, LOI, and magnetics data in the fourth run are shown in Figure 29. The first, second and fourth components are all similar to the grain size only component loadings (Figure 16). The third component has the loading pattern from Component 3 from the grain size and magnetics run (Figure 22C), with the addition of a strongly positive LOI loading opposing the granules and magnetics. This inverse relationship between LOI and the magnetics in Component 3 implies that tills high in carbonate content are low in magnetics and vice versa. Plots on Component 3 for this run (Figure 30) clearly show the Toimi samples as least-calcareous, coarse grained and highly magnetic.

The results of the sixth run, on everything except the geochemistry data, are the two components whose loadings are shown in Figure 31. The first component once again represents variation from coarse grained versus fine grained tills. Component 2 for this analysis is loaded by granules, the magnetics, perthite, basalt, gabbro, and sandstone against LOI, granite, and carbonate. This pattern is interpreted to represent coarse grained, highly magnetic, northeastern Minnesota lithologies versus carbonate and granite rich tills. The biaxial plot of the component scores from this run (Figure 31C) only result in the clear distinction of the Toimi samples. The other samples are very spread out, but there is significant group overlap.

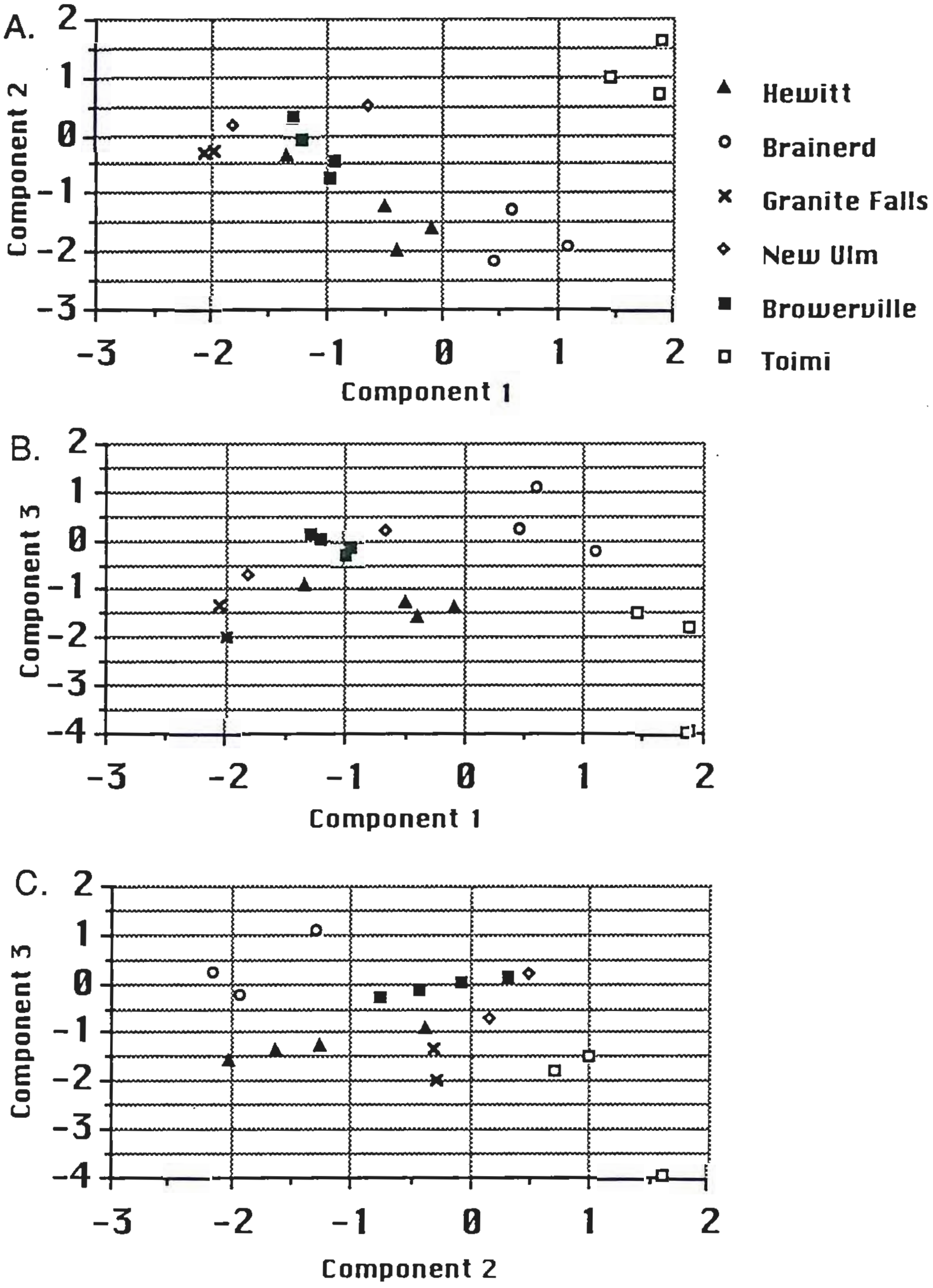

Figure 26. PCA all data component score plots.

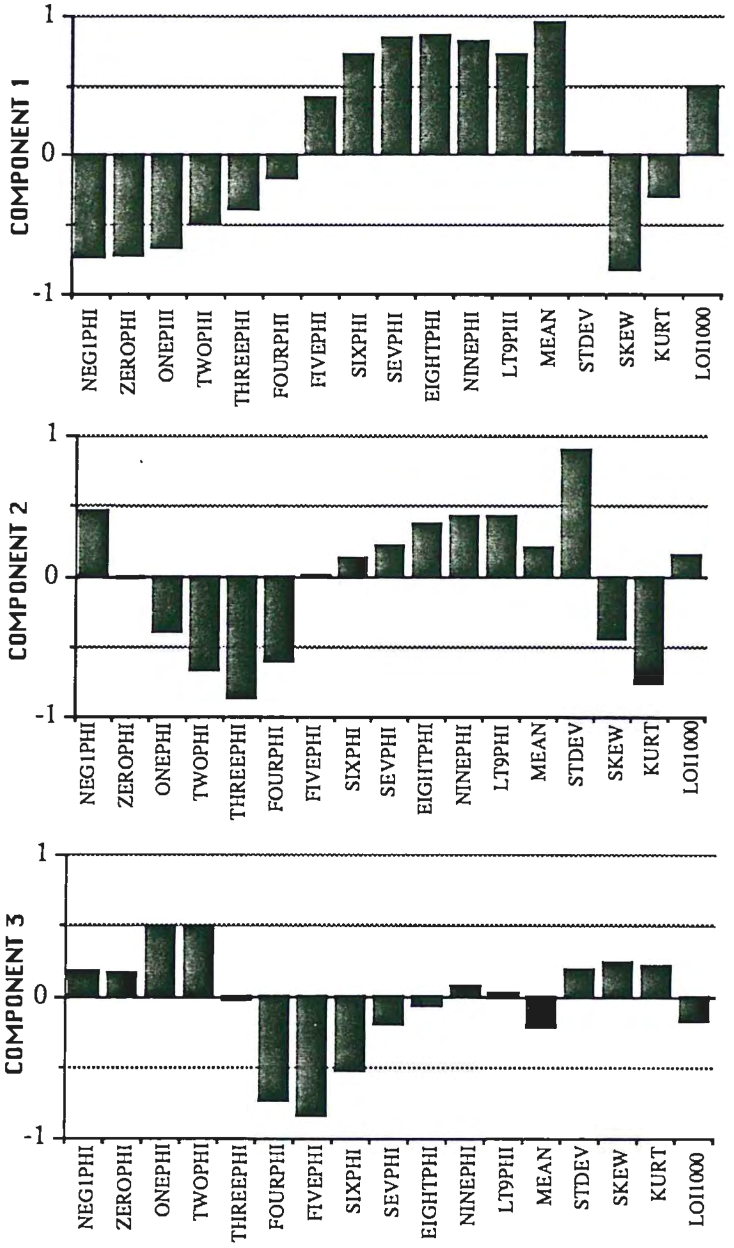

Figure 27. PCA grain size & LOI data component loadings.

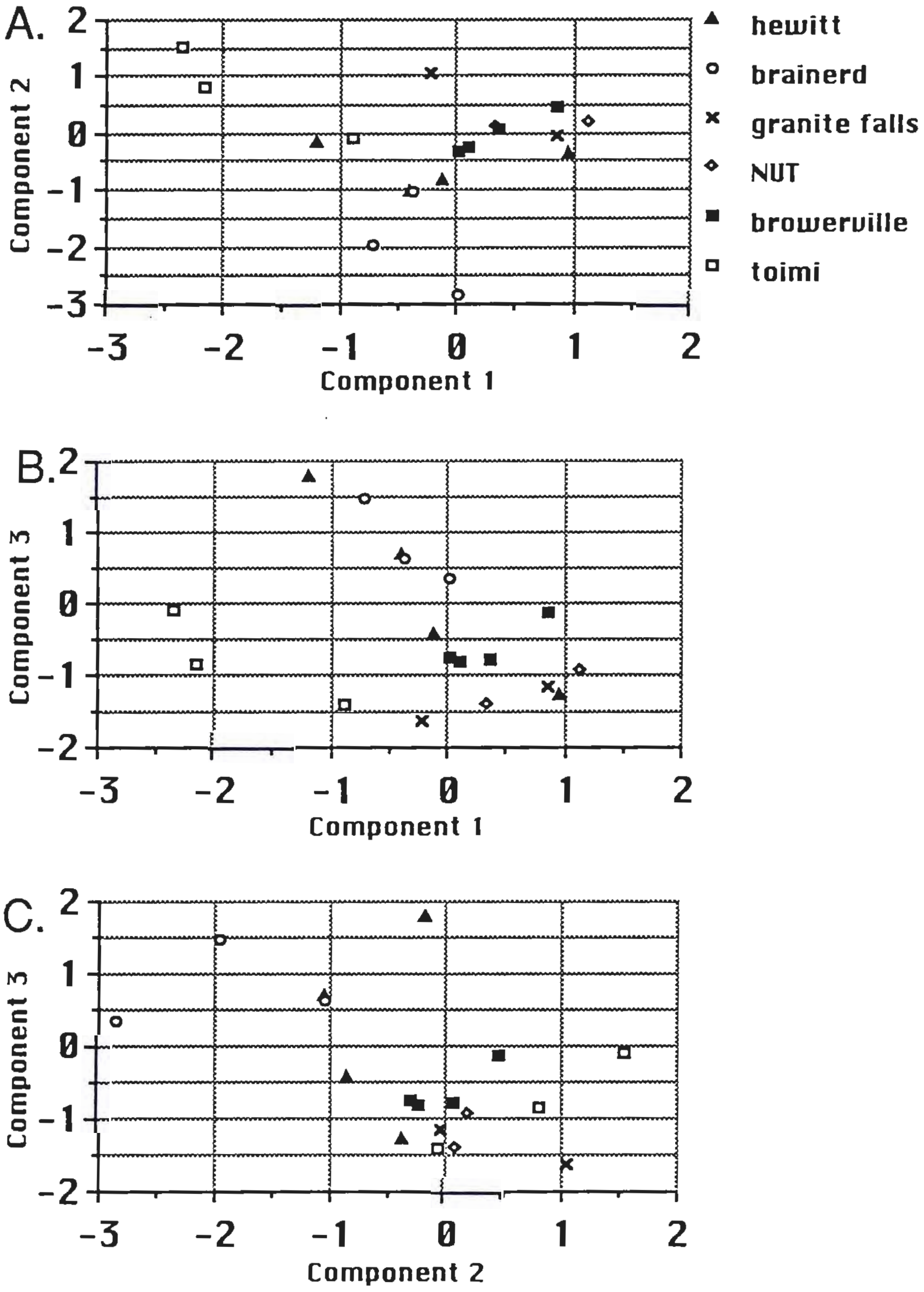

Figure 28. PCA grain size & LOI data component score plots.

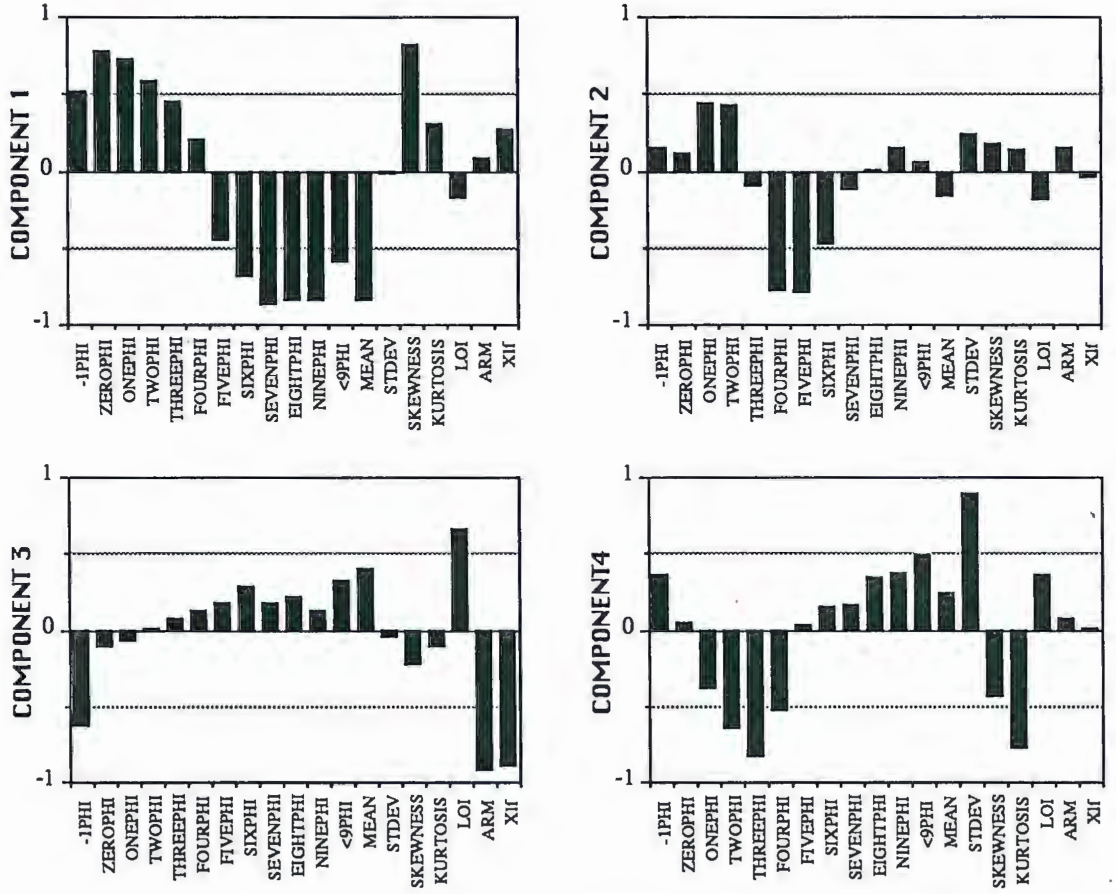

Figure 29. PCA grain size, LOI & magnetics data component loadings.

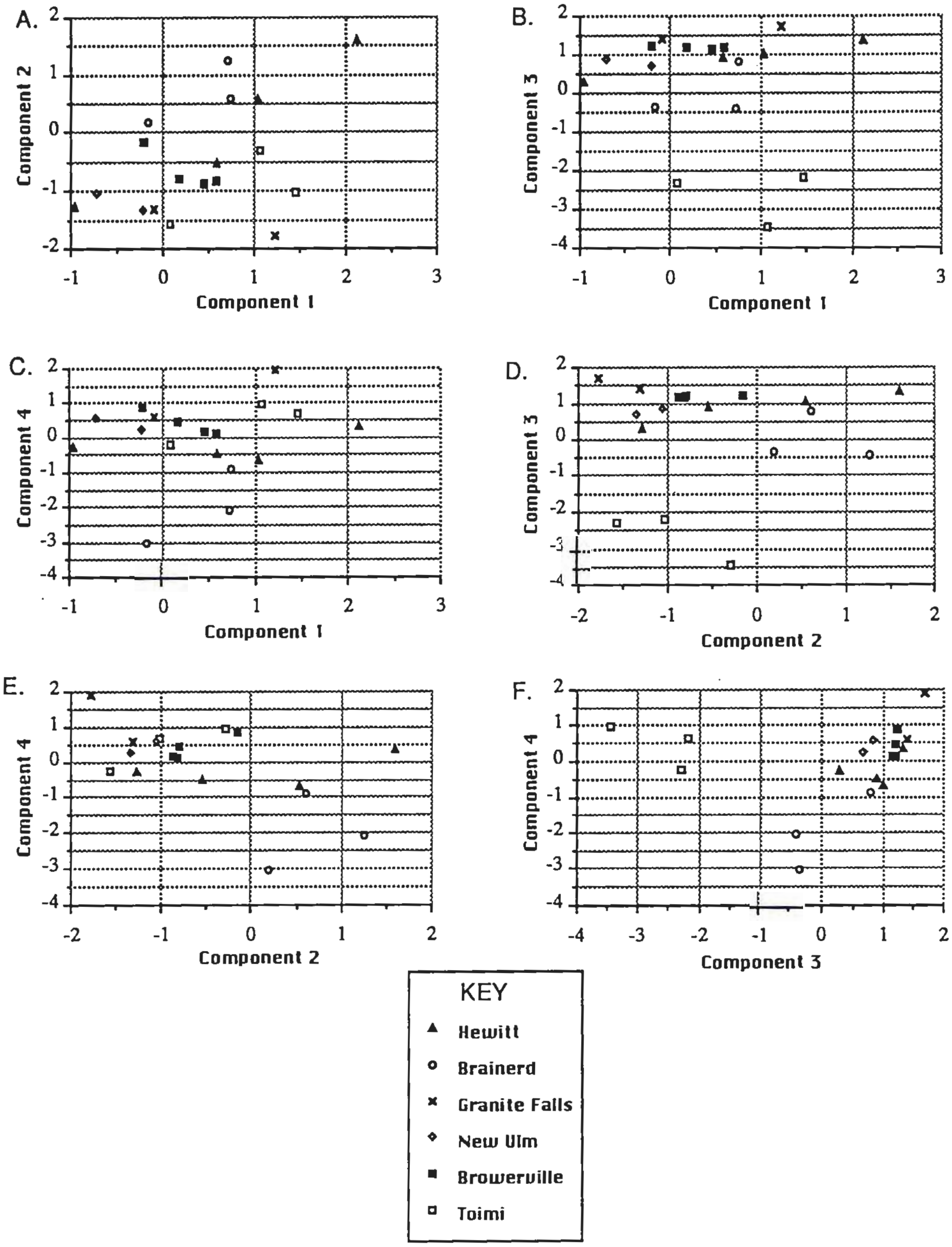

Figure 30. PCA grain size, LOI & magnetics component score plots.

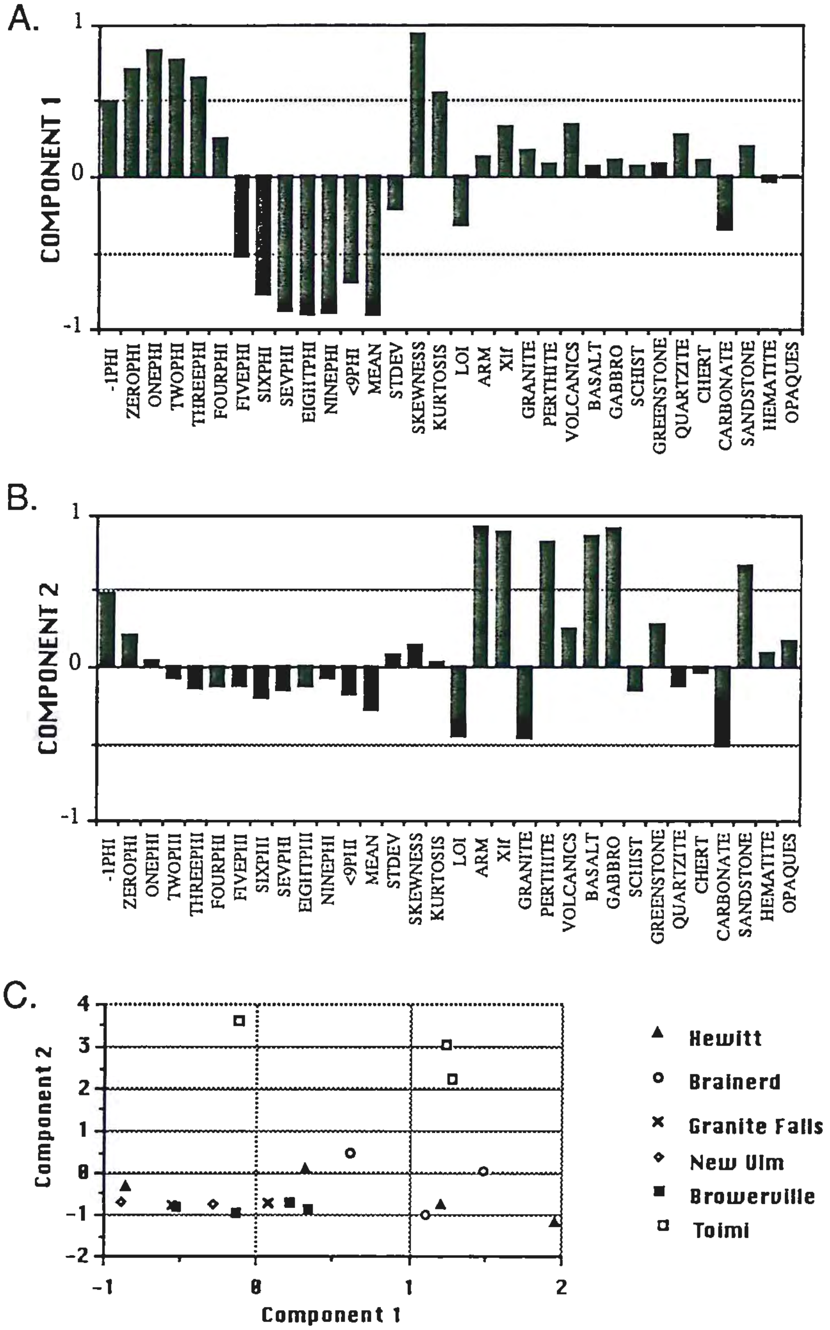

Figure 31. PCA everything but geochemistry data component loadings and scores plot.

Carbonate Pebbles

Principal component analysis of the carbonate pebble geochemistries produced component loadings shown in Figure 32. The largest amount of variance is accounted for by the inverse relationship between cobalt/chromium and seven other elements, including the rare earths. The variance on the second component is loaded by the covariance of magnesium, nickel, antimony, lead, and bismuth versus strontium. The covariance of lithium, copper, zinc, and cadmium loads the variance on the third component. Aluminum, sodium, potassium, zirconium, and arsenic covary on Component 4, and iron, manganese, and vanadium covary on Component 5. A look at the component scores plots for this run (Figure 33), reveals that only Component 1 produces two groups within the samples. However, northeastern and northwestern pebbles plot in both groups, although there is a predominance of northeastern samples in the high cobalt and chromium field.

Discriminant function analysis

Table 6 lists the levels of probability for the discriminant functions of each analysis. These numbers represent the percentage of known samples correctly grouped based on the computed discriminant function. Only those functions with 90% or better probability are considered significant. The discriminant functions themselves are of the form:

$$D = C_1(\text{Variable 1}) + C_2(\text{Variable 2}) + ... + C_n(\text{Variable n}),$$

where C_1, C_2, ..., C_n are coefficients computed in each analysis, and the variables depend on the input data. The variables and coefficients for each significant discriminant function are listed in Table 7.

The goal in DFA is to be able to uniquely define the input sample groups based on the computed discriminant function(s). Sometimes the distinction between groups are enough that the function scores from an individual discriminant function are all that is necessary for this purpose. Usually, however, the scores from two or more discriminant functions must be plotted against each other to achieve group definition in discriminant function space. The seven runs of discriminant analysis produced varying amounts of group discretization when the function scores are plotted. As the purpose of this investigation was to determine which method or methods best distinguish among the groups of tills, any DFA run which has overlap of the sample groups will be considered inadequate.

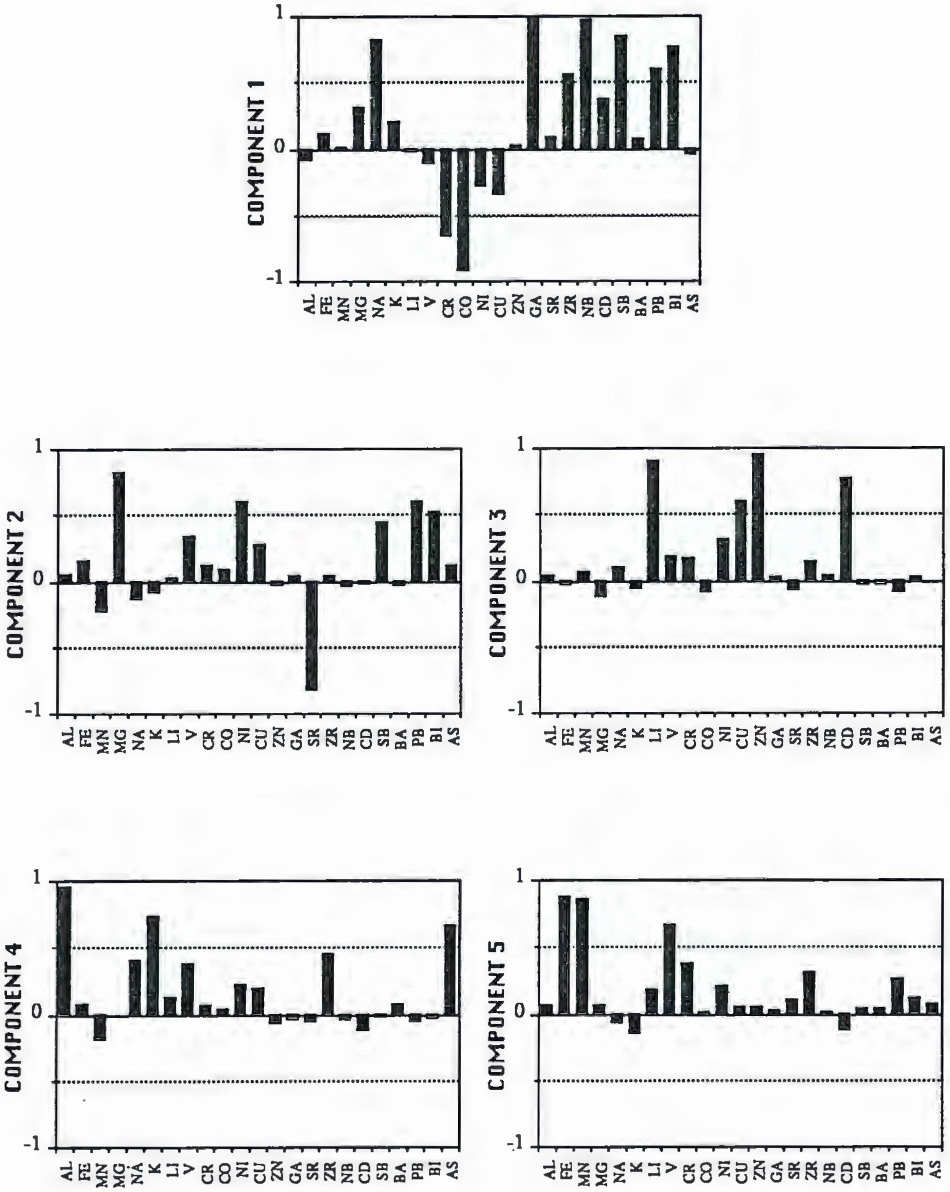

Figure 32. PCA carbonate pebble geochemistry component loadings.

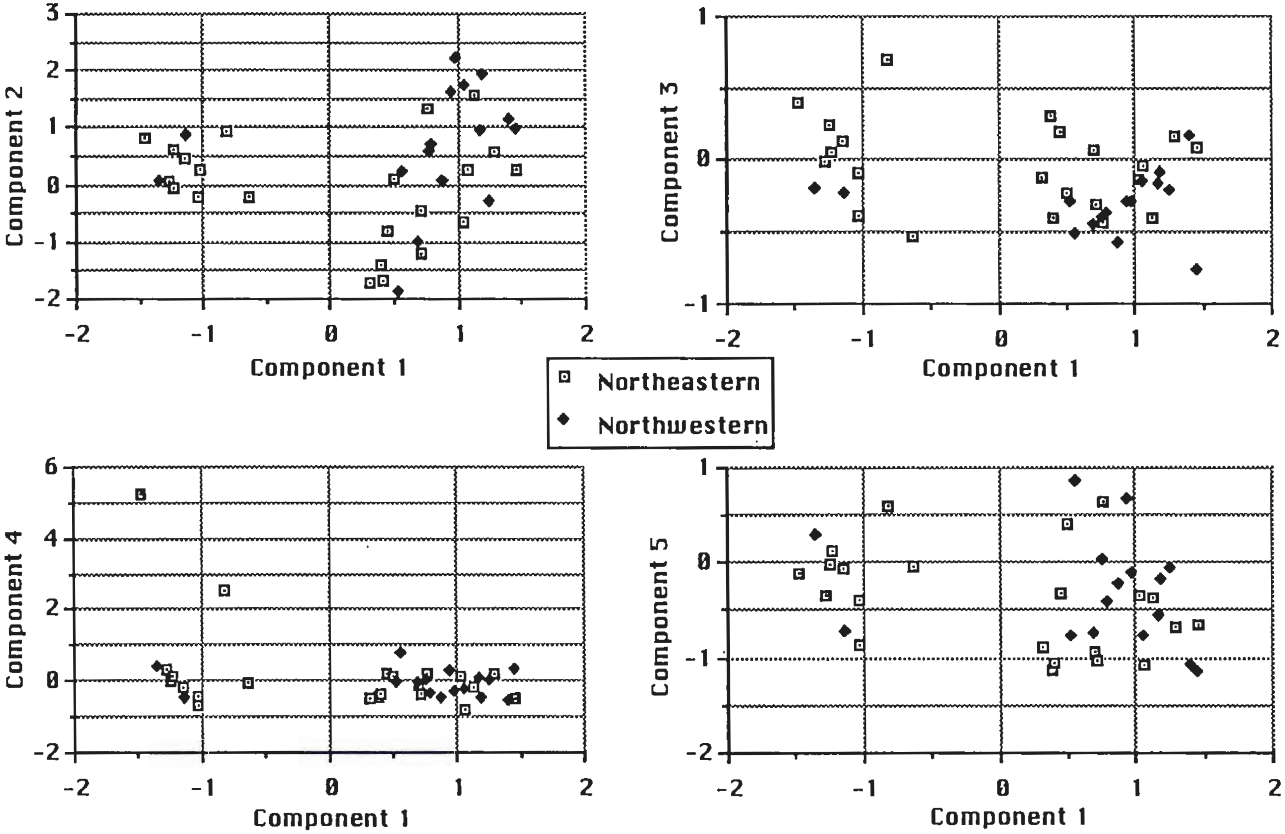

Figure 33. PCA Carbonate Pebble Geochemistry Component Score Plots. Each component is only shown once (against Component 1) to show that they do not separate the samples and to reduce the number of graphs.

TABLE 6.

Probability levels for the discriminant functions for each analysis.

ANALYSIS	PROBABILITY LEVELS (%)
1st RUN	95.5; 93.7; 90.0; [87.1; 73.6]
2nd RUN	99.3; 94.5; 92.7; [87.9; 74.7]
3rd RUN	99.8; 96.0; 92.8; 90.8; [75.5]
4th RUN	99.9; 99.3; 96.0; 91.5; [79.0]
5th RUN	99.5; 96.9; [76.2; 69.3; 41.4]
6th RUN	98.5; 93.4; [77.2; 63.0; 46.6]
7th RUN	[71.2]

The first run, using only grain size data, produced some clustering of the samples, especially the plot of the second and third function scores (Figure 34C). However, there are group overlaps of the Browerville and Brainerd (Figure 34A) and the Browerville and New Ulm (Figure 34B), along with generally closely spaced groups, that suggest a less than optimum definition of the groups based only on these data.

When the LOI data are included (second run) a better clustering occurs (Figure 35). This combination of data defines the Brainerd, Granite Falls, and Toimi groups (Figures 35A and B), but has difficulties when it comes to the Browerville, Hewitt, and New Ulm groups (Figures 35A, B, and C). The Hewitt till has already been shown, from the PCA results and previous investigations (Mooers, 1988), to be substantially different from the Browerville and New Ulm tills. As a result, the discriminant functions from this run are inadequate as well.

The third run, of grain size and magnetics data, produced a group of the Toimi samples (Figures 36A, B, and C), along with the New Ulm and Granite Falls groups (Figures 36A, B, C, D, and E). However the close proximity of the Browerville, Brainerd, and Hewitt sample groups presents a problem as these three tills have already been determined to be significantly different. This combination of data is also eliminated as a tool for discrimination among these six tills.

Discriminant function analysis of the grain size, LOI, and, magnetic data, in the fourth run, resulted in three of the biaxial plots exhibiting a discrete grouping of all six till

TABLE 7. DFA FUNCTION COEFFICIENTS

VARIABLE		COEFFICIENTS												
		RUN 1--GRAIN SIZE ONLY				RUN 2--GRAIN SIZE & LOI				RUN 3--GRAIN SIZE & MAGNETICS				
		DF1	DF2	DF3		DF1	DF2	DF3		DF1	DF2	DF3	DF4	
NEG1PHI		0.315	0.166	-0.201		-0.079	0.303	0.089		-0.066	-0.026	0.045	-0.048	
ZEROPHI		0.031	0.274	-0.256		-0.007	0.137	0.317		-0.029	0.137	0.192	-0.161	
ONEPHI		0.013	0.027	-0.309		-0.044	-0.049	0.197		-0.017	0.107	-0.082	-0.269	
TWOPHI		-0.067	-0.098	-0.237		-0.036	-0.179	0.117		0.006	0.088	-0.178	-0.249	
THREEPHI		-0.043	-0.17	-0.141		-0.038	-0.182	0		0.012	0.004	-0.194	-0.171	
FOURPHI		0.026	-0.105	0.019		-0.021	-0.045	-0.087		0.005	-0.07	-0.076	0.008	
FIVEPHI		-0.085	-0.01	0.106		0.031	-0.05	-0.028		0.02	-0.001	0.037	0.071	
SIXPHI		-0.137	0.035	0.124		0.059	-0.048	-0.004		0.026	-0.012	0.154	0.073	
SEVPHI		-0.082	-0.098	0.139		0.036	-0.079	-0.137		0.024	-0.094	0.046	0.066	
EIGHTPHI		-0.148	0.055	0.203		0.072	-0.029	-0.025		0.03	0	0.163	0.148	
NINEPHI		-0.113	-0.077	0.138		0.04	-0.097	-0.097		0.029	-0.067	0.055	0.069	
LT9PHI		-0.158	-0.068	0.707		0.132	0.006	-0.391		0.052	-0.086	0.077	0.565	
MEAN		-0.219	-0.112	0.446		0.103	-0.131	-0.246		0.057	-0.064	0.056	0.305	
STDEV		0.023	0.053	0.224		0.033	0.103	-0.1		0.001	-0.018	0.058	0.221	
SKEWNESS		0.092	0.04	-0.309		-0.064	0.017	0.177		-0.03	0.082	-0.095	-0.237	
KURTOSIS		0.018	-0.038	-0.25		-0.038	-0.061	0.095		-0.01	-0.007	-0.027	-0.236	
LOI						0.489	0.301	-0.156						
ARM										-0.242	-0.067	0.064	-0.252	
X lf										-0.169	-0.035	0.057	-0.176	
GRANITE														
PERTHITE														
VOLCANIC														
BASALT														
GABBRO														
SCHIST														
GREENSTONE														
QUARTZITE														
CHERT														
CARBONATE														
SANDSTONE														
HEMATITE														
OPAQUES														

TABLE 7. DFA FUNCTION COEFFICIENTS (CONT.)

VARIABLE	COEFFICIENTS						
	RUN 4--GRAIN SIZE, LOI & MAGNETICS					RUN 5--POINT COUNT	
	DF1	DF2	DF3	DF4		DF1	DF2
NEG1PHI	-0.061	-0.03	-0.026	-0.064			
ZEROPHI	-0.025	-0.037	0.139	-0.241			
ONEPHI	-0.019	0.035	0.105	-0.158			
TWOPHI	0.001	0.07	0.084	-0.09			
THREEPHI	0.006	0.075	0	-0.024			
FOURPHI	0.003	0.03	-0.071	0.043			
FIVEPHI	0.019	-0.003	-0.001	0.03			
SIXPHI	0.027	-0.028	-0.01	-0.039			
SEVPHI	0.023	-0.01	-0.094	0.025			
EIGHTPHI	0.031	-0.038	0.003	0.016			
NINEPHI	0.028	-0.002	-0.066	0.015			
LT9PHI	0.055	-0.078	-0.082	0.413			
MEAN	0.057	-0.028	-0.062	0.209			
STDEV	0.004	-0.043	-0.016	0.144			
SKEWNESS	-0.031	0.034	0.08	-0.129			
KURTOSIS	-0.012	0.029	-0.008	-0.171			
LOI	0.135	-0.414	0.157	0.272			
ARM	-0.225	-0.068	-0.067	-0.243			
X lf	-0.157	-0.05	-0.035	-0.176			
GRANITE						0.149	0.392
PERTHITE						-0.15	-0.018
VOLCANIC						-0.043	0.063
BASALT						-0.147	0.134
GABBRO						-0.724	-0.066
SCHIST						0.037	-0.008
GREENSTONE						-0.036	-0.05
QUARTZITE						0.033	0.124
CHERT						0.015	0.051
CARBONATE						0.137	-0.613
SANDSTONE						-0.121	0.067
HEMATITE						0.02	0.101
OPAQUES						-0.014	0.1

TABLE 7. DFA FUNCTION COEFFICIENTS (CONT. 2)

VARIABLE	COEFFICIENTS		
	RUN 6--GEOCHEMISTRY		RUN 7--CARBONATE PEBBLES
	DF1	DF2	DF1
PCA RUN 7 COMPONENT 1	0.404	-0.745	
PCA RUN 7 COMPONENT 2	0.144	0.266	
PCA RUN 7 COMPONENT 3	0.101	0.449	
PCA RUN 7 COMPONENT 4	0.135	0.154	
PCA RUN 7 COMPONENT 5	0.064	0.042	
PCA RUN 7 COMPONENT 6	0.008	-0.018	
AL			0.13
FE			-0.137
MN			0.261
MG			-0.612
NA			-0.134
K			0.072
LI			0.249
V			0.047
CR			0.157
CO			0.179
NI			-0.109
CU			0.145
ZN			0.125
GA			-0.23
SR			0.368
ZR			0.067
NB			-0.178
CD			0.049
SB			-0.396
BA			0.117
PB			-0.311
BI			-0.396
AS			0.071

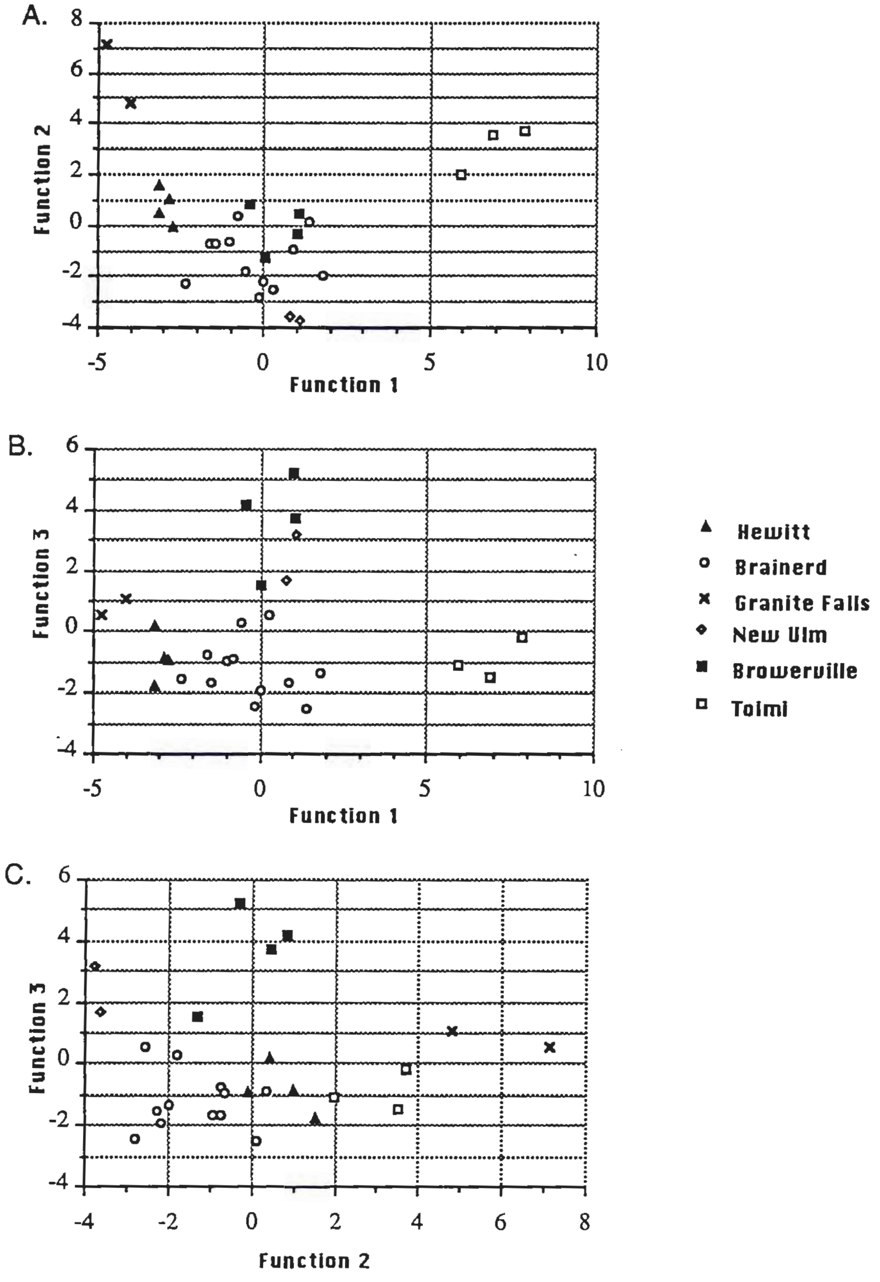

Figure 34. DFA grain size data function score plots.

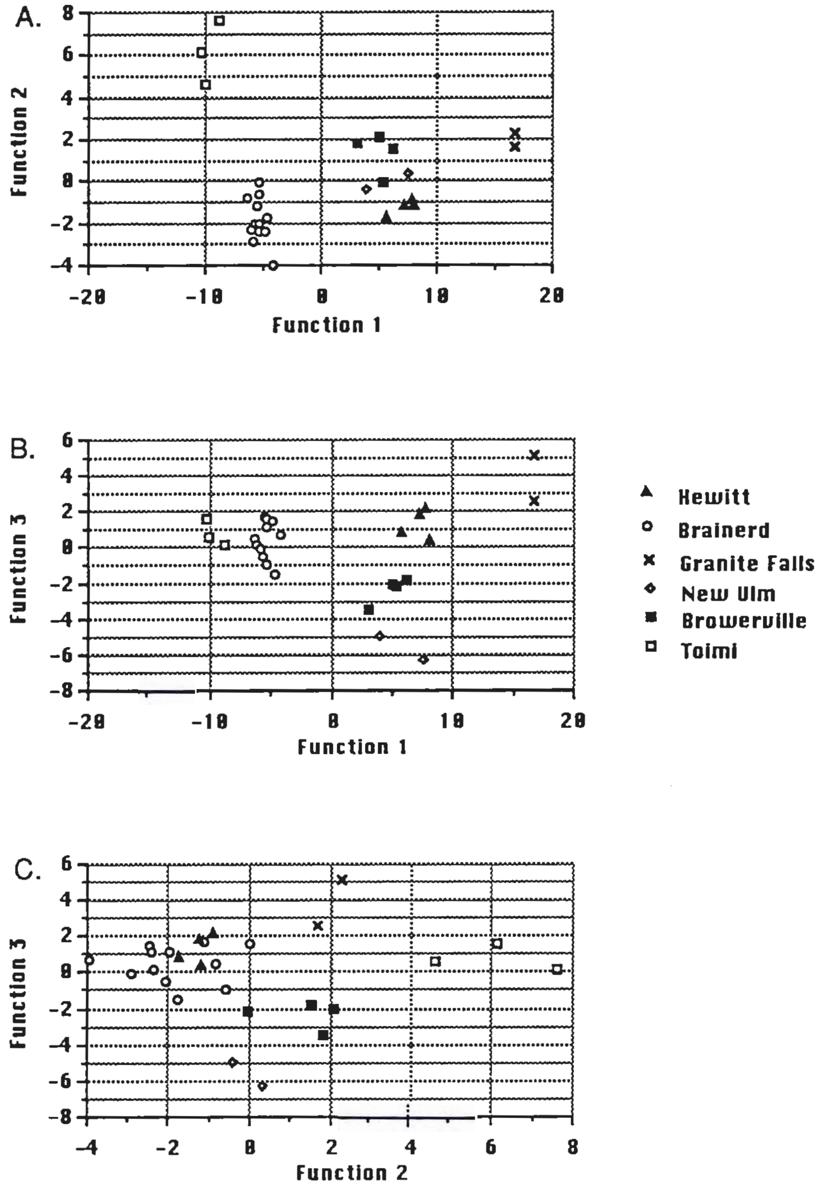

Figure 35. DFA grain size & LOI data function score plots.

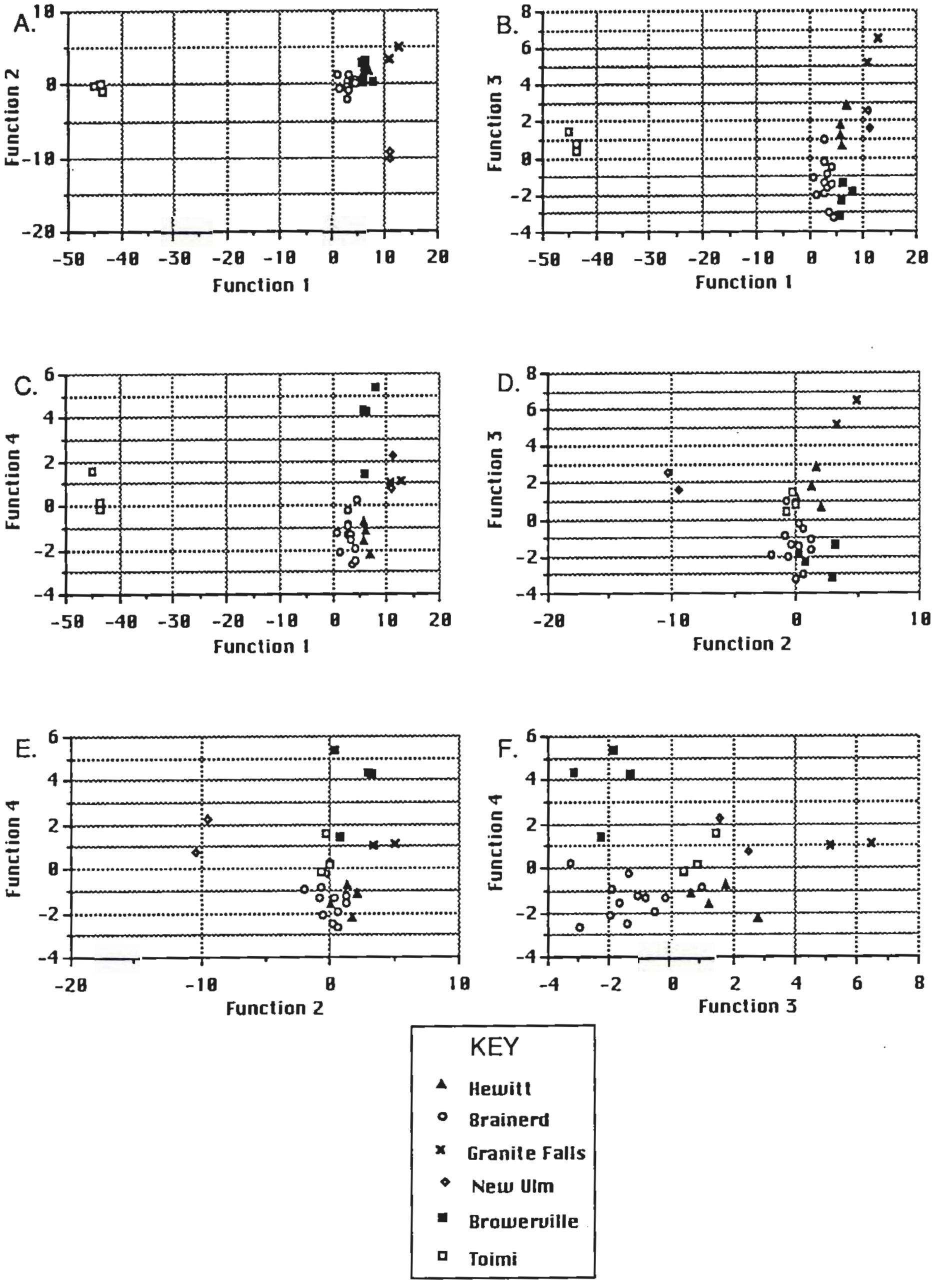

Figure 36. DFA grain size & magnetics data function score plots.

types (Figure 37A, C, and D), however, the proximity of these groups precludes the usefulness of these results.

When the point count data are considered using DFA, only two functions are significant, though both probabilities are over 95% (Table 6). The plot of Function 1 versus Function 2 (Figure 38A) shows a great deal of overlap, with only the Toimi samples a separate group.

In contrast, the two discriminant functions computed from the PCA geochemistry component scores show no overlapping of sample groups (Figure 38B), with the possible exception of the New Ulm and Granite Falls tills. This is to be expected, given the clear groupings seen in the PCA component score plots for Run 7 (geochemistry only, Figure 20), in which the New Ulm and Granite Falls samples plotted similarly. The separation of sample groups using the function scores is a confirmation of the PCA results, that the geochemistry of the silt and clay fractions of these six tills is very distinctive, again with the possible exception of the New Ulm and Granite Falls tills which appear to be very similar geochemically. These results differ from those from the PCA in that there is no indication of provenance from this analysis. Function 1 splits the groups based on carbonate content, irrespective of provenance, with the Brainerd and Toimi samples as the only non-calcareous tills (Figure 38B). This is probably because DFA does not seek to describe the groups, but rather to separate them.

DFA of the carbonate pebble geochemistry produced only one discriminant function, as there were only two groups specified, with which only 71.2% of the knowns can be correctly classified, and as such is not significant. However, a plot of the groups versus discriminant scores (Figure 39) was included in the interest of completeness (0= unknown, 1= northeastern, 2= northwestern).

Core OB-402 Stratigraphy

To quickly evaluate the general core stratigraphy, a number of sedimentary parameters are plotted versus depth, as grain size, LOI, and the magnetics are good indicators of broad lithologic boundaries in the core (Figure 40). The LOI data (Figure 40A) do not show much variation with the exception of the large jump around 125 feet. The magnetics data show a little more detail (Figure 40B), as does the grain size information (Figure 40C). By using these three graphs in conjunction, seven lithologic boundaries are defined, at approximately 10, 26, 45, 120, 136, 146, and 168 feet. The

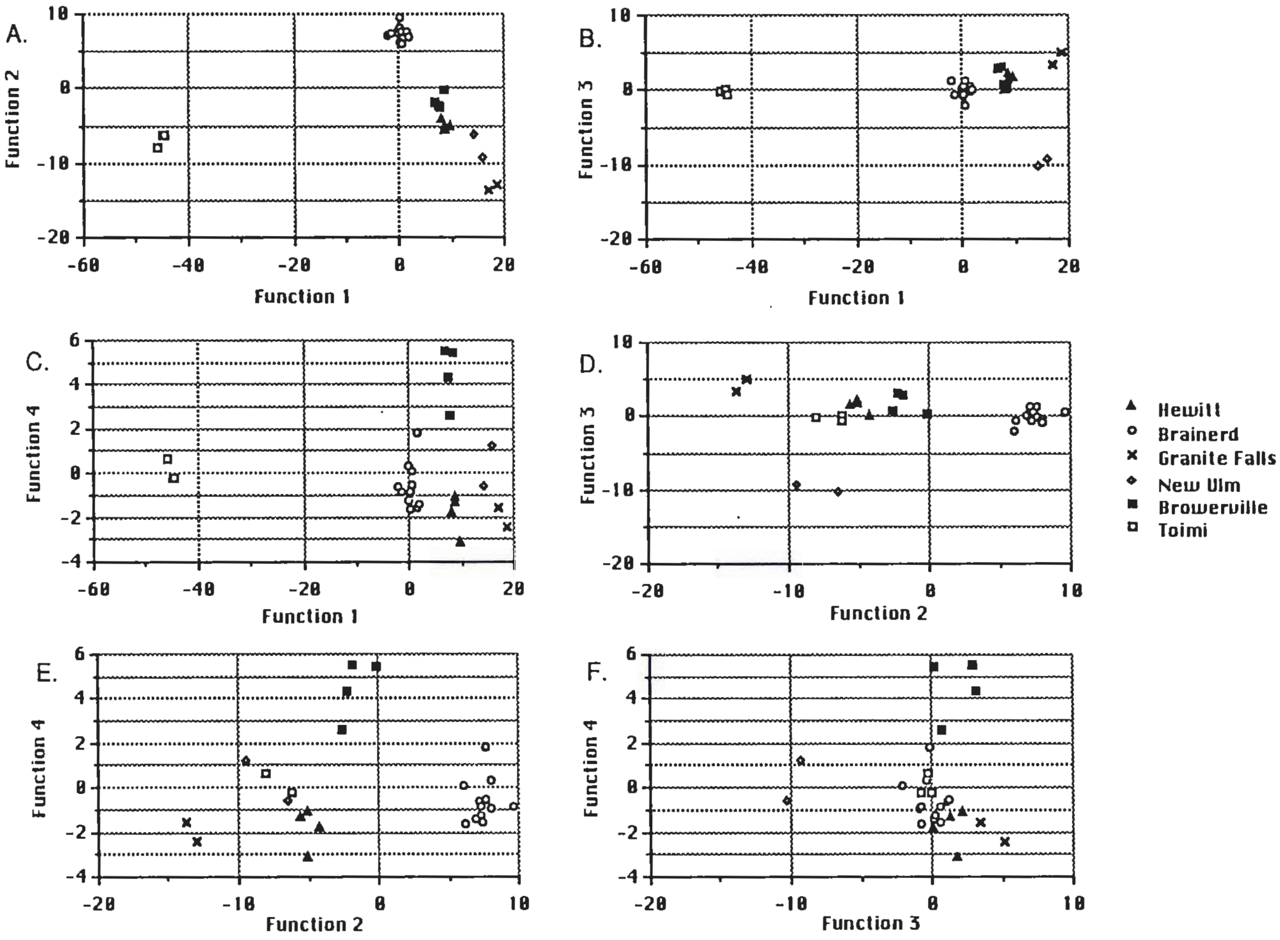

Figure 37. DFA grain size, LOI & magnetics data function score plots.

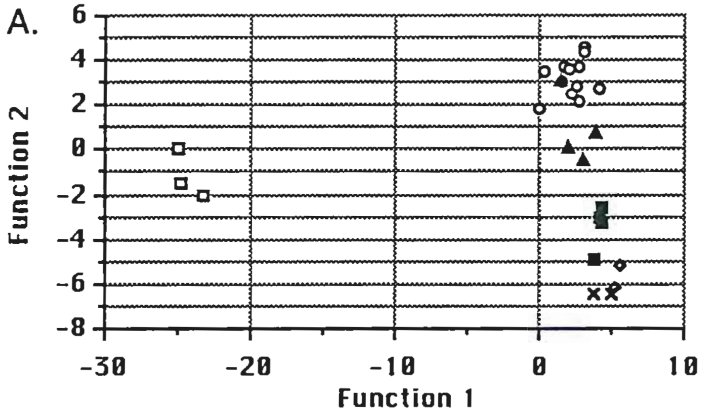

Figure 38A. DFA point count data function score plot.

○ Brainerd
▲ Hewitt
◇ New Ulm
× Granite Falls
■ Browerville
□ Toimi

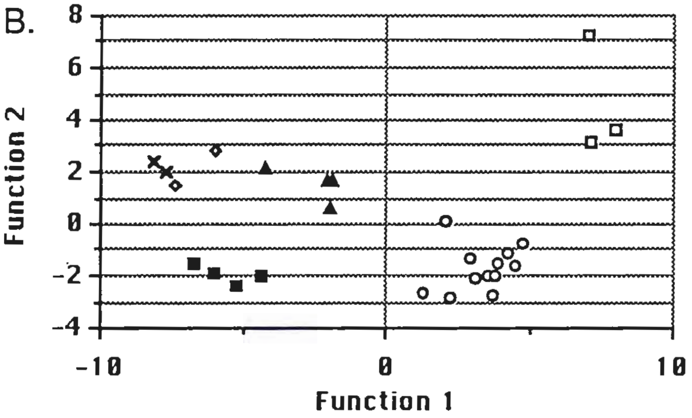

Figure 38B. DFA geochemistry data function score plot.

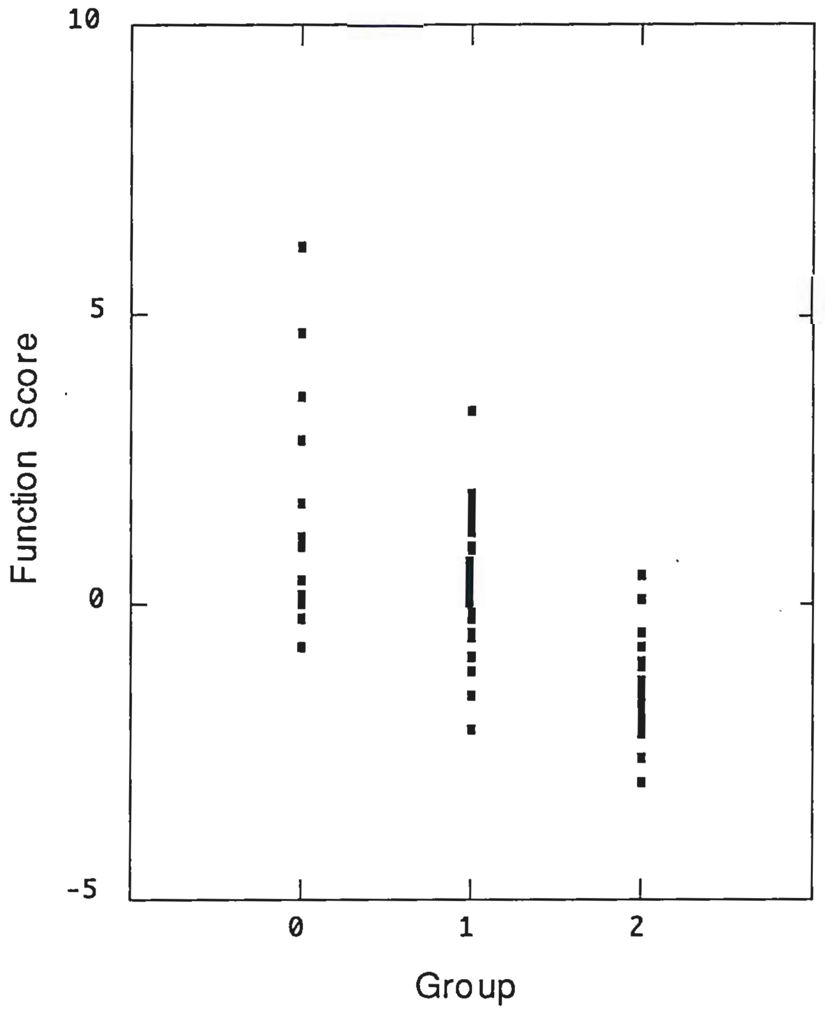

Figure 39. DFA carbonate pebble geochemistry data function score plot. 0 = unknown, 1 = northeastern, 2 = northwestern.

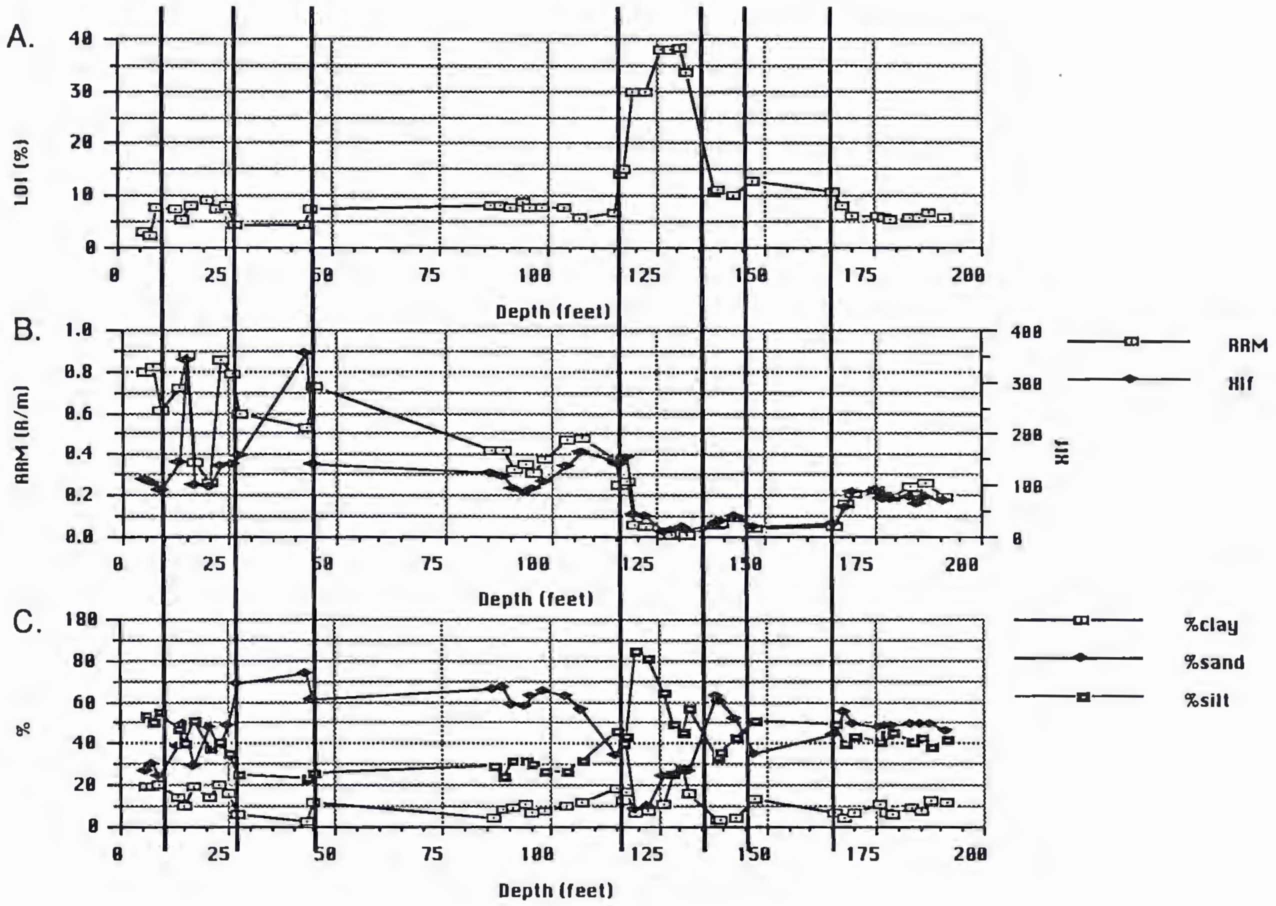

Figure 40. Till prarmeters versus depth in core OB-402.

third boundary (at 45 feet) is not readily apparent from looking at the stratigraphic column (Figure 11), while the others concur fairly well with the column.

The next step is to utilize the results of the principal components and discriminant function analyses to classify the 8 lithologic units delineated in Figure 40 based on the 6 known till groups analyzed earlier. As the best partitioning of the tills occurred with the geochemistry data in the PCA, those results will be considered first.

The plot of Component 1 versus 3 from the geochemistry run was interpreted as the best separation of northwestern versus northeastern provenance. Therefore, the initial conclusion that can be made is that there are at the most ten, and more likely only six, samples of northwestern provenance from core OB-402. Samples 402-31 through 34, 402-38 and 39 are the samples of probable northwestern origin, based on their locations below the northeastern/northwestern gap (Figure 41). Samples 402-35, 36, 37, and 40 are of possible northwestern provenance, based on their plotting within the gap (Figure 41). The placements of all ten of these samples indicate that they do not belong to the three known northwestern till groups.

The rest of the samples from the core plot in the upper "northeastern provenance" field of the graph, as Rainy lobe tills rather than Hewitt tills. There appears to be a slight clustering of samples from regions within the core. For example, samples 402-41 through 48 all plot at the lower right of the main group of samples, and 402-19 through 25 plot a little above and to the left of the previous group, perhaps suggesting separate glacial events (Figure 40).

The eighth run PCA results, which considered all the data, was best at separating the known groups by plotting Component 2 versus Component 3 (Figure 42). However, some of the core samples that were thought to be Rainy tills based on the Run 7 geochemistry results are plotting among the Browerville and New Ulm tills. The amount of carbonate in these core samples (<10%) suggests it is highly unlikely they are of northwestern affinities given the much higher average carbonate contents of the three northwestern tills (Table 4). This graph was included to show that, while the 8th run combined all the data and contained large amounts of geochemical information within its loadings, the addition of non-chemical information produces erroneous results.

Now the results of the DFA, in particular the predicted group memberships for the OB-402 core samples, will be considered. Samples 402-31 through 34 will be used as a test group with which to rate the predictions. These samples all come from one lithologic unit in the core, as can be seen in Figure 11. If the DFA predictions split these four

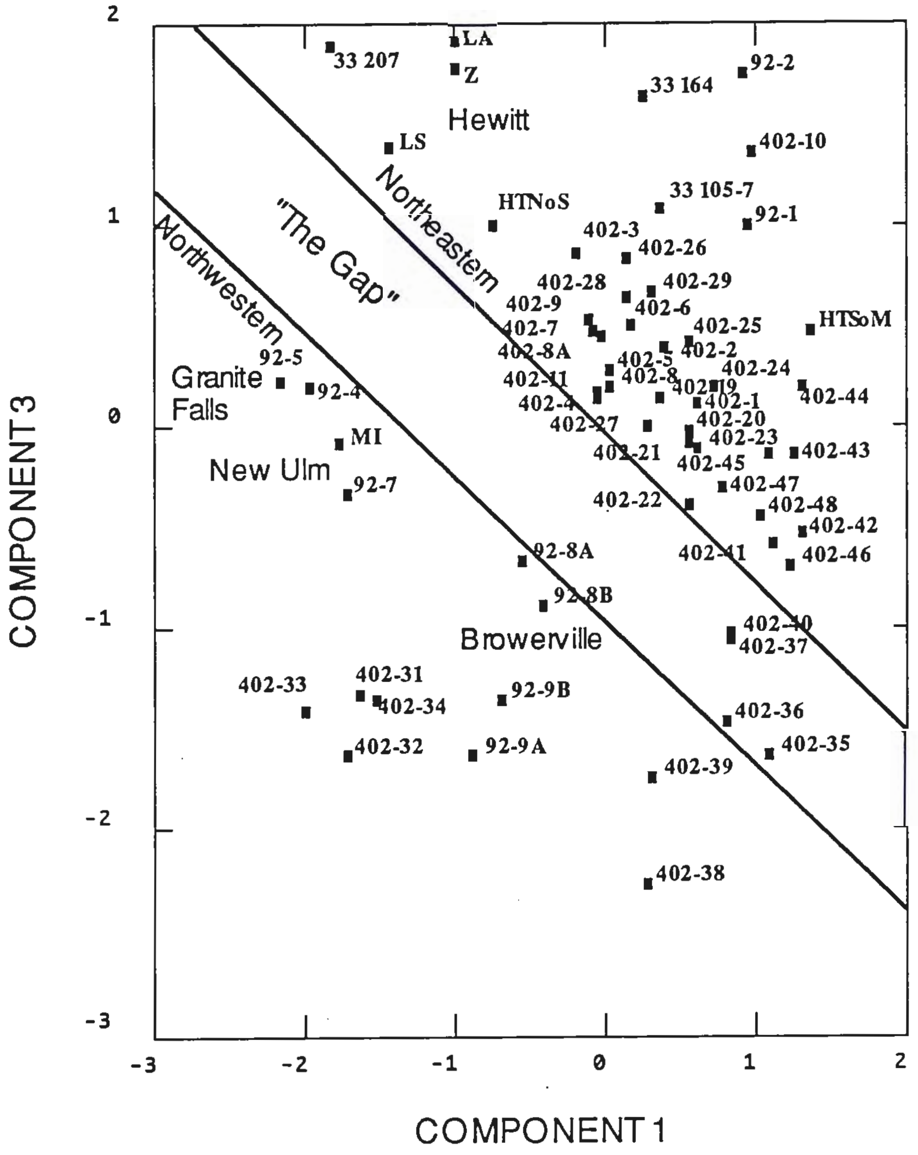

Figure 41. PCA geochemistry data component score plot, including unknowns from core OB-402.

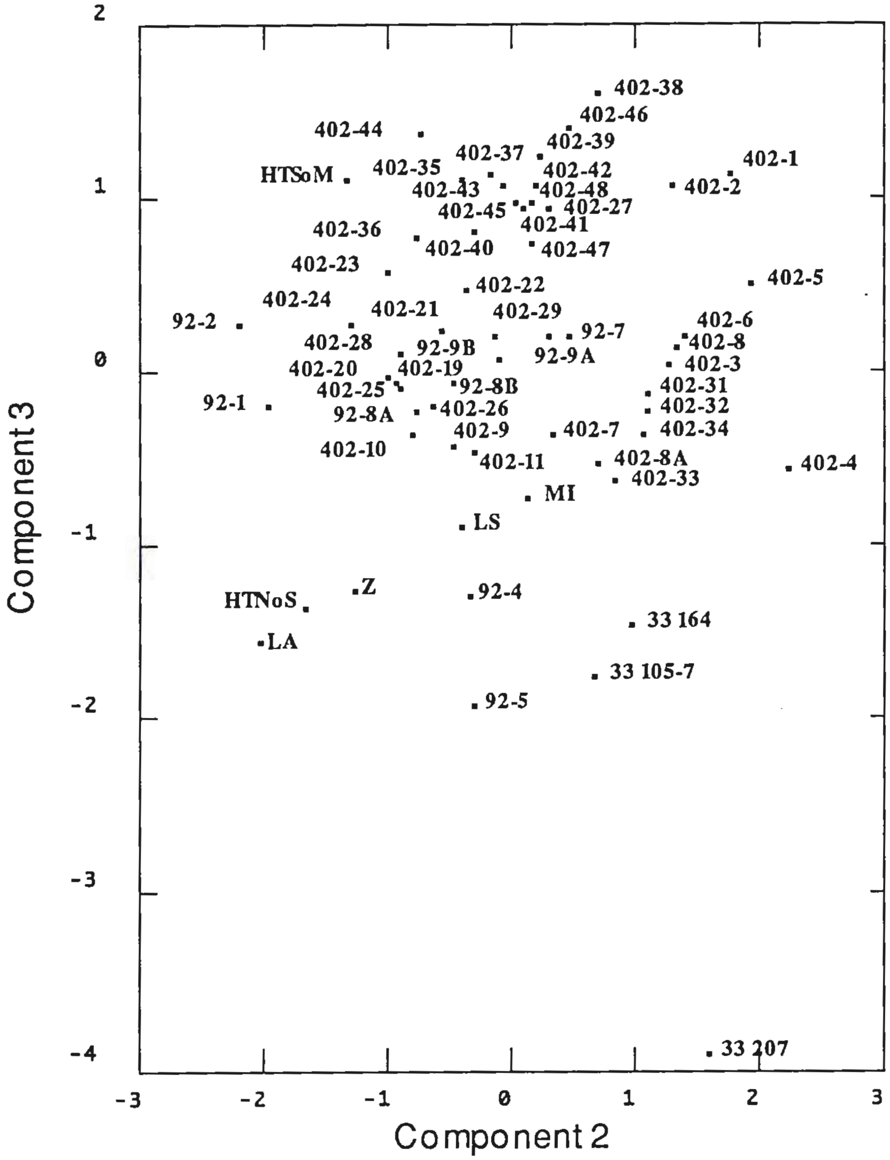

Figure 42. PCA all data component score plot, including unknown samples.

samples into groups that are not in any way similar, the predictions for that run will be considered invalid. In this manner, the second (grain size and LOI) and fourth run (grain size, LOI, and magnetics) predictions are eliminated, as these four samples are split into non-calcareous and calcareous groups, and the first run of grain size only data is eliminated because these samples are placed in groups with different provenance (Table 8). This leaves the predictions of the third, fifth, and sixth DFA runs (grain size and magnetics, point count, and geochemistry) as still viable.

In order to most accurately determine the stratigraphy of core OB-402, the analytical data must be considered along with the statistical predictions to ensure geologically sound conclusions. All three remaining sets of predictions include the appearance of Hewitt till somewhere within the core (Table 8). A comparison of the LOI results for these samples with those of the Hewitt knowns reveals that the core samples are unlikely to be Hewitt tills, as they have significantly less carbonate than the known Hewitt samples. Therefore, any northeastern drifts must have been deposited by the Rainy or Superior lobes, or their pre-Late Wisconsin counterparts.

Looking at the DFA predictions for the core samples, the four samples used as a screen (402-31 through 34) are definitely of northwestern provenance, based on their placements in Figure 41, though they were deposited by some other northwestern ice advance than those which deposited the three known northwestern tills.

Samples 402-35, 36, 37, and 40, described earlier as being of possible northwestern origin, are classed by all three runs as Brainerd tills, with the exception of 402-36 which is consistently grouped as a Browerville till. The likelihood of this sample being a Browerville till is not high given that it contains only a third the carbonate and has a magnetic signal four times the known Browerville samples (Appendix A). It will be therefore grouped with the other three samples as a Brainerd till, as it plots with them in Figure 41.

Samples 402-38 and 39 were described as of probable northwestern provenance above. These samples are classified in all except one case to be northwestern tills (Table 8). A similar problem arises as discussed immediately above with 402-36: they do not appear calcareous enough and are highly magnetic relative to the known northwestern samples. Unfortunately, these two samples are on either side of a lost interval in the core (Figure 11), where it can be seen that these two samples have the color (5Y) that is typical of northwestern tills, agreeing with the statistical predictions. These samples will be

TABLE 8
DISCRIMINANT FUNCTION ANALYSIS GROUP PREDICTIONS

Sample	Group	G. Size	GS & LOI	GS & Mag	GS/LOI/Mag	Pt. Cnt.	Geochem
402-1	0	3	1	1	1	1	6
402-2	0	3	1	6	6	1	1
402-3	0	5	5	1	1	1	6
402-4	0	4	1	1	5	6	6
402-5	0	4	1	4	1	4	6
402-6	0	5	5	4	4	4	1
402-7	0	4	5	1	2	1	1
402-8	0	1	1	1	1	4	1
402-8A	0	5	5	6	6	1	6
402-9	0	4	1	1	1	1	6
402-10	0	2	6	5	1	1	6
402-11	0	1	4	1	1	1	1
402-19	0	1	1	1	1	1	1
402-20	0	1	1	1	1	4	1
402-21	0	1	1	1	1	4	1
402-22	0	1	1	1	1	1	1
402-23	0	1	1	1	1	1	1
402-24	0	1	1	1	1	1	1
402-25	0	1	1	1	1	1	1
402-26	0	1	1	1	1	1	4
402-27	0	3	1	4	1	1	4
402-28	0	1	1	1	4	1	4
402-29	0	5	5	5	5	1	4
402-31	0	4	3	*3*	3	*3*	*2*
402-32	0	3	1	*3*	1	*3*	*5*
402-33	0	3	2	*3*	2	*5*	*2*
402-34	0	4	4	*3*	3	*3*	*2*
402-35	0	6	6	1	1	1	1
402-36	0	1	1	2	1	2	2
402-37	0	1	1	1	1	1	1
402-38	0	3	1	3	1	2	2
402-39	0	4	4	3	4	4	2
402-40	1	1	1	1	1	1	1
402-41	1	1	1	1	1	1	1
402-42	1	1	1	1	1	1	1
402-43	1	1	1	1	1	1	1
402-44	1	1	1	1	1	1	1
402-45	1	1	1	1	1	1	1
402-46	1	1	1	1	1	1	1
402-47	1	1	1	1	1	1	1
402-48	1	1	1	1	1	1	1
HTNoS	4	4	4	4	4	4	4
HTSoM	1	1	1	1	1	1	1
LA	4	4	4	4	4	4	4
LS	4	4	4	4	4	4	4
MI	5	5	5	5	5	5	3
Z	4	4	4	4	4	4	4
92-1	1	1	1	1	1	1	1
92-2	1	1	1	1	1	1	1
92-4	3	3	3	3	3	3	3
92-5	3	3	3	3	3	3	3
92-7	5	5	5	5	5	5	5
92-8A	2	2	2	2	2	2	2
92-8B	2	2	2	2	2	2	2
92-9A	2	2	2	2	2	2	2
92-9B	2	2	2	2	2	2	2
33105-7	6	6	6	6	6	6	6
33164	6	6	6	6	6	6	6
33207	6	6	6	6	6	6	6

0 = unknown; 1 = Brainerd; 2 = Browerville; 3 = Granite Falls; 4 = Hewitt; 5 = New Ulm; 6 = Toimi

classed as northwestern tills, though they appear to be contaminated with northeastern material.

The tills above the undisputed northwestern unit (402-31 through 34) are all predicted to be of northeastern provenance, except for two instances which can be ruled out based on low carbonate content.

Further refinement of this stratigraphy is made possible through the use of information from the visual description of the core and the analytical and statistical results, along with enough of the previously proposed glacial histories for the area (Wright, 1972; Mooers, 1988) to provide a guideline as to the possibilities.

From all this information, the final stratigraphy of core OB-402 is interpreted as:

0-10'	Alborn till
10-45'	Superior till and related deposits
45-118'	Rainy till and related deposits
118-133'	pre-Late Wisconsin northwestern till
133-146'	pre-Late Wisconsin northeastern till
146-168'	pre-Late Wisconsin northwestern till
168-192'	pre-Late Wisconsin northeastern till

The presence of the Alborn till, while it is not represented among the tills analyzed in this study, is justified by the redder color and siltier texture of the samples from the top ten feet of the core and the clayey soil horizon which was not sampled. It is also viewed as the uppermost till in this region by several authors (Mooers, 1988; Matsch and Schneider, 1986; Wright, 1972).

The next unit is Superior till, in this case the Cromwell Formation. These samples are not the typical red color associated with tills of the Superior lobe. Also, the presence of a Superior till is not mandated by accepted glacial histories for this area, though the Mille Lacs moraine could easily encompass the location of core OB-402. There are three arguments for a Superior till unit. 1) This section of the core is slightly coarser than the overlying Alborn till, being composed mostly of loam tills, except for the bottom 6 feet, compared to the silt loam nature of the Alborn till. It also has a finer texture than the underlying till. The coarseness of the bottom 6 feet could be explained by incorporation of the underlying sands. 2) The upper 45 feet of the core has higher ARM values, which is sensitive to finer grained magnetite typical of the basalts of the North Shore Volcanic

Group (Mooers, 1988, 1990b), than the samples below it. 3) There is a higher percentage of basalt and gabbro in this unit, with a corresponding lower percentage of granite, that argues for a source region within the Lake Superior basin, which indicates Superior lobe.

The Late Wisconsin Superior lobe would only have been allowed access to this region after the retreat of the Late Wisconsin Rainy lobe. As a result, the Superior lobe would have had to traverse an area of ice cored Rainy lobe deposits, incorporating them as it advanced (Mooers, 1988). The final deposits by the Superior lobe would then be a mixture of both till types, with occasional areas of less contaminated Superior or Rainy till. This contamination may account for the lack of the diagnostic red color in this Superior till, especially given the limited exposure visible in a core.

The interval from 45-118 feet is interpreted to be Rainy lobe outwash over Rainy lobe (Brainerd) till. The multivariate statistical results group these samples as Brainerd tills. The tills are also very sandy, and have sand lithologies dominated by granite, followed by sandstone. The bottom two samples in this unit exhibit a contamination by silt and carbonate sand grains from the underlying unit. The base of this unit is interpreted to be the horizon marking the beginning of the Late Wisconsinan sequence.

The choice of northwestern over northeastern provenance for the 146-168 foot interval was made based on the plot of samples 402-38 and 39 in Figure 41 and slightly higher carbonate content than their northeastern neighbors. These samples appear to be slight mixtures of mostly northwestern till with under and overlying northeastern material.

CONCLUSIONS

The results of this investigation have provided several specific conclusions related to tills in Minnesota in general. Foremost among them is that northeastern tills do contain carbonate. The Hewitt till has been shown geochemically to be of northeastern provenance in spite of the fact that it is calcareous. Goldstein (1985, 1989) argued that the carbonate in the Hewitt till was from contamination with underlying northwestern drifts. The placement of the Hewitt samples in Figure 20 is clearly within the northeastern provenance field, indicating that there is no contamination from northwestern sources.

Of the six tills used as control groups, all except two are geochemically distinct. The New Ulm and Granite Falls samples plot very close together in the graphs in Figure 20. This indicates that these two tills were deposited by separate advances of the same glacier, or at least had the same source region.

With reference to northeastern carbonate, geochemical analysis of the carbonate pebbles from tills of known provenance has shown that the northeastern and northwestern carbonates are indistinguishable based on the analyses used in this investigation.

The glacial history of the region north of Mille Lacs Lake, as reflected in the stratigraphy of core OB-402, shows a repeated alternation of northeastern and northwestern glaciers, the Old Rainy and Winnipeg lobes of Meyer (in Martin, *et al.*, 1988, 1989), during the pre-Late Wisconsin. The first Late Wisconsin glacier to occupy the area was the Rainy lobe. Upon withdrawal of the Rainy lobe, the Superior lobe was able to spread into the region during its Automba phase (Wright, 1972; Mooers, 1988). The final glacial advance recorded is by the St. Louis sublobe of the Des Moines lobe.

This investigation shows that the commonly employed methods of grain size analysis, carbonate content, sand grain lithology, and rock magnetic properties for describing tills in Minnesota are broadly related to provenance but provide no systematic information and cannot always distinguish among till groups. The parameter that best defines the individual tills is the geochemistry of the silt and clay fractions, which does distinguish between northeastern and northwestern provenance.

As a result, the method(s) used in glacial geological investigations should be tailored to the goals of the project and the tills to be investigated. For instance, studies into the regional variability of a particular till sheet might want to employ grain size, carbonate content, sand grain lithology, and rock magnetic properties as variables with which to describe variation in the till. However, if it is desired to develop the stratigraphy for an area in which the general sequence is already known, the actual methods of analysis used should be dependent on the expected units. A study in an area where there are no northwestern drifts would not need to look at carbonate content, and rock magnetic properties would not need to be considered in northeastern tills, unless a variation in magnetite grain size is expected in the units.

Over all, a general stratigraphic study, especially over a large region, should employ geochemistry of the silt and clay fractions as the major distinguishing and correlating tool. Secondary to this, in decreasing order of importance, are rock magnetic properties, sand grain lithologies, and grain size analysis. A measure of the carbonate content does not need to be made as it is included in the geochemistry.

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APPENDIX A

RAW AND NORMALIZED TILL SAMPLE DATA

Sample no	Location	Depth	Color	Type	-1 phi(%)	0 phi(%)	1 phi(%)	2 phi(%)	3 phi(%)	4 phi(%)	5 phi(%)	6 phi(%)
402-1	46-28W-10CD	5-6'	7.5YR 4/4		2.94	1.73	3.77	7.66	7.23	5.49	13.56	9.13
402-2	46-28W-10CD	6-8'	7.5YR 4/4		0.58	1.42	4.61	9.22	8.51	6.21	14.74	9.74
402-3	46-28W-10CD	12-14'	10YR 3/3		13.82	4.89	6	8.77	7.75	5.77	12.81	6.95
402-4	46-28W-10CD	14-16'	10YR 3/3		17.11	7.36	7.73	10.59	8.78	6.33	10.5	7.93
402-5	46-28W-10CD	8-9.5'	7.5YR 4/4		9.71	2.54	3.74	6.04	5.58	3.76	14.32	7.73
402-6	46-28W-10CD	16-17'	7.5YR 4/4		16.38	2.7	4.21	6.56	5.8	5.35	14.23	8.2
402-7	46-28W-10CD	20-21'	10YR 4/3		22.48	4.61	7.33	11.48	8.78	5.1	11.24	6.99
402-8	46-28W-10CD	22.5-23.5'	10YR 4/3		12.43	3.38	7.1	10.81	7.81	4.63	9.62	7.37
402-8A	46-28W-10CD	25-25.5'	10YR 4/3		28.11	5.17	7.87	11.18	7.24	3.81	9.78	3.03
402-9	46-28W-10CD	26-28'	10YR 4/2		17.13	6.41	13.77	20.45	11.55	5.22	6.49	4.46
402-10	46-28W-10CD	42-44'	10YR 3/3		25.36	3.43	6.92	17.53	16.44	10.89	10.2	3.57
402-11	46-28W-10CD	44.5-45'	10YR 4/2		14.13	3.24	8.29	23.96	13.37	4.04	7.18	4.99
402-19	46-28W-10CD	85.5-87'	10YR 4/2		11.23	6.43	10.32	19.57	14.85	7.65	9.52	5.34
402-20	46-28W-10CD	88-89'	10YR 4/2		7.02	6.01	11.62	21.35	15.51	8.05	7.99	4.18
402-21	46-28W-10CD	90.5-91.5'	10YR 4/2		9.52	5.15	9.23	17.61	13.65	7.55	9.19	5.5
402-22	46-28W-10CD	93-94'	10YR 4/2		10.7	4.82	9.06	17.06	13.28	7.4	9.74	5.3
402-23	46-28W-10CD	94.7-96'	10YR 3/3		4.67	4.85	9.83	20.03	16.14	8.87	10.58	5.58
402-24	46-28W-10CD	97.5-98.5'	10YR 3/3		6.83	5.56	9.9	21.31	16.7	7.8	9.39	4.61
402-25	46-28W-10CD	101.5-105'	10YR 3/3		11.63	4.96	9.19	19.04	15.02	7.28	8.78	4.82
402-26	46-28W-10CD	106-108'	10YR 3/3		8.97	4.24	8.72	17.08	13.64	7.76	10.09	6
402-27	46-28W-10CD	114.5-116'	10YR 3/3		2.5	2.28	4.93	10.32	9.97	6.24	11.9	11.15
402-28	46-28W-10CD	116-116.4'	10YR 4/2		2.05	2.21	5.42	11.57	16.3	9.97	15.64	10.75
402-29	46-28W-10CD	116.5-118'	10YR 3/3		9.57	3.04	6.67	10.13	9.05	7.05	10.96	11.27
402-29A	46-28W-10CD	119.2-120'	2.5Y 5/2		1.6	0.65	0.89	1.41	1.94	3.63	27.41	32.64
402-30	46-28W-10CD	121-123'	2.5Y 5/2		5.59	1.63	1.33	2.16	2.36	2.42	22.47	31.2
402-31	46-28W-10CD	125.5-126.5'	5Y 4/1		5.69	2.38	3.57	5.71	5.82	5.75	12.75	12.21
402-32	46-28W-10CD	128-129'	5Y 4/1		2.92	2.51	3.92	5.99	6.05	5.47	10.25	9.67
402-33	46-28W-10CD	130-131'	5Y 4/1		4.43	2.59	4.26	7.14	6.46	5.32	11.98	7.87
402-34	46-28W-10CD	131-133'	5Y 4/1		8.66	2.53	4.08	6.47	6.04	5.33	12.18	10.18
402-35	46-28W-10CD	137.5-139'	7.5YR 4/4		16.98	4.97	9.58	16.82	13.16	7.5	5.18	7.82
402-36	46-28W-10CD	139-140'	7.5YR 4/4		9.05	4.81	9.95	17.55	14.92	8.05	12.72	6.76
402-37	46-28W-10CD	142.5-143.5'	7.5YR 4/4		5.28	4.4	9.02	15.44	12.68	7.95	11.69	8.49
402-38	46-28W-10CD	145.5-148.5'	5Y 4/2		3.47	3.46	6.06	9.68	8.42	6.58	15.29	9.82
402-39	46-28W-10CD	165-166'	5Y 3/2		7.39	3.95	7.22	11.99	10.07	7.84	14.81	10.51
402-40	46-28W-10CD	167.5-168.4'	10YR 3/3		8.1	4.81	9.34	14.58	12.22	10	13.59	8.43

Sample no	Location	Depth	Color	Type	-1 phi(%)	0 phi(%)	1 phi(%)	2 phi(%)	3 phi(%)	4 phi(%)	5 phi(%)	6 phi(%)
402-41	46-28W-10CD	169.5-170.5'	2.5Y 4/2		15.39	4.89	7.03	10.85	10.25	8.8	13.32	8.02
402-42	46-28W-10CD	175-176'	2.5Y 4/2		7.68	5	7.72	12.29	10.48	8.39	12	8.34
402-43	46-28W-10CD	176.5-178'	2.5Y 4/2		4.58	4.25	7.24	12.22	13.02	9.78	16.58	7.94
402-44	46-28W-10CD	178.5-179.5'	2.5Y 4/2		1.84	2.22	4.02	10.76	17.68	13.39	19.37	9.52
402-45	46-28W-10CD	182.5-184'	2.5Y 3/2		10.08	3.58	5.92	10.96	12.77	11.02	15.97	8.18
402-46	46-28W-10CD	185-186'	2.5Y 3/2		10.58	4.51	7.36	12.54	11.06	8.62	12.23	8.23
402-47	46-28W-10CD	186.5-188'	2.5Y 3/2		5.64	4.7	7.59	13.22	12.66	8.36	12.81	8.31
402-48	46-28W-10CD	190.5-192'	2.5Y 4/2		5.09	4.13	7.61	12.45	10.45	9.29	14.6	9.1
HT NoS	137-35W-27C	Surface sample	2.5Y 5/4	Hewitt	14.26	8.24	14.46	19.15	11.32	5.66	7.28	4.49
HT SoM	137-35W-4AAA	Surface sample	2.5Y 5/4	Brainerd	4.46	4.29	10.17	19.73	16.03	8.68	10.74	5.12
L A	143-35W-27BBAD	Surface sample	2.5Y 5/4	Hewitt	6.77	6.38	11.71	19.38	14.22	7.82	10.24	6.97
LS	143-36W-24AA	Surface sample	2.5Y 5/4	Hewitt	2.92	2.46	4.76	8.86	9.97	9.18	16.73	10.5
MI	147-42W-35BBCC	Surface sample	2.5Y 5/4	New Ulm	5.58	1.59	2.81	5.85	10.02	9.82	13.35	9.63
Z	144-37W-5DD	Surface sample	2.5Y 6/4	Hewitt	3.88	4.72	9.34	16.15	13.51	9.06	14.35	7.47
92-1	43-30W-12CCD	Surface sample	10YR 4/4	Brainerd	10.68	6.06	12	23.21	16.82	8.22	8.32	3.22
92-2	43-30W-14ABA	Surface sample	10YR 4/3	Brainerd	3.31	3.66	9.39	23.39	19.86	9.75	10.99	7.39
92-4	116-39W-28DBBB	Surface sample	2.5Y 5/4	Granite Falls	2.53	3.79	5.37	8.46	9.5	9	15.34	11.31
92-5	116-39W-28DBBB	Surface sample	2.5Y 5/4	Granite Falls	6.44	8.66	4.3	7.06	8.64	8.73	16.23	10.01
92-7	112-34W-4BD	Surface sample	5Y 4/3	New Ulm	6.2	3	4.28	7.88	11.4	10.16	15.45	8.76
92-8A	130-33-16DBC	Surface sample	5Y 4/2	Browerville	4.26	3.55	6.9	13.62	13.39	9.56	14.41	7.23
92-8B	130-33-16DBC	Surface sample	5Y 4/3	Browerville	4.71	3.08	6.49	12.93	13.05	9.65	14.27	7.72
92-9A	128-32W-16CAC	Surface sample	5Y 4/2	Browerville	3.99	2.58	5.3	9.56	9.48	7.9	12.5	7.8
92-9B	128-32W-16CAC	Surface sample	5Y 4/2	Browerville	4.27	3.26	6.04	11.05	11.17	9.21	14.39	8.3
33 105-7	57-10W-21A	105-7'	10YR 3/3	Toimi	25.2	8.36	8.7	10.66	10.87	8.79	10.87	5.09
33 164	57-10W-21A	164'	10YR 4/3	Toimi	10.54	6.19	7.91	11.43	12.3	11.06	13.32	8.44
33 207	57-10W-21A	207'	10YR 4/2	Toimi	37.99	5.1	9.47	9.61	7.07	6.29	8.92	4.75
average		**NORMALIZED DATA BELOW**			9.23	4.15	7.2	12.75	11.15	7.61	12.51	8.39
Stdev					7.19	1.74	2.82	5.37	3.77	2.16	3.67	4.89
402-1	46-28W-10CD	5-6'	7.5YR 4/4		-0.87	-1.4	-1.22	-0.95	-1.04	-0.98	0.28	0.15
402-2	46-28W-10CD	6-8'	7.5YR 4/4		-1.2	-1.57	-0.92	-0.66	-0.7	-0.65	0.61	0.28
402-3	46-28W-10CD	12-14'	10YR 3/3		0.64	0.42	-0.43	-0.74	-0.9	-0.85	0.08	-0.3
402-4	46-28W-10CD	14-16'	10YR 3/3		1.1	1.85	0.19	-0.4	-0.63	-0.59	-0.55	-0.1
402-5	46-28W-10CD	8-9.5'	7.5YR 4/4		0.07	-0.93	-1.23	-1.25	-1.48	-1.78	0.49	-0.14

Sample no	Location	Depth	Color	Type	-1 phi(%)	0 phi(%)	1 phi(%)	2 phi(%)	3 phi(%)	4 phi(%)	5 phi(%)	6 phi(%)
402-6	46-28W-10CD	16-17'	7.5YR 4/4		0.99	-0.84	-1.06	-1.15	-1.42	-1.05	0.47	-0.04
402-7	46-28W-10CD	20-21'	10YR 4/3		1.84	0.26	0.05	-0.24	-0.63	-1.16	-0.35	-0.29
402-8	46-28W-10CD	22.5-23.5'	10YR 4/3		0.45	-0.45	-0.04	-0.36	-0.89	-1.38	-0.79	-0.21
402-8A	46-28W-10CD	25-25.5'	10YR 4/3		2.63	0.59	0.24	-0.29	-1.04	-1.76	-0.74	-1.1
402-9	46-28W-10CD	26-28'	10YR 4/2		1.1	1.3	2.33	1.43	0.11	-1.11	-1.64	-0.8
402-10	46-28W-10CD	42-44'	10YR 3/3		2.24	-0.42	-0.1	0.89	1.4	1.52	-0.63	-0.99
402-11	46-28W-10CD	44.5-45'	10YR 4/2		0.68	-0.53	0.39	2.09	0.59	-1.65	-1.45	-0.7
402-19	46-28W-10CD	85.5-87'	10YR 4/2		0.28	1.31	1.11	1.27	0.98	0.02	-0.82	-0.62
402-20	46-28W-10CD	88-89'	10YR 4/2		-0.31	1.07	1.57	1.6	1.16	0.2	-1.23	-0.86
402-21	46-28W-10CD	90.5-91.5'	10YR 4/2		0.04	0.57	0.72	0.91	0.66	-0.03	-0.91	-0.59
402-22	46-28W-10CD	93-94'	10YR 4/2		0.2	0.38	0.66	0.8	0.57	-0.1	-0.76	-0.63
402-23	46-28W-10CD	94.7-96'	10YR 3/3		-0.63	0.4	0.93	1.36	1.32	0.58	-0.53	-0.58
402-24	46-28W-10CD	97.5-98.5'	10YR 3/3		-0.33	0.81	0.96	1.59	1.47	0.09	-0.85	-0.77
402-25	46-28W-10CD	101.5-105'	10YR 3/3		0.33	0.46	0.71	1.17	1.03	-0.15	-1.02	-0.73
402-26	46-28W-10CD	106-108'	10YR 3/3		-0.04	0.05	0.54	0.81	0.66	0.07	-0.66	-0.49
402-27	46-28W-10CD	114.5-116'	10YR 3/3		-0.94	-1.08	-0.81	-0.45	-0.31	-0.64	-0.17	0.56
402-28	46-28W-10CD	116-116.4'	10YR 4/2		-1	-1.12	-0.63	-0.22	1.37	1.09	0.85	0.48
402-29	46-28W-10CD	116.5-118'	10YR 3/3		0.05	-0.64	-0.19	-0.49	-0.56	-0.26	-0.42	0.59
402-29A	46-28W-10CD	119.2-120'	2.5Y 5/2		-1.06	-2.02	-2.24	-2.11	-2.44	-1.84	4.06	4.96
402-30	46-28W-10CD	121-123'	2.5Y 5/2		-0.51	-1.45	-2.08	-1.97	-2.33	-2.41	2.71	4.66
402-31	46-28W-10CD	125.5-126.5'	5Y 4/1		-0.49	-1.02	-1.29	-1.31	-1.41	-0.86	0.06	0.78
402-32	46-28W-10CD	128-129'	5Y 4/1		-0.88	-0.95	-1.16	-1.26	-1.35	-0.99	-0.62	0.26
402-33	46-28W-10CD	130-131'	5Y 4/1		-0.67	-0.9	-1.04	-1.04	-1.24	-1.06	-0.15	-0.11
402-34	46-28W-10CD	131-133'	5Y 4/1		-0.08	-0.93	-1.11	-1.17	-1.36	-1.06	-0.09	0.37
402-35	46-28W-10CD	137.5-139'	7.5YR 4/4		1.08	0.47	0.84	0.76	0.53	-0.05	-2	-0.12
402-36	46-28W-10CD	139-140'	7.5YR 4/4		-0.02	0.38	0.97	0.89	1	0.2	0.06	-0.33
402-37	46-28W-10CD	142.5-143.5'	7.5YR 4/4		-0.55	0.14	0.64	0.5	0.41	0.16	-0.22	0.02
402-38	46-28W-10CD	145.5-148.5'	5Y 4/2		-0.8	-0.4	-0.41	-0.57	-0.72	-0.48	0.76	0.29
402-39	46-28W-10CD	165-166'	5Y 3/2		-0.26	-0.12	0.01	-0.14	-0.29	0.11	0.63	0.43
402-40	46-28W-10CD	167.5-168.4'	10YR 3/3		-0.16	0.38	0.76	0.34	0.28	1.11	0.29	0.01
402-41	46-28W-10CD	169.5-170.5'	2.5Y 4/2		0.86	0.42	-0.06	-0.35	-0.24	0.55	0.22	-0.08
402-42	46-28W-10CD	175-176'	2.5Y 4/2		-0.22	0.49	0.18	-0.08	-0.18	0.36	-0.14	-0.01
402-43	46-28W-10CD	176.5-178'	2.5Y 4/2		-0.65	0.06	0.01	-0.1	0.5	1.01	1.11	-0.09
402-44	46-28W-10CD	178.5-179.5'	2.5Y 4/2		-1.03	-1.11	-1.13	-0.37	1.73	2.68	1.87	0.23
402-45	46-28W-10CD	182.5-184'	2.5Y 3/2		0.12	-0.33	-0.45	-0.33	0.43	1.58	0.94	-0.04

Sample no	Location	Depth	Color	Type	-1 phi(%)	0 phi(%)	1 phi(%)	2 phi(%)	3 phi(%)	4 phi(%)	5 phi(%)	6 phi(%)
402-46	46-28W-10CD	185-186'	2.5Y 3/2		0.19	0.21	0.06	-0.04	-0.02	0.47	-0.08	-0.03
402-47	46-28W-10CD	186.5-188'	2.5Y 3/2		-0.5	0.31	0.14	0.09	0.4	0.35	0.08	-0.02
402-48	46-28W-10CD	190.5-192'	2.5Y 4/2		-0.58	-0.01	0.14	-0.06	-0.19	0.78	0.57	0.14
HT NoS	137-35W-27C	Surface sample	2.5Y 5/4	Hewitt	0.7	2.35	2.58	1.19	0.05	-0.9	-1.43	-0.8
HT SoM	137-35W-4AAA	Surface sample	2.5Y 5/4	Brainerd	-0.66	0.08	1.05	1.3	1.29	0.5	-0.48	-0.67
L A	143-35W-27BBAD	Surface sample	2.5Y 5/4	Hewitt	-0.34	1.28	1.6	1.23	0.81	0.1	-0.62	-0.29
LS	143-36W-24AA	Surface sample	2.5Y 5/4	Hewitt	-0.88	-0.98	-0.87	-0.72	-0.31	0.73	1.15	0.43
MI	147-42W-35BBCC	Surface sample	2.5Y 5/4	New Ulm	-0.51	-1.48	-1.56	-1.28	-0.3	1.02	0.23	0.26
Z	144-37W-5DD	Surface sample	2.5Y 6/4	Hewitt	-0.74	0.33	0.76	0.63	0.63	0.67	0.5	-0.19
92-1	43-30W-12CCD	Surface sample	10YR 4/4	Brainerd	0.2	1.1	1.7	1.95	1.5	0.28	-1.14	-1.06
92-2	43-30W-14ABA	Surface sample	10YR 4/3	Brainerd	-0.82	-0.28	0.78	1.98	2.31	0.99	-0.42	-0.21
92-4	116-39W-28DBBB	Surface sample	2.5Y 5/4	Granite Falls	-0.93	-0.21	-0.65	-0.8	-0.44	0.64	0.77	0.6
92-5	116-39W-28DBBB	Surface sample	2.5Y 5/4	Granite Falls	-0.39	2.59	-1.03	-1.06	-0.67	0.52	1.01	0.33
92-7	112-34W-4BD	Surface sample	5Y 4/3	New Ulm	-0.42	-0.66	-1.04	-0.91	0.07	1.18	0.8	0.07
92-8A	130-33-16DBC	Surface sample	5Y 4/2	Browerville	-0.69	-0.35	-0.11	0.16	0.59	0.9	0.52	-0.24
92-8B	130-33-16DBC	Surface sample	5Y 4/3	Browerville	-0.63	-0.62	-0.25	0.03	0.5	0.95	0.48	-0.14
92-9A	128-32W-16CAC	Surface sample	5Y 4/2	Browerville	-0.73	-0.91	-0.67	-0.59	-0.44	0.13	0	-0.12
92-9B	128-32W-16CAC	Surface sample	5Y 4/2	Browerville	-0.69	-0.51	-0.41	-0.32	0.01	0.74	0.51	-0.02
33 105-7	57-10W-21A	105-7'	10YR 3/3	Toimi	2.22	2.42	0.53	-0.39	-0.07	0.55	-0.45	-0.68
33 164	57-10W-21A	164'	10YR 4/3	Toimi	0.18	1.17	0.25	-0.24	0.31	1.6	0.22	0.01
33 207	57-10W-21A	207'	10YR 4/2	Toimi	4	0.54	0.8	-0.58	-1.08	-0.61	-0.98	-0.75

Sample no	7 phi(%)	8 phi(%)	9 phi(%)	<9 phi(%)	% gravel	%clay	%sand	%silt	% clay SSC	% sand SSC	% silt SSC	mean size	Std. Dev.
402-1	9.99	9.62	10.05	18.85	2.94	18.85	25.88	52.34	19.42	26.66	53.92	5.58	3.1
402-2	9.01	9.57	7.33	19.09	0.58	19.09	29.96	50.37	19.2	30.13	50.66	5.51	2.96
402-3	8.34	6.84	5.93	12.14	13.82	12.14	33.19	40.86	14.09	38.51	47.41	4	3.61
402-4	6.07	5.06	4.05	8.48	17.11	8.48	40.79	33.61	10.23	49.22	40.55	3.18	3.52
402-5	9.84	9.66	8.68	18.39	9.71	18.39	21.66	50.23	20.37	23.99	55.64	5.14	3.53
402-6	8.18	6.88	5.62	15.88	16.38	15.88	24.62	43.11	18.99	29.45	51.56	4.32	3.74
402-7	3.48	3.64	3.91	10.96	22.48	10.96	37.29	29.27	14.14	48.1	37.76	3.01	3.68
402-8	7.42	6.44	5.22	17.78	12.43	17.78	33.72	36.07	20.3	38.51	41.19	4.29	3.74
402-8A	4.94	3.86	3.51	11.5	28.11	11.5	35.28	25.12	15.99	49.07	34.94	2.68	3.84
402-9	5.46	2.34	1.93	4.81	17.13	4.81	57.39	20.67	5.8	69.25	24.94	2.25	3.04
402-10	2.08	1.15	0.41	2.03	25.36	2.03	55.2	17.41	2.72	73.95	23.33	1.8	2.63
402-11	3.96	3.26	3.27	10.3	14.13	10.3	52.9	22.66	12	61.61	26.39	3	3.36
402-19	4.45	3.54	3.02	4.08	11.23	4.08	58.81	25.88	4.6	66.25	29.15	2.71	2.93
402-20	4.06	3.65	2.56	7.99	7.02	7.99	62.54	22.45	8.59	67.26	24.14	3.02	3.04
402-21	4.89	4.76	4.27	8.68	9.52	8.68	53.19	28.61	9.59	58.79	31.62	3.33	3.25
402-22	4.73	4.27	4.24	9.39	10.7	9.39	51.62	28.29	10.52	57.81	31.68	3.32	3.3
402-23	4.83	3.89	3.95	6.79	4.67	6.79	59.72	28.82	7.12	62.65	30.23	3.34	2.93
402-24	4.36	3.5	3.22	6.83	6.83	6.83	61.26	25.08	7.33	65.75	26.92	3.07	2.97
402-25	3.54	4.09	2.74	8.92	11.63	8.92	55.48	23.98	10.09	62.77	27.13	3.04	3.22
402-26	5.07	4.09	3.72	10.61	8.97	10.61	51.45	28.97	11.66	56.52	31.82	3.5	3.28
402-27	10.36	6.93	5.04	18.38	2.5	18.38	33.74	45.38	18.85	34.61	46.54	5.11	3.13
402-28	5.54	4.52	3.4	12.61	2.05	12.61	45.47	39.86	12.88	46.43	40.7	4.4	2.89
402-29	7.97	4.97	4.03	15.29	9.57	15.29	35.93	39.21	16.91	39.73	43.36	4.3	3.45
402-29A	14.64	5.09	3.73	6.37	1.6	6.37	8.52	83.51	6.47	8.66	84.87	5.46	1.94
402-30	14.6	5.13	3.62	7.49	5.59	7.49	9.91	77.02	7.93	10.5	81.57	5.17	2.51
402-31	14.42	12.82	8.88	10.02	5.69	10.02	23.22	61.07	10.62	24.62	64.75	5.2	3.05
402-32	9.77	9.43	9.35	24.67	2.92	24.67	23.95	48.47	25.41	24.67	49.92	5.87	3.2
402-33	7.61	7.95	7.69	26.71	4.43	26.71	25.77	43.09	27.95	26.96	45.09	5.65	3.4
402-34	11.57	10.77	7.8	14.37	8.66	14.37	24.47	52.5	15.73	26.79	57.48	5.01	3.38
402-35	6.79	5.61	2.8	2.79	16.98	2.79	52.03	28.2	3.36	62.67	33.97	2.64	3.09
402-36	6.03	4.65	2.79	2.72	9.05	2.72	55.28	32.95	2.99	60.78	36.23	2.99	2.81
402-37	9.15	6.91	4.63	4.35	5.28	4.35	49.5	40.87	4.59	52.26	43.15	3.68	2.94
402-38	8.82	8.15	7.18	13.08	3.47	13.08	34.2	49.25	13.55	35.43	51.02	4.81	3.14
402-39	9.5	6.75	4.13	5.84	7.39	5.84	41.08	45.7	6.31	44.35	49.34	3.89	3.03
402-40	7.48	4.57	3.22	3.65	8.1	3.65	50.95	37.29	3.97	55.45	40.58	3.3	2.88

Sample no	7 phi(%)	8 phi(%)	9 phi(%)	<9 phi(%)	% gravel	%clay	%sand	%silt	% clay SSC	% sand SSC	% silt SSC	mean size	Std. Dev.
402-41	5.99	5.46	4.13	5.88	15.39	5.88	41.82	36.91	6.95	49.43	43.62	3.26	3.28
402-42	7.13	5.44	5.11	10.4	7.68	10.4	43.89	38.03	11.27	47.54	41.19	3.93	3.29
402-43	8.19	5.43	4.58	6.18	4.58	6.18	46.51	42.73	6.48	48.74	44.78	3.9	2.9
402-44	7.61	4.45	3.27	5.88	1.84	5.88	48.07	44.22	5.99	48.97	45.04	4.11	2.51
402-45	5.11	4.01	3.92	8.48	10.08	8.48	44.26	37.18	9.43	49.22	41.35	3.67	3.13
402-46	7.05	5.62	5.26	6.94	10.58	6.94	44.09	38.4	7.76	49.3	42.94	3.61	3.23
402-47	5.75	5.46	3.89	11.61	5.64	11.61	46.54	36.21	12.3	49.32	38.37	3.99	3.2
402-48	6.84	5.93	3.38	11.12	5.09	11.12	43.94	39.86	11.72	46.29	41.99	4.11	3.13
HT NoS	2.39	2.71	1.65	8.39	14.26	8.39	58.83	18.52	9.79	68.61	21.6	2.46	3.21
HT SoM	4.09	2.5	2.2	11.99	4.46	11.99	58.9	24.65	12.55	61.65	25.8	3.51	3.1
L A	5.07	3.08	2.85	5.52	6.77	5.52	59.51	28.2	5.92	63.83	30.25	3.02	2.91
LS	10.46	7.36	3.99	12.8	2.92	12.8	35.23	49.05	13.18	36.29	50.52	4.79	2.94
MI	8.8	6.82	5.11	20.57	5.58	20.57	30.09	43.76	21.79	31.87	46.35	5.21	3.23
Z	6.3	3.96	2.8	8.46	3.88	8.46	52.77	34.88	8.8	54.91	36.29	3.67	2.95
92-1	3.46	3.09	1.32	3.59	10.68	3.59	66.32	19.41	4.02	74.25	21.73	2.39	2.69
92-2	5.29	2.73	1.07	3.18	3.31	3.18	66.04	27.47	3.29	68.3	28.41	3.01	2.43
92-4	8.82	6.54	4.27	15.07	2.53	15.07	36.13	46.27	15.46	37.07	47.47	4.82	3.06
92-5	4.85	8.33	4.45	12.3	6.44	12.3	37.39	43.87	13.15	39.96	46.89	4.28	3.32
92-7	8.82	5.15	4.21	14.7	6.2	14.7	36.71	42.39	15.67	39.14	45.19	4.56	3.19
92-8A	5.26	4.66	2.92	14.24	4.26	14.24	47.01	34.49	14.87	49.1	36.02	4.17	3.16
92-8B	5.86	4.29	3.2	14.75	4.71	14.75	45.2	35.34	15.48	47.43	37.09	4.25	3.18
92-9A	7.69	6.64	3.77	22.78	3.99	22.78	34.83	38.41	23.72	36.27	40	5.09	3.34
92-9B	7.09	5.12	3.98	16.12	4.27	16.12	40.73	38.88	16.84	42.55	40.61	4.54	3.22
33 105-7	3.96	2.52	1.58	3.39	25.2	3.39	47.39	24.01	4.53	63.36	32.1	2.03	3.08
33 164	5.74	4.73	2.81	5.5	10.54	5.5	48.9	35.05	6.15	54.67	39.18	3.27	3.05
33 207	3.88	2.67	1.8	2.43	37.99	2.43	37.54	22.03	3.92	60.55	35.53	1.49	3.16
average	6.89	5.39	4.15	10.56	9.23	10.56	42.86	37.35	11.5	47.68	40.82	3.85	3.12
Stdev	2.79	2.28	2.01	5.82	7.19	5.82	13.17	12.67	6.06	15.29	12.33	1.04	0.33
402-1	1.11	1.86	2.93	1.43	-0.87	1.43	-1.29	1.18	1.31	-1.38	1.06	1.67	-0.07
402-2	0.76	1.83	1.58	1.47	-1.2	1.47	-0.98	1.03	1.27	-1.15	0.8	1.6	-0.5
402-3	0.52	0.63	0.88	0.27	0.64	0.27	-0.73	0.28	0.43	-0.6	0.53	0.15	1.5
402-4	-0.29	-0.15	-0.05	-0.36	1.1	-0.36	-0.16	-0.3	-0.21	0.1	-0.02	-0.64	1.22
402-5	1.06	1.87	2.25	1.35	0.07	1.35	-1.61	1.02	1.46	-1.55	1.2	1.25	1.25

Sample no	7 phi(%)	8 phi(%)	9 phi(%)	<9 phi(%)	% gravel	%clay	%sand	%silt	% clay SSC	% sand SSC	% silt SSC	mean size	Std. Dev.
402-6	0.46	0.65	0.73	0.91	0.99	0.91	-1.39	0.45	1.24	-1.19	0.87	0.46	1.9
402-7	-1.22	-0.77	-0.12	0.07	1.84	0.07	-0.42	-0.64	0.44	0.03	-0.25	-0.81	1.72
402-8	0.19	0.46	0.53	1.24	0.45	1.24	-0.69	-0.1	1.45	-0.6	0.03	0.43	1.9
402-8A	-0.7	-0.67	-0.32	0.16	2.63	0.16	-0.58	-0.97	0.74	0.09	-0.48	-1.13	2.21
402-9	-0.51	-1.34	-1.11	-0.99	1.1	-0.99	1.1	-1.32	-0.94	1.41	-1.29	-1.54	-0.25
402-10	-1.72	-1.86	-1.86	-1.47	2.24	-1.47	0.94	-1.57	-1.45	1.72	-1.42	-1.98	-1.51
402-11	-1.05	-0.94	-0.44	-0.04	0.68	-0.04	0.76	-1.16	0.08	0.91	-1.17	-0.82	0.73
402-19	-0.87	-0.81	-0.56	-1.11	0.28	-1.11	1.21	-0.91	-1.14	1.21	-0.95	-1.1	-0.59
402-20	-1.01	-0.77	-0.79	-0.44	-0.31	-0.44	1.49	-1.18	-0.48	1.28	-1.35	-0.8	-0.25
402-21	-0.72	-0.28	0.06	-0.32	0.04	-0.32	0.78	-0.69	-0.31	0.73	-0.75	-0.5	0.4
402-22	-0.77	-0.49	0.04	-0.2	0.2	-0.2	0.67	-0.71	-0.16	0.66	-0.74	-0.51	0.55
402-23	-0.74	-0.66	-0.1	-0.65	-0.63	-0.65	1.28	-0.67	-0.72	0.98	-0.86	-0.49	-0.59
402-24	-0.91	-0.83	-0.46	-0.64	-0.33	-0.64	1.4	-0.97	-0.69	1.18	-1.13	-0.75	-0.46
402-25	-1.2	-0.57	-0.7	-0.28	0.33	-0.28	0.96	-1.06	-0.23	0.99	-1.11	-0.78	0.3
402-26	-0.65	-0.57	-0.22	0.01	-0.04	0.01	0.65	-0.66	0.03	0.58	-0.73	-0.34	0.49
402-27	1.24	0.67	0.44	1.34	-0.94	1.34	-0.69	0.63	1.21	-0.86	0.46	1.22	0.03
402-28	-0.48	-0.38	-0.38	0.35	-1	0.35	0.2	0.2	0.23	-0.08	-0.01	0.53	-0.71
402-29	0.39	-0.19	-0.06	0.81	0.05	0.81	-0.53	0.15	0.89	-0.52	0.21	0.44	1.01
402-29A	2.77	-0.13	-0.21	-0.72	-1.06	-0.72	-2.61	3.64	-0.83	-2.55	3.57	1.56	-3.63
402-30	2.76	-0.12	-0.27	-0.53	-0.51	-0.53	-2.5	3.13	-0.59	-2.43	3.3	1.28	-1.88
402-31	2.69	3.26	2.35	-0.09	-0.49	-0.09	-1.49	1.87	-0.14	-1.51	1.94	1.3	-0.22
402-32	1.03	1.77	2.58	2.43	-0.88	2.43	-1.44	0.88	2.3	-1.51	0.74	1.95	0.24
402-33	0.26	1.12	1.76	2.78	-0.67	2.78	-1.3	0.45	2.71	-1.36	0.35	1.74	0.86
402-34	1.67	2.36	1.81	0.66	-0.08	0.66	-1.4	1.2	0.7	-1.37	1.35	1.12	0.79
402-35	-0.04	0.09	-0.67	-1.34	1.08	-1.34	0.7	-0.72	-1.34	0.98	-0.56	-1.16	-0.1
402-36	-0.31	-0.33	-0.68	-1.35	-0.02	-1.35	0.94	-0.35	-1.4	0.86	-0.37	-0.83	-0.96
402-37	0.81	0.67	0.24	-1.07	-0.55	-1.07	0.5	0.28	-1.14	0.3	0.19	-0.16	-0.56
402-38	0.69	1.21	1.5	0.43	-0.8	0.43	-0.66	0.94	0.34	-0.8	0.83	0.93	0.06
402-39	0.93	0.6	-0.01	-0.81	-0.26	-0.81	-0.14	0.66	-0.86	-0.22	0.69	0.04	-0.28
402-40	0.21	-0.36	-0.46	-1.19	-0.16	-1.19	0.61	0	-1.24	0.51	-0.02	-0.53	-0.74
402-41	-0.32	0.03	-0.01	-0.8	0.86	-0.8	-0.08	-0.03	-0.75	0.11	0.23	-0.57	0.49
402-42	0.08	0.02	0.48	-0.03	-0.22	-0.03	0.08	0.05	-0.04	-0.01	0.03	0.08	0.52
402-43	0.46	0.02	0.21	-0.75	-0.65	-0.75	0.28	0.42	-0.83	0.07	0.32	0.05	-0.68
402-44	0.26	-0.41	-0.44	-0.8	-1.03	-0.8	0.4	0.54	-0.91	0.08	0.34	0.25	-1.88
402-45	-0.64	-0.61	-0.12	-0.36	0.12	-0.36	0.11	-0.01	-0.34	0.1	0.04	-0.17	0.03

Sample no	7 phi(%)	8 phi(%)	9 phi(%)	<9 phi(%)	% gravel	%clay	%sand	%silt	% clay SSC	% sand SSC	% silt SSC	mean size	Std. Dev.
402-46	0.06	0.1	0.55	-0.62	0.19	-0.62	0.09	0.08	-0.62	0.11	0.17	-0.23	0.33
402-47	-0.41	0.03	-0.13	0.18	-0.5	0.18	0.28	-0.09	0.13	0.11	-0.2	0.14	0.24
402-48	-0.02	0.24	-0.39	0.1	-0.58	0.1	0.08	0.2	0.04	-0.09	0.1	0.25	0.03
HT NoS	-1.61	-1.18	-1.25	-0.37	0.7	-0.37	1.21	-1.49	-0.28	1.37	-1.56	-1.34	0.27
HT SoM	-1	-1.27	-0.97	0.25	-0.66	0.25	1.22	-1	0.17	0.91	-1.22	-0.33	-0.07
L A	-0.65	-1.02	-0.65	-0.87	-0.34	-0.87	1.26	-0.72	-0.92	1.06	-0.86	-0.8	-0.65
LS	1.28	0.86	-0.08	0.38	-0.88	0.38	-0.58	0.92	0.28	-0.75	0.79	0.91	-0.55
MI	0.68	0.63	0.48	1.72	-0.51	1.72	-0.97	0.51	1.7	-1.03	0.45	1.31	0.33
Z	-0.21	-0.63	-0.67	-0.36	-0.74	-0.36	0.75	-0.19	-0.44	0.47	-0.37	-0.17	-0.53
92-1	-1.23	-1.01	-1.41	-1.2	0.2	-1.2	1.78	-1.42	-1.23	1.74	-1.55	-1.41	-1.32
92-2	-0.57	-1.17	-1.53	-1.27	-0.82	-1.27	1.76	-0.78	-1.35	1.35	-1.01	-0.81	-2.12
92-4	0.69	0.5	0.06	0.78	-0.93	0.78	-0.51	0.7	0.65	-0.69	0.54	0.94	-0.19
92-5	-0.73	1.29	0.15	0.3	-0.39	0.3	-0.42	0.51	0.27	-0.51	0.49	0.42	0.61
92-7	0.69	-0.11	0.03	0.71	-0.42	0.71	-0.47	0.4	0.69	-0.56	0.35	0.69	0.21
92-8A	-0.58	-0.32	-0.61	0.63	-0.69	0.63	0.31	-0.23	0.56	0.09	-0.39	0.31	0.12
92-8B	-0.37	-0.49	-0.47	0.72	-0.63	0.72	0.18	-0.16	0.66	-0.02	-0.3	0.39	0.18
92-9A	0.29	0.55	-0.19	2.1	-0.73	2.1	-0.61	0.08	2.02	-0.75	-0.07	1.2	0.67
92-9B	0.07	-0.12	-0.09	0.96	-0.69	0.96	-0.16	0.12	0.88	-0.34	-0.02	0.67	0.3
33 105-7	-1.05	-1.26	-1.28	-1.23	2.22	-1.23	0.34	-1.05	-1.15	1.03	-0.71	-1.75	-0.13
33 164	-0.41	-0.29	-0.67	-0.87	0.18	-0.87	0.46	-0.18	-0.88	0.46	-0.13	-0.56	-0.22
33 207	-1.08	-1.2	-1.17	-1.4	4	-1.4	-0.4	-1.21	-1.25	0.84	-0.43	-2.27	0.12

Sample no	skewness	kurtosis	LOI	ARM	X lf	Ti %	Al %	Fe %	Mn ppm	Mg %	Ca %	Na %	K %	Li ppm	Sc ppm	V ppm	Cr ppm	Co ppm
402-1	-0.42	2.21	3.15	0.8	111	0.41	3.58	3.65	714	1.29	1.32	1.29	1.71	30	7	85	84	18
402-2	-0.19	1.94	2.2	0.82	104	0.42	4.74	3.52	772	1.07	1.21	1.28	1.39	29	8	82	87	16
402-3	-0.03	1.81	7.43	0.72	146	0.41	4.48	3.75	816	1.8	3.18	1.5	1.82	27	8	85	93	20
402-4	0.27	1.92	5.38	0.88	344	0.62	4.66	5.38	1001	1.55	3.3	1.61	1.52	27	9	157	88	26
402-5	-0.47	2.11	7.85	0.61	91.5	0.41	4.76	3.76	689	1.79	2.8	1.28	1.67	31	8	87	88	18
402-6	-0.19	1.82	8.22	0.36	100	0.4	4.4	3.55	704	1.64	3.02	1.31	1.53	26	7	84	77	16
402-7	0.37	1.95	9.03	0.26	97.8	0.4	4.37	3.61	906	1.68	3.21	1.25	1.21	24	7	81	78	17
402-8	-0.04	1.72	7.54	0.86	136	0.41	4.79	3.8	719	1.67	2.87	1.28	1.56	29	8	87	88	18
402-8A	0.5	1.92	8.06	0.79	141	0.41	4.74	3.87	909	1.73	3.08	1.28	1.77	28	8	90	85	17
402-9	0.78	2.86	4.29	0.6	157	0.38	5.38	4.7	1461	1.03	2.04	1.22	1.38	24	9	107	92	17
402-10	0.53	3.05	4.45	0.53	357	0.54	3.78	4.75	1354	1.02	2.59	1.32	1.57	16	7	100	86	19
402-11	0.6	2.36	7.35	0.73	141	0.4	4.34	3.91	889	1.56	2.86	1.18	0.98	26	8	86	86	18
402-19	0.59	2.7	8.19	0.42	125	0.36	4.53	3.42	633	1.15	3.73	1.07	1.62	24	7	80	74	13
402-20	0.72	2.7	7.94	0.42	117	0.37	4.86	3.48	631	1.11	3.75	1.05	1.65	26	8	81	74	12
402-21	0.45	2.23	7.86	0.33	95	0.36	4.75	3.28	560	1.05	3.56	0.93	1.6	28	7	78	72	12
402-22	0.44	2.21	8.83	0.35	88.4	0.37	5.24	3.52	606	1.17	3.8	0.93	1.59	30	8	82	78	14
402-23	0.59	2.56	7.85	0.31	93.8	0.36	4.88	3.46	587	1.11	3.63	0.96	1.66	27	8	75	69	13
402-24	0.66	2.71	7.69	0.38	106	0.36	4.5	3.28	581	1.07	3.43	1.01	1.43	26	7	75	73	12
402-25	0.58	2.46	7.58	0.47	138	0.36	4.76	3.39	684	1.1	3.38	1.12	1.44	25	7	77	71	12
402-26	0.41	2.2	5.8	0.48	166	0.32	4.39	2.92	570	0.9	2.84	1.2	1.6	21	6	65	66	11
402-27	-0.14	2	6.73	0.38	148	0.33	4.4	3.01	545	1.06	2.7	1.02	1.14	27	7	73	72	11
402-28	0.29	2.29	14.1	0.25	143	0.26	4.47	2.82	480	1.5	4.67	0.98	1.13	20	6	55	57	9
402-29	-0.03	1.95	15.2	0.27	155	0.29	5.14	2.69	545	1.74	5.32	1.05	1.65	22	6	60	63	10
402-29A	-0.53	5.51	30	0.06	43.5	0.22	3.84	1.52	438	3.03	9.15	0.99	1.48	14	4	38	49	7
402-30	-0.9	4.32	29.9	0.05	40.8	0.23	4.13	1.6	454	3.15	9.55	1.06	1.3	16	5	40	52	7
402-31	-0.59	2.55	38	0.01	10.9	0.23	5.02	2.43	542	3.8	10	0.42	1.39	41	6	66	66	13
402-32	-0.57	2.27	37.9	0.01	12.2	0.23	5.17	2.43	529	3.78	10	0.42	1.2	43	6	69	71	12
402-33	-0.47	2.07	38.4	0.02	19.3	0.21	4.6	2.36	504	3.69	10	0.42	1.07	39	6	62	72	13
402-34	-0.45	2.18	33.5	0.01	11.8	0.22	5.02	2.32	493	3.41	10	0.48	1.37	41	6	64	63	12
402-35	0.42	2.24	10.9	0.06	27.5	0.36	5.43	4.02	507	1.2	3.99	0.52	1.64	39	9	77	84	14
402-36	0.37	2.5	11	0.07	30	0.33	5.22	3.86	505	1.19	3.97	0.53	1.15	36	8	72	79	13
402-37	0.19	2.14	10.1	0.09	40.3	0.35	5.81	4.04	546	1.34	4.04	0.71	1.63	35	9	77	93	16
402-38	-0.14	2.05	12.7	0.04	21.3	0.33	5.54	3.42	445	1.13	5.87	0.46	1.42	43	8	90	77	15
402-39	0.01	2.17	10.6	0.05	27.1	0.33	5.02	3.59	444	1.01	5.07	0.54	1.45	36	7	82	72	14
402-40	0.24	2.36	7.94	0.16	58.7	0.37	5.51	3.85	598	1	3.18	0.72	1.15	33	8	72	84	16

Sample no	skewness	kurtosis	LOI	ARM	X lf	Ti %	Al %	Fe %	Mn ppm	Mg %	Ca %	Na %	K %	Li ppm	Sc ppm	V ppm	Cr ppm	Co ppm
402-41	0.18	2.08	5.91	0.21	87.8	0.41	5.4	4.09	701	1.04	2.62	0.87	1.51	27	9	72	84	16
402-42	0.14	2.02	5.96	0.23	90.9	0.39	5.44	4.28	701	1	2.44	0.82	1.46	27	8	70	84	16
402-43	0.16	2.32	5.72	0.2	75.5	0.42	5.08	4.02	694	0.95	2.56	0.93	1.5	24	8	68	86	14
402-44	0.31	2.8	5.42	0.19	75.4	0.41	4.84	3.85	623	0.93	2.42	0.95	1.5	22	7	64	82	14
402-45	0.18	2.34	5.64	0.24	78.6	0.41	5.19	4.5	736	1	2.61	0.91	1.5	23	8	73	97	16
402-46	0.15	2.09	5.64	0.2	65.5	0.42	5.7	4.58	749	1.1	2.59	0.86	1.62	28	9	80	125	17
402-47	0.22	2.1	6.62	0.26	75.9	0.39	5.5	4.64	884	1.11	3.02	0.9	1.55	25	9	78	91	18
402-48	0.15	2.15	5.8	0.19	69.6	0.41	5.57	4.54	720	1.06	2.51	0.84	1.55	26	9	75	85	17
HT NoS	0.84	2.83	21.5	0.13	42	0.25	5.22	2.44	654	2.27	7.09	1.2	1.14	22	6	59	57	13
HT SoM	0.63	2.49	1.94	0.1	39	0.33	6.55	3.21	675	0.72	1.38	1.37	1.68	27	8	75	73	14
L A	0.59	2.64	20.9	0.15	57.6	0.24	5.13	2.14	491	2.45	6.89	1.45	1.34	17	6	52	58	11
LS	-0.07	2.27	25.9	0.21	67.5	0.22	4.86	2	549	2.9	7.9	1.29	1.43	20	5	53	52	8
MI	-0.27	2.21	38	0.11	45.7	0.2	4.54	1.99	441	3.87	10	0.76	1.45	28	5	66	53	8
Z	0.41	2.4	22.3	0.11	65.3	0.24	5.13	2.12	480	2.7	7.2	1.43	1.2	18	6	52	58	9
92-1	0.81	3.38	1.41	0.52	160	0.41	5.81	3.63	770	0.53	1.16	1.38	1.27	19	9	77	74	15
92-2	0.68	3.26	1.08	0.44	127	0.39	4.84	2.2	615	0.36	0.83	1.27	1.76	19	5	57	59	9
92-4	-0.06	2.14	45.5	0.02	30.6	0.18	3.7	1.7	437	4.45	10	0.69	1.21	23	4	50	47	8
92-5	-0.05	2.03	46.9	0.01	25.4	0.17	3.52	1.67	496	4.71	10	0.66	0.93	22	4	48	47	8
92-7	-0.05	2.19	20.3	0.02	19.4	0.26	5.31	2.48	1047	2.35	6.15	0.75	1.52	31	7	93	70	13
92-8A	0.27	2.14	24.6	0.02	29.5	0.25	4.92	2.28	439	2.36	7.8	0.66	1.16	34	6	62	57	11
92-8B	0.22	2.13	24.8	0.01	24.4	0.27	5.15	2.54	467	2.4	7.91	0.65	1.3	35	7	66	65	11
92-9A	-0.14	1.9	28.3	0.01	20.8	0.26	5.16	2.31	425	2.78	8.88	0.49	1.51	45	6	73	61	12
92-9B	0.07	2.04	27.1	0.01	12.2	0.25	4.79	2.42	373	2.56	8.19	0.5	1.01	41	6	70	56	10
33 105-7	0.59	2.51	6.4	1.2	317	0.65	5.77	4.4	755	1.88	4.73	1.71	1.26	19	11	124	93	21
33 164	0.24	2.32	4.23	1.4	308	0.6	6.04	4.42	730	1.64	4.26	1.82	1.24	15	10	105	84	20
33 207	0.79	2.56	2.92	1.24	465	0.49	7.28	5.48	826	3.82	5.19	1.63	0.95	14	9	88	97	49
average	0.18	2.38	14	0.33	100	0.35	4.96	3.33	653.1	1.83	4.81	1	1.42	27.2	7.21	75.26	74.72	14.41
Stdev	0.4	0.59	12.1	0.33	91.4	0.1	0.67	0.96	207.5	1.05	2.8	0.35	0.22	7.7	1.5	18.88	15.06	5.9
402-1	-1.48	-0.29	-0.9	1.42	0.11	0.59	-2.1	0.34	0.29	-0.5	-1.3	0.81	1.33	0.36	-0.14	0.52	0.62	0.61
402-2	-0.91	-0.75	-1	1.48	0.04	0.69	-0.3	0.2	0.57	-0.7	-1.3	0.78	-0.1	0.23	0.53	0.36	0.82	0.27
402-3	-0.51	-0.97	-0.5	1.18	0.5	0.59	-0.7	0.44	0.78	0	-0.6	1.41	1.83	0	0.53	0.52	1.21	0.95
402-4	0.23	-0.79	-0.7	1.66	2.66	2.63	-0.5	2.13	1.68	-0.3	-0.5	1.72	0.47	0	1.19	4.33	0.88	1.96
402-5	-1.6	-0.46	-0.5	0.85	-0.1	0.59	-0.3	0.45	0.17	0	-0.7	0.78	1.15	0.49	0.53	0.62	0.88	0.61

Sample no	skewness	kurtosis	LOI	ARM	X lf	Ti %	Al %	Fe %	Mn ppm	Mg %	Ca %	Na %	K %	Li ppm	Sc ppm	V ppm	Cr ppm	Co ppm
402-6	-0.91	-0.96	-0.5	0.09	0	0.5	-0.8	0.23	0.25	-0.2	-0.6	0.87	0.52	-0.2	-0.14	0.46	0.15	0.27
402-7	0.48	-0.73	-0.4	-0.2	0	0.5	-0.9	0.29	1.22	-0.1	-0.6	0.7	-0.9	-0.4	-0.14	0.3	0.22	0.44
402-8	-0.54	-1.12	-0.5	1.6	0.39	0.59	-0.3	0.49	0.32	-0.2	-0.7	0.78	0.65	0.23	0.53	0.62	0.88	0.61
402-8A	0.8	-0.79	-0.5	1.39	0.44	0.59	-0.3	0.56	1.23	-0.1	-0.6	0.78	1.61	0.1	0.53	0.78	0.68	0.44
402-9	1.49	0.81	-0.8	0.82	0.62	0.3	0.63	1.43	3.89	-0.8	-1	0.61	-0.2	-0.4	1.19	1.68	1.15	0.44
402-10	0.87	1.13	-0.8	0.61	2.8	1.86	-1.8	1.48	3.38	-0.8	-0.8	0.9	0.7	-1.5	-0.14	1.31	0.75	0.78
402-11	1.04	-0.04	-0.6	1.21	0.44	0.5	-0.9	0.61	1.14	-0.3	-0.7	0.5	-2	-0.2	0.53	0.57	0.75	0.61
402-19	1.02	0.54	-0.5	0.27	0.27	0.11	-0.7	0.1	-0.1	-0.7	-0.4	0.19	0.92	-0.4	-0.14	0.25	-0.05	-0.24
402-20	1.34	0.54	-0.5	0.27	0.19	0.21	-0.2	0.16	-0.11	-0.7	-0.4	0.13	1.06	-0.2	0.53	0.3	-0.05	-0.41
402-21	0.67	-0.26	-0.5	0	-0.1	0.11	-0.3	-0.1	-0.45	-0.7	-0.5	-0.2	0.83	0.1	-0.14	0.14	-0.18	-0.41
402-22	0.65	-0.29	-0.4	0.06	-0.1	0.21	0.42	0.2	-0.23	-0.6	-0.4	-0.2	0.79	0.36	0.53	0.36	0.22	-0.07
402-23	1.02	0.3	-0.5	-0.1	-0.1	0.11	-0.1	0.14	-0.32	-0.7	-0.4	-0.1	1.11	0	0.53	-0.01	-0.38	-0.24
402-24	1.19	0.55	-0.5	0.15	0.06	0.11	-0.7	-0.1	-0.35	-0.7	-0.5	0.02	0.06	-0.2	-0.14	-0.01	-0.11	-0.41
402-25	0.99	0.13	-0.5	0.42	0.41	0.11	-0.3	0.07	0.15	-0.7	-0.5	0.33	0.11	-0.3	-0.14	0.09	-0.25	-0.41
402-26	0.57	-0.31	-0.7	0.45	0.72	-0.3	-0.9	-0.4	-0.4	-0.9	-0.7	0.56	0.83	-0.8	-0.81	-0.54	-0.58	-0.58
402-27	-0.79	-0.65	-0.6	0.15	0.52	-0.2	-0.8	-0.3	-0.52	-0.7	-0.8	0.05	-1.3	0	-0.14	-0.12	-0.18	-0.58
402-28	0.28	-0.16	0.01	-0.2	0.46	-0.9	-0.7	-0.5	-0.83	-0.3	-0.1	-0.1	-1.3	-0.9	-0.81	-1.07	-1.18	-0.92
402-29	-0.51	-0.73	0.1	-0.2	0.6	-0.6	0.27	-0.7	-0.52	-0.1	0.18	0.13	1.06	-0.7	-0.81	-0.81	-0.78	-0.75
402-29A	-1.75	5.3	1.33	-0.8	-0.6	-1.3	-1.7	-1.9	-1.04	1.15	1.55	0	0.29	-1.7	-2.15	-1.97	-1.71	-1.26
402-30	-2.66	3.28	1.32	-0.8	-0.7	-1.2	-1.3	-1.8	-0.96	1.26	1.69	0.16	-0.5	-1.5	-1.48	-1.87	-1.51	-1.26
402-31	-1.9	0.28	1.98	-1	-1	-1.2	0.09	-0.9	-0.54	1.88	1.85	-1.7	-0.1	1.79	-0.81	-0.49	-0.58	-0.24
402-32	-1.85	-0.19	1.98	-1	-1	-1.2	0.31	-0.9	-0.6	1.86	1.85	-1.7	-1	2.05	-0.81	-0.33	-0.25	-0.41
402-33	-1.6	-0.53	2.02	-0.9	-0.9	-1.4	-0.5	-1	-0.72	1.78	1.85	-1.7	-1.6	1.53	-0.81	-0.7	-0.18	-0.24
402-34	-1.55	-0.34	1.61	-1	-1	-1.3	0.09	-1	-0.77	1.51	1.85	-1.5	-0.2	1.79	-0.81	-0.6	-0.78	-0.41
402-35	0.6	-0.24	-0.3	-0.8	-0.8	0.11	0.7	0.72	-0.7	-0.6	-0.3	-1.4	1.02	1.53	1.19	0.09	0.62	-0.07
402-36	0.48	0.2	-0.3	-0.8	-0.8	-0.2	0.39	0.55	-0.71	-0.6	-0.3	-1.3	-1.2	1.14	0.53	-0.17	0.28	-0.24
402-37	0.03	-0.41	-0.3	-0.7	-0.7	0.01	1.27	0.74	-0.52	-0.5	-0.3	-0.8	0.97	1.01	1.19	0.09	1.21	0.27
402-38	-0.79	-0.57	-0.1	-0.9	-0.9	-0.2	0.87	0.1	-1	-0.7	0.38	-1.5	0.01	2.05	0.53	0.78	0.15	0.1
402-39	-0.41	-0.36	-0.3	-0.8	-0.8	-0.2	0.09	0.27	-1.01	-0.8	0.09	-1.3	0.15	1.14	-0.14	0.36	-0.18	-0.07
402-40	0.15	-0.04	-0.5	-0.5	-0.5	0.21	0.82	0.54	-0.27	-0.8	-0.6	-0.8	-1.2	0.75	0.53	-0.17	0.62	0.27
402-41	0.01	-0.51	-0.7	-0.4	-0.1	0.59	0.66	0.79	0.23	-0.8	-0.8	-0.4	0.42	0	1.19	-0.17	0.62	0.27
402-42	-0.09	-0.62	-0.7	-0.3	-0.1	0.4	0.72	0.99	0.23	-0.8	-0.9	-0.5	0.2	0	0.53	-0.28	0.62	0.27
402-43	-0.04	-0.11	-0.7	-0.4	-0.3	0.69	0.18	0.72	0.2	-0.8	-0.8	-0.2	0.38	-0.4	0.53	-0.38	0.75	-0.07
402-44	0.33	0.71	-0.7	-0.4	-0.3	0.59	-0.2	0.54	-0.15	-0.9	-0.9	-0.2	0.38	-0.7	-0.14	-0.6	0.48	-0.07
402-45	0.01	-0.07	-0.7	-0.3	-0.2	0.59	0.34	1.22	0.4	-0.8	-0.8	-0.3	0.38	-0.6	0.53	-0.12	1.48	0.27

Sample no	skewness	kurtosis	LOI	ARM	X lf	Ti %	Al %	Fe %	Mn ppm	Mg %	Ca %	Na %	K %	Li ppm	Sc ppm	V ppm	Cr ppm	Co ppm
402-46	-0.07	-0.5	-0.7	-0.4	-0.4	0.69	1.11	1.3	0.46	-0.7	-0.8	-0.4	0.92	0.1	1.19	0.25	3.34	0.44
402-47	0.1	-0.48	-0.6	-0.2	-0.3	0.4	0.81	1.36	1.11	-0.7	-0.6	-0.3	0.61	-0.3	1.19	0.14	1.08	0.61
402-48	-0.07	-0.4	-0.7	-0.4	-0.3	0.59	0.91	1.26	0.32	-0.7	-0.8	-0.5	0.61	-0.2	1.19	-0.01	0.68	0.44
HT NoS	1.64	0.76	0.62	-0.6	-0.6	-1	0.39	-0.9	0	0.42	0.81	0.56	-1.3	-0.7	-0.81	-0.86	-1.18	-0.24
HT SoM	1.12	0.18	-1	-0.7	-0.7	-0.2	2.38	-0.1	0.11	-1.1	-1.2	1.04	1.2	0	0.53	-0.01	-0.11	-0.07
L A	1.02	0.44	0.57	-0.5	-0.5	-1.1	0.25	-1.2	-0.78	0.59	0.74	1.27	-0.4	-1.3	-0.81	-1.23	-1.11	-0.58
LS	-0.61	-0.2	0.99	-0.4	-0.4	-1.3	-0.2	-1.4	-0.5	1.02	1.1	0.81	0.06	-0.9	-1.48	-1.18	-1.51	-1.09
MI	-1.11	-0.29	1.98	-0.7	-0.6	-1.5	-0.6	-1.4	-1.02	1.95	1.85	-0.7	0.15	0.1	-1.48	-0.49	-1.44	-1.09
Z	0.57	0.03	0.69	-0.7	-0.4	-1.1	0.25	-1.3	-0.83	0.83	0.85	1.21	-1	-1.2	-0.81	-1.23	-1.11	-0.92
92-1	1.56	1.69	-1	0.58	0.65	0.59	1.27	0.32	0.56	-1.2	-1.3	1.07	-0.7	-1.1	1.19	0.09	-0.05	0.1
92-2	1.24	1.49	-1.1	0.33	0.29	0.4	-0.2	-1.2	-0.18	-1.4	-1.4	0.76	1.56	-1.1	-1.48	-0.97	-1.04	-0.92
92-4	-0.59	-0.41	2.6	-0.9	-0.8	-1.6	-1.9	-1.7	-1.04	2.5	1.85	-0.9	-0.9	-0.6	-2.15	-1.34	-1.84	-1.09
92-5	-0.56	-0.6	2.72	-1	-0.8	-1.7	-2.2	-1.7	-0.76	2.75	1.85	-1	-2.2	-0.7	-2.15	-1.44	-1.84	-1.09
92-7	-0.56	-0.33	0.52	-0.9	-0.9	-0.9	0.52	-0.9	1.9	0.5	0.48	-0.7	0.47	0.49	-0.14	0.94	-0.31	-0.24
92-8A	0.23	-0.41	0.87	-0.9	-0.8	-1	-0.1	-1.1	-1.03	0.51	1.07	-1	-1.2	0.88	-0.81	-0.7	-1.18	-0.58
92-8B	0.1	-0.43	0.89	-1	-0.8	-0.8	0.28	-0.8	-0.9	0.55	1.11	-1	-0.5	1.01	-0.14	-0.49	-0.65	-0.58
92-9A	-0.79	-0.82	1.18	-1	-0.9	-0.9	0.3	-1.1	-1.1	0.91	1.45	-1.5	0.42	2.31	-0.81	-0.12	-0.91	-0.41
92-9B	-0.27	-0.58	1.09	-1	-1	-1	-0.3	-0.9	-1.35	0.7	1.21	-1.4	-1.9	1.79	-0.81	-0.28	-1.24	-0.75
33 105-7	1.02	0.21	-0.6	2.62	2.37	2.93	1.21	1.11	0.49	0.05	0	2	-0.7	-1.1	2.53	2.58	1.21	1.12
33 164	0.15	-0.11	-0.8	3.23	2.27	2.44	1.62	1.14	0.37	-0.2	-0.2	2.31	-0.8	-1.6	1.86	1.57	0.62	0.95
33 207	1.51	0.3	-0.9	2.74	3.99	1.37	3.48	2.24	0.83	1.9	0.14	1.78	-2.1	-1.7	1.19	0.67	1.48	5.86

Sample no	Ni ppm	Cu ppm	Zn ppm	Ga ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	Ag ppm	Sb ppm	Ba ppm	La ppm	Ta ppm	Pb ppm	Bi ppm	As ppm
402-1	48	43	71	19	135	12	142	15	0.4	10	418	22	17	19	5	15
402-2	43	36	76	19	153	13	143	12	0.2	12	438	23	12	19	5	14
402-3	50	46	79	23	218	12	134	13	0.2	12	487	25	11	21	5	29
402-4	46	129	96	24	177	17	162	15	0.5	12	408	27	12	21	5	5
402-5	46	44	74	23	154	13	134	12	0.2	13	429	23	13	22	6	5
402-6	40	39	71	22	156	13	140	12	0.4	14	414	22	12	22	5	12
402-7	42	39	68	21	156	13	145	12	0.4	13	423	22	11	23	6	23
402-8	45	44	75	23	157	14	141	12	0.2	13	443	24	13	24	5	12
402-8A	44	43	74	22	163	13	146	12	0.2	13	436	23	13	23	5	14
402-9	42	51	70	20	198	13	131	11	0.5	14	429	26	11	24	5	26
402-10	34	37	58	19	174	12	189	12	0.4	11	377	26	16	18	5	14
402-11	47	40	70	22	147	13	138	12	0.3	12	407	22	17	23	5	22
402-19	35	33	62	20	158	14	133	12	0.3	12	372	24	11	23	5	20
402-20	37	31	61	21	163	15	143	13	0.2	12	385	26	8	24	5	18
402-21	35	30	63	20	149	14	137	12	0.2	12	368	25	9	22	5	10
402-22	38	33	69	21	156	15	140	13	0.3	14	383	27	10	23	5	18
402-23	35	30	63	20	155	15	145	13	0.2	13	388	26	7	23	5	19
402-24	34	29	57	20	152	14	131	12	0.3	11	391	24	7	19	5	17
402-25	33	28	58	21	162	14	139	12	0.2	13	415	26	12	23	5	5
402-26	30	22	64	20	167	12	108	11	0.2	12	409	20	6	20	5	15
402-27	30	28	62	21	136	13	127	12	0.2	13	480	24	8	22	5	26
402-28	24	16	42	18	147	11	128	11	0.2	13	389	22	7	22	7	19
402-29	25	17	48	18	162	12	130	11	0.2	13	458	26	5	23	6	7
402-29A	18	12	31	11	159	10	121	7	0.2	12	346	18	7	23	10	5
402-30	19	13	33	12	168	10	122	7	0.2	11	373	18	6	23	8	5
402-31	34	24	64	12	115	11	99	7	0.2	13	307	23	6	27	9	6
402-32	35	23	64	13	118	11	91	8	0.2	11	307	24	5	28	10	5
402-33	35	25	60	12	113	10	88	8	0.3	13	285	21	7	28	12	16
402-34	34	24	63	13	120	11	90	8	0.2	12	304	23	10	27	9	6
402-35	38	29	64	23	109	14	140	14	0.4	13	322	30	7	24	5	8
402-36	37	33	63	22	108	14	134	13	0.3	14	313	30	9	23	5	19
402-37	43	32	64	23	131	14	137	13	0.2	13	329	30	9	24	5	6
402-38	44	30	85	19	130	16	127	15	0.3	12	333	30	8	25	5	25
402-39	42	31	81	17	132	15	124	14	0.2	12	315	31	9	24	5	23
402-40	45	32	69	21	120	14	127	13	0.4	13	349	29	11	22	5	8

Sample no	Ni ppm	Cu ppm	Zn ppm	Ga ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	Ag ppm	Sb ppm	Ba ppm	La ppm	Ta ppm	Pb ppm	Bi ppm	As ppm
402-41	45	32	65	20	139	15	145	13	0.4	13	382	31	11	22	5	25
402-42	42	33	66	20	133	15	140	13	0.4	12	364	31	14	20	5	10
402-43	38	30	60	19	139	15	148	13	0.3	12	373	29	15	21	5	13
402-44	38	28	58	18	136	15	153	12	0.3	13	371	28	5	19	5	7
402-45	41	36	62	19	145	15	142	12	0.5	13	368	28	14	23	5	6
402-46	45	36	70	21	137	16	147	13	0.4	14	388	31	11	23	5	8
402-47	44	38	67	21	153	15	137	13	0.4	14	377	29	9	23	5	19
402-48	41	33	64	21	139	16	145	13	0.4	14	381	28	11	24	5	15
HT NoS	34	20	52	17	199	11	113	9	0.2	13	365	22	11	24	6	16
HT SoM	42	26	61	21	206	20	154	12	0.2	14	463	35	9	23	5	7
L A	27	18	43	17	230	10	120	8	0.2	13	390	19	5	24	10	13
LS	24	16	46	16	209	9	109	8	0.2	13	374	20	5	26	12	7
MI	22	19	56	10	155	10	96	7	0.2	12	339	19	5	27	8	10
Z	25	18	44	17	225	10	115	8	0.2	13	383	19	9	24	9	10
92-1	35	32	57	18	198	15	147	11	0.5	13	429	26	11	21	5	25
92-2	19	11	59	15	180	9	155	11	0.3	11	596	22	6	16	5	19
92-4	19	16	48	10	142	9	88	6	0.2	11	293	18	5	25	11	5
92-5	22	15	47	10	135	8	88	6	0.2	10	296	16	5	26	10	5
92-7	39	21	94	19	177	12	97	11	0.2	14	560	23	7	26	10	24
92-8A	31	19	54	15	137	12	126	10	0.2	13	323	25	5	25	8	12
92-8B	32	20	60	16	137	13	132	11	0.2	13	332	26	8	25	9	11
92-9A	32	21	64	14	120	12	116	10	0.2	12	287	25	9	26	8	14
92-9B	29	20	65	15	119	12	118	10	0.2	12	309	25	8	24	8	8
33 105-7	48	46	70	21	191	16	176	12	0.5	14	353	21	16	21	5	25
33 164	52	49	68	21	220	17	170	12	0.2	15	358	23	10	22	5	18
33 207	230	55	74	23	220	13	116	10	0.3	17	241	19	13	26	5	13
average	39.39	31.21	63.05	18.51	156.4	13.07	131.1	11.2	0.28	12.69	379.1	24.59	9.49	23.07	6.34	13.8
Stdev	26.23	16.39	12.14	3.73	31.03	2.33	21.35	2.27	0.1	1.18	63.41	4.03	3.3	2.43	2.1	6.93
402-1	0.33	0.72	0.65	0.13	-0.69	-0.46	0.51	1.67	1.19	-2.28	0.61	-0.64	2.28	-1.67	-0.64	0.17
402-2	0.14	0.29	1.07	0.13	-0.11	-0.03	0.56	0.35	-0.77	-0.59	0.93	-0.39	0.76	-1.67	-0.64	0.03
402-3	0.4	0.9	1.31	1.2	1.99	-0.46	0.13	0.79	-0.77	-0.59	1.7	0.1	0.46	-0.85	-0.64	2.19
402-4	0.25	5.97	2.71	1.47	0.66	1.69	1.45	1.67	2.17	-0.59	0.46	0.6	0.76	-0.85	-0.64	-1.27
402-5	0.25	0.78	0.9	1.2	-0.08	-0.03	0.13	0.35	-0.77	0.26	0.79	-0.39	1.06	-0.44	-0.16	-1.27

Sample no	Ni ppm	Cu ppm	Zn ppm	Ga ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	Ag ppm	Sb ppm	Ba ppm	La ppm	Ta ppm	Pb ppm	Bi ppm	As ppm
402-6	0.02	0.48	0.65	0.94	-0.01	-0.03	0.42	0.35	1.19	1.11	0.55	-0.64	0.76	-0.44	-0.64	-0.26
402-7	0.1	0.48	0.41	0.67	-0.01	-0.03	0.65	0.35	1.19	0.26	0.69	-0.64	0.46	-0.03	-0.16	1.33
402-8	0.21	0.78	0.98	1.2	0.02	0.4	0.46	0.35	-0.77	0.26	1.01	-0.15	1.06	0.38	-0.64	-0.26
402-8A	0.18	0.72	0.9	0.94	0.21	-0.03	0.7	0.35	-0.77	0.26	0.9	-0.39	1.06	-0.03	-0.64	0.03
402-9	0.1	1.21	0.57	0.4	1.34	-0.03	-0.01	-0.09	2.17	1.11	0.79	0.35	0.46	0.38	-0.64	1.76
402-10	-0.21	0.35	-0.42	0.13	0.57	-0.46	2.71	0.35	1.19	-1.43	-0.03	0.35	1.97	-2.09	-0.64	0.03
402-11	0.29	0.54	0.57	0.94	-0.3	-0.03	0.32	0.35	0.21	-0.59	0.44	-0.64	2.28	-0.03	-0.64	1.18
402-19	-0.17	0.11	-0.09	0.4	0.05	0.4	0.09	0.35	0.21	-0.59	-0.11	-0.15	0.46	-0.03	-0.64	0.89
402-20	-0.09	-0.01	-0.17	0.67	0.21	0.83	0.56	0.79	-0.77	-0.59	0.09	0.35	-0.45	0.38	-0.64	0.61
402-21	-0.17	-0.07	0	0.4	-0.24	0.4	0.27	0.35	-0.77	-0.59	-0.18	0.1	-0.15	-0.44	-0.64	-0.55
402-22	-0.05	0.11	0.49	0.67	-0.01	0.83	0.42	0.79	0.21	1.11	0.06	0.6	0.15	-0.03	-0.64	0.61
402-23	-0.17	-0.07	0	0.4	-0.04	0.83	0.65	0.79	-0.77	0.26	0.14	0.35	-0.76	-0.03	-0.64	0.75
402-24	-0.21	-0.14	-0.5	0.4	-0.14	0.4	-0.01	0.35	0.21	-1.43	0.19	-0.15	-0.76	-1.67	-0.64	0.46
402-25	-0.24	-0.2	-0.42	0.67	0.18	0.4	0.37	0.35	-0.77	0.26	0.57	0.35	0.76	-0.03	-0.64	-1.27
402-26	-0.36	-0.56	0.08	0.4	0.34	-0.46	-1.08	-0.09	-0.77	-0.59	0.47	-1.14	-1.06	-1.26	-0.64	0.17
402-27	-0.36	-0.2	-0.09	0.67	-0.66	-0.03	-0.19	0.35	-0.77	0.26	1.59	-0.15	-0.45	-0.44	-0.64	1.76
402-28	-0.59	-0.93	-1.73	-0.14	-0.3	-0.89	-0.15	-0.09	-0.77	0.26	0.16	-0.64	-0.76	-0.44	0.31	0.75
402-29	-0.55	-0.87	-1.24	-0.14	0.18	-0.46	-0.05	-0.09	-0.77	0.26	1.24	0.35	-1.36	-0.03	-0.16	-0.98
402-29A	-0.82	-1.17	-2.64	-2.01	0.08	-1.32	-0.47	-1.85	-0.77	-0.59	-0.52	-1.64	-0.76	-0.03	1.74	-1.27
402-30	-0.78	-1.11	-2.47	-1.74	0.37	-1.32	-0.43	-1.85	-0.77	-1.43	-0.1	-1.64	-1.06	-0.03	0.79	-1.27
402-31	-0.21	-0.44	0.08	-1.74	-1.33	-0.89	-1.5	-1.85	-0.77	0.26	-1.14	-0.39	-1.06	1.62	1.26	-1.13
402-32	-0.17	-0.5	0.08	-1.48	-1.24	-0.89	-1.88	-1.41	-0.77	-1.43	-1.14	-0.15	-1.36	2.03	1.74	-1.27
402-33	-0.17	-0.38	-0.25	-1.74	-1.4	-1.32	-2.02	-1.41	0.21	0.26	-1.48	-0.89	-0.76	2.03	2.69	0.32
402-34	-0.21	-0.44	0	-1.48	-1.17	-0.89	-1.93	-1.41	-0.77	-0.59	-1.18	-0.39	0.15	1.62	1.26	-1.13
402-35	-0.05	-0.14	0.08	1.2	-1.53	0.4	0.42	1.23	1.19	0.26	-0.9	1.34	-0.76	0.38	-0.64	-0.84
402-36	-0.09	0.11	0	0.94	-1.56	0.4	0.13	0.79	0.21	1.11	-1.04	1.34	-0.15	-0.03	-0.64	0.75
402-37	0.14	0.05	0.08	1.2	-0.82	0.4	0.27	0.79	-0.77	0.26	-0.79	1.34	-0.15	0.38	-0.64	-1.13
402-38	0.18	-0.07	1.81	0.13	-0.85	1.26	-0.19	1.67	0.21	-0.59	-0.73	1.34	-0.45	0.8	-0.64	1.62
402-39	0.1	-0.01	1.48	-0.4	-0.79	0.83	-0.33	1.23	-0.77	-0.59	-1.01	1.59	-0.15	0.38	-0.64	1.33
402-40	0.21	0.05	0.49	0.67	-1.17	0.4	-0.19	0.79	1.19	0.26	-0.47	1.09	0.46	-0.44	-0.64	-0.84
402-41	0.21	0.05	0.16	0.4	-0.56	0.83	0.65	0.79	1.19	0.26	0.05	1.59	0.46	-0.44	-0.64	1.62
402-42	0.1	0.11	0.24	0.4	-0.75	0.83	0.42	0.79	1.19	-0.59	-0.24	1.59	1.37	-1.26	-0.64	-0.55
402-43	-0.05	-0.07	-0.25	0.13	-0.56	0.83	0.79	0.79	0.21	-0.59	-0.1	1.09	1.67	-0.85	-0.64	-0.12
402-44	-0.05	-0.2	-0.42	-0.14	-0.66	0.83	1.02	0.35	0.21	0.26	-0.13	0.85	-1.36	-1.67	-0.64	-0.98
402-45	0.06	0.29	-0.09	0.13	-0.37	0.83	0.51	0.35	2.17	0.26	-0.18	0.85	1.37	-0.03	-0.64	-1.13

Sample no	Ni ppm	Cu ppm	Zn ppm	Ga ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	Ag ppm	Sb ppm	Ba ppm	La ppm	Ta ppm	Pb ppm	Bi ppm	As ppm
402-46	0.21	0.29	0.57	0.67	-0.62	1.26	0.74	0.79	1.19	1.11	0.14	1.59	0.46	-0.03	-0.64	-0.84
402-47	0.18	0.41	0.33	0.67	-0.11	0.83	0.27	0.79	1.19	1.11	-0.03	1.09	-0.15	-0.03	-0.64	0.75
402-48	0.06	0.11	0.08	0.67	-0.56	1.26	0.65	0.79	1.19	1.11	0.03	0.85	0.46	0.38	-0.64	0.17
HT NoS	-0.21	-0.68	-0.91	-0.4	1.37	-0.89	-0.85	-0.97	-0.77	0.26	-0.22	-0.64	0.46	0.38	-0.16	0.32
HT SoM	0.1	-0.32	-0.17	0.67	1.6	2.98	1.07	0.35	-0.77	1.11	1.32	2.58	-0.15	-0.03	-0.64	-0.98
L A	-0.47	-0.81	-1.65	-0.4	2.37	-1.32	-0.52	-1.41	-0.77	0.26	0.17	-1.39	-1.36	0.38	1.74	-0.12
LS	-0.59	-0.93	-1.4	-0.67	1.7	-1.74	-1.04	-1.41	-0.77	0.26	-0.08	-1.14	-1.36	1.21	2.69	-0.98
MI	-0.66	-0.75	-0.58	-2.28	-0.04	-1.32	-1.65	-1.85	-0.77	-0.59	-0.63	-1.39	-1.36	1.62	0.79	-0.55
Z	-0.55	-0.81	-1.57	-0.4	2.21	-1.32	-0.76	-1.41	-0.77	0.26	0.06	-1.39	-0.15	0.38	1.26	-0.55
92-1	-0.17	0.05	-0.5	-0.14	1.34	0.83	0.74	-0.09	2.17	0.26	0.79	0.35	0.46	-0.85	-0.64	1.62
92-2	-0.78	-1.23	-0.33	-0.94	0.76	-1.74	1.12	-0.09	0.21	-1.43	3.42	-0.64	-1.06	-2.91	-0.64	0.75
92-4	-0.78	-0.93	-1.24	-2.28	-0.46	-1.74	-2.02	-2.29	-0.77	-1.43	-1.36	-1.64	-1.36	0.8	2.21	-1.27
92-5	-0.66	-0.99	-1.32	-2.28	-0.69	-2.17	-2.02	-2.29	-0.77	-2.28	-1.31	-2.13	-1.36	1.21	1.74	-1.27
92-7	-0.01	-0.62	2.55	0.13	0.66	-0.46	-1.6	-0.09	-0.77	1.11	2.85	-0.39	-0.76	1.21	1.74	1.47
92-8A	-0.32	-0.75	-0.75	-0.94	-0.62	-0.46	-0.24	-0.53	-0.77	0.26	-0.88	0.1	-1.36	0.8	0.79	-0.26
92-8B	-0.28	-0.68	-0.25	-0.67	-0.62	-0.03	0.04	-0.09	-0.77	0.26	-0.74	0.35	-0.45	0.8	1.26	-0.4
92-9A	-0.28	-0.62	0.08	-1.21	-1.17	-0.46	-0.71	-0.53	-0.77	-0.59	-1.45	0.1	-0.15	1.21	0.79	0.03
92-9B	-0.4	-0.68	0.16	-0.94	-1.2	-0.46	-0.61	-0.53	-0.77	-0.59	-1.11	0.1	-0.45	0.38	0.79	-0.84
33 105-7	0.33	0.9	0.57	0.67	1.12	1.26	2.1	0.35	2.17	1.11	-0.41	-0.89	1.97	-0.85	-0.64	1.62
33 164	0.48	1.09	0.41	0.67	2.05	1.69	1.82	0.35	-0.77	1.96	-0.33	-0.39	0.15	-0.44	-0.64	0.61
33 207	7.27	1.45	0.9	1.2	2.05	-0.03	-0.71	-0.53	0.21	3.66	-2.18	-1.39	1.06	1.21	-0.64	-0.12

Sample no	%granite	%perthite	%volcanic	%basalt	%gabbro	%schist	%greenstone	%quartzite	%chert	%carbonate	%sandstone	%hematite	%opaques
402-1	47	2	2	10	8	1	0	2	0	0	24	1	3
402-2	56	1	0	13	5	1	1	2	1	0	18	2	1
402-3	48	1	2	6	12	2	1	2	0	0	27	1	0
402-4	32	12	3	11	21	1	0	2	0	1	16	1	1
402-5	43	1	2	11	4	1	1	3	0	0	30	0	2
402-6	46	1	4	8	7	3	2	3	0	1	22	0	3
402-7	53	1	1	10	5	4	2	5	0	1	19	1	0
402-8	50	1	1	7	5	2	2	2	0	2	27	0	1
402-8A	49	0	5	12	5	1	1	1	1	1	22	0	1
402-9	47	1	1	8	5	2	0	5	0	2	25	2	3
402-10	44	2	0	8	6	1	2	3	1	2	26	0	4
402-11	43	0	9	6	7	7	0	5	2	2	17	3	0
402-19	47	1	1	6	3	0	1	6	0	7	24	0	2
402-20	51	3	2	7	1	1	0	2	0	4	28	0	1
402-21	63	1	5	5	1	0	0	2	0	3	18	0	0
402-22	59	1	1	4	1	1	0	2	2	5	23	0	1
402-23	62	1	1	5	1	1	2	3	1	6	16	0	1
402-24	56	1	1	4	0	2	1	6	0	6	22	1	1
402-25	53	1	4	5	4	2	0	7	0	5	19	0	1
402-26	57	2	2	5	6	1	1	1	1	5	19	0	1
402-27	60	1	1	7	1	0	0	7	1	7	14	0	2
402-28	58	0	0	4	1	1	1	2	1	18	15	0	1
402-29	53	0	0	3	3	1	0	2	1	23	13	0	1
402-29A	33	0	0	4	1	3	1	2	1	34	19	0	2
402-30	40	0	0	2	1	2	0	1	0	32	21	0	1
402-31	34	0	0	0	0	1	0	1	0	58	8	0	0
402-32	32	0	0	0	0	1	0	1	0	54	13	0	1
402-33	38	0	0	0	0	2	0	1	1	45	12	0	0
402-34	23	0	0	1	0	1	0	2	0	58	14	0	0
402-35	68	0	0	1	1	1	0	1	0	10	15	1	1
402-36	45	0	1	1	0	2	0	3	1	21	20	0	3
402-37	59	0	1	1	0	2	0	6	0	16	15	0	0
402-38	58	0	0	1	0	2	0	6	0	23	10	0	0
402-39	59	0	0	1	1	1	1	2	0	18	14	0	1
402-40	61	2	2	3	1	0	0	1	1	14	16	0	1

Sample no.	%granite	%perthite	%volcanic	%basalt	%gabbro	%schist	%greenstone	%quartzite	%chert	%carbonate	%sandstone	%hematite	%opaques
402-41	64	0	1	3	1	0	0	2	0	9	18	0	1
402-42	61	0	0	6	4	1	1	5	0	7	14	0	0
402-43	55	0	1	2	4	0	0	3	0	7	27	1	1
402-44	58	0	0	3	2	1	0	1	1	13	15	0	5
402-45	59	0	6	2	3	2	0	1	0	11	9	2	4
402-46	65	0	0	2	2	0	0	2	0	7	18	1	2
402-47	51	0	3	4	1	1	0	4	0	8	26	1	0
402-48	49	0	2	5	1	2	0	6	0	12	21	1	1
HT NoS	49	0	10	1	0	5	0	7	1	18	7	0	0
HT SoM	52	0	4	1	0	1	0	2	0	26	15	0	0
L A	43	0	0	0	0	2	0	0	0	44	10	0	0
LS	62	0	0	1	0	0	0	2	0	20	15	0	0
MI	80	0	2	0	0	1	1	6	0	0	9	0	0
Z	53	2	3	7	0	1	0	6	0	1	24	0	0
92-1	56	0	4	7	0	2	0	9	1	13	8	0	0
92-2	57	1	1	10	3	2	0	4	0	0	21	1	0
92-4	33	0	0	0	0	1	0	1	0	53	12	0	0
92-5	22	0	1	0	1	1	0	2	0	57	18	0	0
92-7	46	0	1	1	0	1	2	0	0	39	9	1	0
92-8A	45	0	1	0	1	3	0	4	0	33	13	0	0
92-8B	25	0	1	0	0	0	0	6	0	59	8	0	0
92-9A	48	0	1	1	1	2	0	1	1	36	10	0	0
92-9B	46	0	0	0	0	0	0	1	0	39	13	0	1
33 105-7	15	2	7	9	24	0	0	1	0	2	37	0	2
33 164	21	9	1	15	24	0	1	0	0	0	26	0	1
33 207	14	5	5	12	22	0	1	1	0	1	37	0	0
average	48.46	0.92	1.75	4.46	3.46	1.36	0.43	2.93	0.33	16.38	18.05	0.34	0.97
Stdev	13.31	2.03	2.22	3.96	5.74	1.25	0.67	2.16	0.54	18.11	6.86	0.66	1.17
402-1	-0.12	0.6	-0.04	1.31	0.8	-0.1	-0.05	-0.36	0.03	-0.9	0.86	0.79	1.39
402-2	0.55	-0.06	-0.81	2.25	0.22	-0.2	0.52	-0.42	0.7	-0.9	0	2.01	0.2
402-3	-0.02	-0.17	-0.01	0.48	1.43	0.77	1.09	-0.53	-0.7	-0.9	1.24	1.32	-0.84
402-4	-1.24	5.42	0.49	1.62	3.15	-0.2	-0.7	-0.59	0	-0.8	-0.3	0.73	-0.13
402-5	-0.42	0.04	0.32	1.72	0.17	0.06	0.82	0.03	-0.7	-0.9	1.78	-0.6	1.33

Sample no.	%granite	%perthite	%volcanic	%basalt	%gabbro	%schist	%greenstonc	%quartzite	%chert	%carbonate	%sandstone	%hematite	%opaques
402-6	-0.19	0	1.07	0.93	0.67	1.11	2.1	-0.08	-0.7	-0.8	0.61	-0.6	1.56
402-7	0.35	0.07	-0.57	1.39	0.22	1.9	1.73	0.84	-0.7	-0.9	0.13	0.27	-0.84
402-8	0.13	-0.04	-0.24	0.65	0.19	0.22	1.85	-0.57	-0.7	-0.8	1.28	0.08	0.26
402-8A	0.04	-0.46	1.29	1.99	0.31	-0.6	1.31	-0.73	1.63	-0.8	0.6	-0.6	-0.26
402-9	-0.14	-0.04	-0.23	0.77	0.27	0.23	-0.7	1.17	-0.7	-0.8	1.03	2.17	1.38
402-10	-0.35	0.53	-0.58	0.98	0.43	-0.4	2.33	0.25	1.05	-0.8	1.09	0.21	2.63
402-11	-0.4	-0.46	3.1	0.34	0.6	4.6	-0.7	0.86	3.1	-0.8	-0.2	4.67	-0.84
402-19	-0.08	0.02	-0.15	0.32	-0.02	-0.8	0.77	1.52	-0.7	-0.5	0.91	0.19	0.84
402-20	0.16	1.07	0.03	0.71	-0.4	-0.2	-0.7	-0.49	-0.7	-0.7	1.44	-0.6	-0.3
402-21	1.11	0.25	1.46	0.21	-0.36	-0.9	-0.7	-0.52	-0.1	-0.8	0.04	-0.6	-0.84
402-22	0.79	-0.16	-0.54	-0.2	-0.4	-0.2	-0.7	-0.24	3.56	-0.6	0.74	-0.6	-0.32
402-23	1	0.07	-0.33	0.13	-0.38	-0.1	2.55	0.24	1.17	-0.6	-0.4	-0.6	-0.14
402-24	0.54	-0.16	-0.54	-0.1	-0.61	0.83	1.14	1.41	-0.7	-0.6	0.59	0.39	-0.31
402-25	0.38	-0.11	0.94	0.01	0.06	0.28	-0.7	1.85	-0.7	-0.7	0.2	0	-0.23
402-26	0.66	0.42	-0.01	0.2	0.44	-0.3	0.38	-0.68	0.54	-0.7	0.13	-0.6	-0.22
402-27	0.86	-0.16	-0.54	0.53	-0.51	-1.2	-0.7	1.96	1.43	-0.5	-0.5	-0.6	0.74
402-28	0.69	-0.46	-0.81	-0.2	-0.39	-0.6	0.27	-0.46	0.41	0.11	-0.5	-0.6	-0.28
402-29	0.33	-0.46	-0.81	-0.3	-0.15	-0.4	-0.25	-0.26	0.32	0.36	-0.7	-0.6	0.18
402-29A	-1.17	-0.46	-0.81	0	-0.46	1	0.63	-0.34	0.83	0.98	0.2	-0.6	0.68
402-30	-0.66	-0.28	-0.81	-0.5	-0.36	0.31	-0.7	-1	-0.7	0.88	0.36	-0.6	-0.21
402-31	-1.12	-0.46	-0.81	-1.1	-0.61	-0.7	-0.7	-1.07	-0.7	2.27	-1.5	-0.6	-0.84
402-32	-1.24	-0.46	-0.81	-1.1	-0.61	-0.7	-0.7	-1.09	-0.7	2.07	-0.8	-0.6	-0.39
402-33	-0.8	-0.31	-0.81	-1.1	-0.61	0.52	-0.7	-0.8	0.32	1.6	-0.8	-0.6	-0.58
402-34	-1.89	-0.46	-0.66	-0.9	-0.61	-0.6	-0.7	-0.44	-0.1	2.31	-0.6	-0.6	-0.84
402-35	1.49	-0.34	-0.71	-0.8	-0.49	-0.6	-0.35	-0.81	0.1	-0.3	-0.5	0.53	0.16
402-36	-0.23	-0.46	-0.21	-0.9	-0.61	0.75	-0.2	0.18	1.64	0.27	0.33	-0.1	1.77
402-37	0.77	-0.46	-0.16	-0.9	-0.53	0.41	-0.7	1.27	-0.7	0	-0.4	-0.6	-0.84
402-38	0.74	-0.46	-0.81	-0.8	-0.61	0.74	-0.7	1.29	-0.7	0.36	-1.2	-0.6	-0.84
402-39	0.79	-0.46	-0.65	-0.8	-0.36	0.02	0.4	-0.51	-0.1	0.1	-0.6	-0.6	0.42
402-40	0.96	0.43	0.27	-0.4	-0.51	-1.2	-0.7	-1.06	0.33	-0.2	-0.3	-0.6	-0.32
402-41	1.19	-0.46	-0.2	-0.5	-0.49	-0.9	-0.7	-0.27	-0.7	-0.4	0	-0.6	0.32
402-42	0.96	-0.46	-0.81	0.28	0.13	0	0.74	0.81	-0.7	-0.5	-0.6	0.17	-0.43
402-43	0.46	-0.46	-0.48	-0.6	0.03	-0.9	-0.14	-0.16	-0.7	-0.5	1.22	0.6	0.44
402-44	0.74	-0.46	-0.81	-0.4	-0.25	-0.1	-0.7	-0.76	1.51	-0.2	-0.5	-0.6	3.52
402-45	0.82	-0.46	1.79	-0.7	-0.03	0.4	-0.7	-0.89	0.12	-0.3	-1.3	2.51	2.9

Sample no.	%granite	%perthite	%volcanic	%basalt	%gabbro	%schist	%greenstone	%quartzite	%chert	%carbonate	%sandstone	%hematite	%opaques
402-46	1.26	-0.24	-0.81	-0.7	-0.22	-0.8	-0.7	-0.32	-0.7	-0.5	-0.1	0.85	1.1
402-47	0.19	-0.46	0.53	0	-0.44	0.05	-0.7	0.45	0.15	-0.5	1.1	1	-0.41
402-48	0.01	-0.46	0.08	0.09	-0.35	0.45	-0.7	1.34	-0.7	-0.3	0.47	1.8	0.02
HT NoS	1.02	-0.46	-0.81	-1	-0.61	-1.2	-0.7	-0.41	-0.7	0.2	-0.4	-0.6	-0.84
HT SoM	2.38	-0.25	0.31	-1.1	-0.61	-0.5	1.18	1.28	0.01	-0.9	-1.4	-0.6	-0.84
L A	0.04	-0.46	3.87	-0.8	-0.61	3.37	-0.7	1.79	1.72	0.11	-1.5	-0.6	-0.84
LS	0.24	-0.46	0.95	-0.9	-0.54	-0.5	-0.7	-0.54	-0.7	0.51	-0.5	-0.6	-0.84
MI	-0.39	-0.24	-0.81	-1.1	-0.54	0.6	-0.05	-1.33	-0.7	1.51	-1.2	-0.6	-0.84
Z	0.35	0.76	0.53	0.59	-0.52	0.05	-0.7	1.57	0.15	-0.9	0.91	0.2	-0.84
92-1	0.58	-0.46	0.97	0.55	-0.61	0.22	-0.7	2.99	1.27	-0.2	-1.5	-0.6	-0.84
92-2	0.61	0.09	-0.31	1.48	-0.08	0.2	-0.7	0.42	-0.7	-0.9	0.43	0.75	-0.6
92-4	-1.2	-0.46	-0.81	-1.1	-0.61	-0.4	-0.7	-1.04	-0.7	2.05	-0.9	-0.1	-0.56
92-5	-2	-0.46	-0.58	-1.1	-0.52	-0.3	-0.7	-0.63	-0.7	2.24	0	-0.6	-0.84
92-7	-0.18	-0.46	-0.45	-0.9	-0.61	-0.5	2.91	-1.33	-0.7	1.25	-1.3	0.69	-0.84
92-8A	-0.25	-0.46	-0.13	-1.1	-0.48	1.3	-0.7	0.37	-0.7	0.89	-0.7	-0.6	-0.84
92-8B	-1.74	-0.46	-0.26	-1.1	-0.61	-1.2	-0.7	1.43	-0.7	2.36	-1.4	-0.6	-0.84
92-9A	-0.07	-0.46	-0.39	-0.8	-0.5	0.09	-0.7	-0.77	1.46	1.07	-1.2	-0.6	-0.57
92-9B	-0.2	-0.46	-0.81	-1.1	-0.61	-0.9	-0.7	-0.82	-0.1	1.26	-0.8	-0.6	-0.19
33 105-7	-2.48	0.4	2.47	1.1	3.55	-0.9	-0.26	-0.8	-0.7	-0.8	2.79	-0.6	1.17
33 164	-2.04	4.14	-0.14	2.57	3.58	-0.9	1	-1.33	-0.7	-0.9	1.21	0	-0.19
33 207	-2.57	1.92	1.58	1.97	3.21	-0.8	1.49	-0.89	-0.7	-0.9	2.79	-0.6	-0.42

APPENDIX B

CARBONATE PEBBLES GEOCHEMISTRY DATA

Sample	Ti %	Al %	Fe %	Mn ppm	Mg %	Ca %	Na %	K %	Li ppm
C402-7	<0.01	0.07	0.21	659	2.57	>10.00	0.03	0.05	3
C402-8	<0.01	0.14	0.98	1813	>10.00	>10.00	0.19	0.12	7
C402-8A	<0.01	0.99	0.37	1143	5.82	>10.00	0.33	0.15	10
C402-9	<0.01	0.17	1.06	1242	3.45	>10.00	0.03	0.05	3
C402-10	0.02	0.31	1.5	2778	6.99	>10.00	0.23	0.2	15
C402-11	0.01	0.19	0.31	1166	2.65	>10.00	0.17	0.17	15
C402-19	<0.01	0.16	0.09	343	2.16	>10.00	0.03	0.08	5
C402-20	0.01	0.27	0.4	409	6.16	>10.00	0.19	0.23	9
C402-21	<0.01	0.26	0.24	212	5.19	>10.00	0.14	0.17	7
C402-22	<0.01	0.44	0.21	627	1.32	>10.00	0.38	0.16	11
C402-23	<0.01	0.24	0.22	368	3.75	>10.00	0.02	0.09	9
C402-24	0.03	1.23	0.6	278	4.5	>10.00	0.03	0.08	28
C402-25	<0.01	0.1	0.58	597	8.8	>10.00	0.03	0.05	4
C402-26	<0.01	1.09	0.08	330	2.88	>10.00	0.08	0.81	3
C402-27	0.02	0.56	0.3	211	1.42	>10.00	0.04	0.46	10
C402-28	0.03	1.78	0.32	214	2.17	>10.00	0.87	0.84	8
C402-29	<0.01	0.14	0.21	215	1.93	>10.00	0.03	0.06	15
C402-29A	<0.01	0.14	0.18	168	6.15	>10.00	0.24	0.15	10
C402-30	<0.01	0.17	0.1	1048	4.49	>10.00	0.02	0.08	11
C402-31	0.01	0.3	0.34	247	8.18	>10.00	0.02	0.14	6
C402-32	<0.01	0.21	0.23	220	9.35	>10.00	0.02	0.13	6
C402-33	<0.01	0.26	0.3	210	7.48	>10.00	0.02	0.11	6
C402-34	0.01	0.27	0.36	249	9.09	>10.00	0.02	0.13	11
C402-35	0.01	0.25	0.24	398	2.89	>10.00	0.03	0.22	13
C402-36	<0.01	0.21	0.05	649	1.06	>10.00	0.01	0.07	7
C402-37	<0.01	0.19	0.1	213	4.71	>10.00	0.03	0.12	4
C402-38	<0.01	0.13	0.42	315	7.62	>10.00	0.28	0.09	7
C402-39	<0.01	0.16	0.27	299	4.49	>10.00	0.32	0.18	63
C402-40	<0.01	0.06	0.03	813	2.27	>10.00	0.03	0.04	3
C402-41	<0.01	0.15	0.33	875	1.74	>10.00	0.03	0.05	4
C402-42	<0.01	0.3	0.23	600	0.8	>10.00	0.25	0.11	8
C402-43	<0.01	0.1	0.16	519	0.2	>10.00	0.03	0.03	5
C402-44	<0.01	0.04	0.13	456	0.31	>10.00	0.25	0.06	5
C402-45	<0.01	0.16	0.08	733	0.61	>10.00	0.03	0.1	8
C402-46	<0.01	0.29	0.23	792	3.04	>10.00	0.31	0.13	68
C402-47	<0.01	0.09	0.78	1430	0.37	>10.00	0.21	0.11	20
C402-48	0.03	0.17	0.16	767	0.39	>10.00	0.24	0.19	7
C92-4	<0.01	0.11	0.26	121	>10.00	>10.00	0.25	0.14	8
C92-5	<0.01	0.25	0.33	165	>10.00	>10.00	0.23	0.14	8
C92-7	0.02	0.61	0.6	290	6.26	>10.00	0.37	0.2	7
C92-8A	<0.01	0.29	0.32	165	7.42	>10.00	0.25	0.12	9
C92-8B	<0.01	0.12	0.21	147	7.18	>10.00	0.29	0.13	7
C92-9A	0.02	0.32	0.47	343	>10.00	>10.00	0.33	0.19	9
C92-9B	<0.01	0.31	0.28	256	6.83	>10.00	0.35	0.17	7
C HT NoS	<0.01	0.19	0.4	294	9.19	>10.00	0.24	0.19	7
C HT SoM	0.01	0.34	0.21	206	0.05	0.11	0.02	0.07	19

Sample	Sc ppm	V ppm	Cr ppm	Co ppm	Ni ppm	Cu ppm	Zn ppm	Ga ppm	Sr ppm
C402-7	<1	5	30	5	4	1	2	<10	156
C402-8	<1	17	16	<1	9	5	2	91	54
C402-8A	<1	6	15	<1	5	<1	<1	85	115
C402-9	<1	5	26	6	5	2	6	<10	109
C402-10	<1	10	23	<1	1	<1	<1	95	263
C402-11	<1	6	23	<1	<1	<1	<1	91	119
C402-19	<1	4	27	6	3	2	3	<10	157
C402-20	<1	6	18	<1	4	<1	<1	91	124
C402-21	<1	4	17	<1	7	<1	<1	94	148
C402-22	<1	5	15	<1	6	<1	<1	87	212
C402-23	<1	6	22	4	4	3	5	<10	130
C402-24	<1	17	36	4	9	3	6	<10	55
C402-25	<1	5	19	5	5	3	5	<10	59
C402-26	<1	<2	22	4	3	1	3	<10	112
C402-27	<1	5	27	7	6	2	13	<10	154
C402-28	<1	6	13	<1	3	<1	3	84	200
C402-29	<1	3	18	4	4	2	2	<10	108
C402-29A	<1	<2	11	<1	7	<1	<1	82	141
C402-30	<1	3	24	4	8	2	11	<10	57
C402-31	<1	4	22	4	7	1	6	<10	97
C402-32	<1	3	22	4	6	1	5	<10	65
C402-33	<1	3	20	4	7	4	4	<10	72
C402-34	<1	4	27	5	6	2	4	<10	71
C402-35	<1	5	29	6	6	<1	4	<10	145
C402-36	<1	<2	15	1	2	<1	4	<10	48
C402-37	<1	3	28	5	5	5	3	<10	125
C402-38	<1	4	14	<1	<1	<1	<1	77	203
C402-39	<1	7	26	<1	11	6	121	78	123
C402-40	<1	2	29	5	3	1	8	<10	119
C402-41	1	6	37	8	9	2	8	<10	195
C402-42	<1	<2	28	<1	2	<1	<1	66	392
C402-43	<1	2	32	7	6	2	4	<10	201
C402-44	<1	4	19	<1	<1	<1	<1	63	164
C402-45	<1	3	28	5	3	1	5	<10	190
C402-46	<1	7	27	<1	9	8	238	75	107
C402-47	<1	5	19	<1	6	<1	64	63	153
C402-48	<1	5	21	<1	<1	<1	<1	72	217
C92-4	<1	6	24	<1	8	<1	<1	105	50
C92-5	2	4	21	<1	15	<1	2	101	54
C92-7	2	12	16	<1	3	<1	3	67	110
C92-8A	2	6	19	<1	5	<1	<1	85	142
C92-8B	<1	4	17	<1	5	<1	<1	88	84
C92-9A	<1	10	23	<1	11	<1	2	97	75
C92-9B	<1	3	23	<1	1	<1	<1	98	223
C HT NoS	<1	9	35	<1	8	<1	<1	97	91
C HT SoM	<1	5	22	1	13	2	4	<10	10

Sample	Y ppm	Zr ppm	Nb ppm	Mo ppm	Ag ppm	Cd ppm	Sn ppm	Sb ppm	Te ppm
C402-7	<5	2	<5	<1	<0.2	0.8	<20	<5	<25
C402-8	<5	20	26	4	<0.2	<0.5	<20	28	55
C402-8A	<5	14	25	7	<0.2	<0.5	<20	22	44
C402-9	<5	2	<5	<1	<0.2	<0.5	<20	<5	<25
C402-10	5	18	28	6	<0.2	3.4	<20	25	51
C402-11	<5	15	29	5	<0.2	<0.5	<20	18	52
C402-19	<5	2	<5	<1	<0.2	0.7	<20	<5	<25
C402-20	<5	22	28	<1	<0.2	<0.5	<20	27	53
C402-21	<5	14	29	<1	<0.2	<0.5	41	21	63
C402-22	<5	17	29	<1	<0.2	2.3	<20	15	37
C402-23	<5	6	<5	<1	<0.2	<0.5	<20	<5	<25
C402-24	<5	30	<5	<1	<0.2	<0.5	<20	7	<25
C402-25	<5	3	<5	<1	<0.2	<0.5	<20	<5	<25
C402-26	<5	4	<5	<1	<0.2	<0.5	<20	6	<25
C402-27	<5	6	<5	<1	<0.2	<0.5	<20	<5	<25
C402-28	<5	31	25	5	<0.2	1.1	<20	16	38
C402-29	<5	3	<5	<1	<0.2	<0.5	<20	<5	<25
C402-29A	<5	14	23	<1	<0.2	1.2	<20	22	51
C402-30	<5	5	<5	<1	<0.2	1.1	<20	<5	<25
C402-31	<5	5	<5	<1	<0.2	<0.5	<20	<5	<25
C402-32	<5	5	<5	<1	<0.2	<0.5	<20	<5	<25
C402-33	<5	4	<5	<1	<0.2	0.5	<20	<5	<25
C402-34	<5	6	<5	<1	<0.2	0.6	<20	<5	<25
C402-35	<5	4	<5	<1	<0.2	<0.5	<20	<5	<25
C402-36	<5	4	<5	<1	<0.2	<0.5	<20	<5	<25
C402-37	<5	2	<5	<1	<0.2	0.5	<20	<5	<25
C402-38	<5	13	23	<1	<0.2	<0.5	<20	22	36
C402-39	<5	15	25	7	<0.2	8.2	<20	20	45
C402-40	<5	<1	<5	<1	<0.2	<0.5	<20	<5	<25
C402-41	6	3	<5	<1	<0.2	<0.5	<20	<5	<25
C402-42	<5	12	22	2	<0.2	<0.5	<20	7	<25
C402-43	<5	<1	<5	<1	<0.2	<0.5	<20	<5	<25
C402-44	<5	10	21	2	<0.2	2.2	<20	<5	<25
C402-45	<5	2	<5	<1	<0.2	<0.5	<20	<5	<25
C402-46	<5	17	23	3	<0.2	17.7	<20	16	36
C402-47	<5	13	22	<1	<0.2	1.2	<20	<5	<25
C402-48	<5	33	26	3	<0.2	<0.5	<20	7	28
C92-4	<5	16	30	6	<0.2	3.7	<20	31	50
C92-5	<5	16	30	<1	<0.2	<0.5	<20	34	66
C92-7	<5	14	18	7	<0.2	<0.5	<20	20	33
C92-8A	<5	14	24	<1	<0.2	<0.5	<20	23	46
C92-8B	<5	14	26	<1	<0.2	<0.5	<20	23	47
C92-9A	<5	17	27	1	0.4	1	<20	30	52
C92-9B	<5	15	30	3	<0.2	3.5	<20	28	60
C HT NoS	<5	16	29	<1	<0.2	<0.5	<20	28	43
C HT SoM	<5	7	<5	<1	<0.2	<0.5	<20	<5	<25

Sample	Ba ppm	La ppm	Ta ppm	W ppm	Pb ppm	Bi ppm	As ppm
C402-7	7	<5	<5	<20	19	11	<5
C402-8	12	<5	7	<20	63	45	9
C402-8A	14	<5	<5	<20	47	54	22
C402-9	14	5	<5	<20	23	11	<5
C402-10	21	<5	5	<20	48	52	9
C402-11	20	<5	13	<20	36	38	15
C402-19	9	<5	<5	<20	21	13	<5
C402-20	20	<5	<5	<20	58	51	9
C402-21	17	<5	<5	<20	59	39	8
C402-22	34	<5	<5	<20	23	11	<5
C402-23	21	<5	<5	<20	18	14	<5
C402-24	55	<5	<5	<20	15	11	8
C402-25	8	<5	<5	<20	6	<5	<5
C402-26	24	<5	<5	<20	24	12	<5
C402-27	73	<5	<5	<20	18	11	<5
C402-28	134	<5	<5	<20	16	30	15
C402-29	13	<5	<5	<20	13	11	<5
C402-29A	11	<5	<5	<20	39	37	<5
C402-30	15	<5	<5	<20	17	10	8
C402-31	13	<5	<5	<20	14	<5	<5
C402-32	12	<5	<5	<20	11	<5	<5
C402-33	15	<5	<5	<20	13	<5	<5
C402-34	13	<5	<5	<20	9	<5	<5
C402-35	14	<5	<5	<20	20	11	<5
C402-36	11	<5	<5	<20	10	6	<5
C402-37	11	<5	<5	<20	20	12	<5
C402-38	10	<5	<5	<20	41	50	<5
C402-39	13	<5	7	<20	39	51	5
C402-40	15	<5	<5	<20	20	11	<5
C402-41	12	7	<5	<20	21	10	11
C402-42	21	<5	<5	<20	<2	<5	<5
C402-43	92	<5	<5	<20	14	<5	<5
C402-44	7	<5	<5	<20	<2	8	6
C402-45	10	<5	<5	<20	15	7	5
C402-46	15	<5	<5	<20	21	37	<5
C402-47	12	<5	<5	<20	6	<5	<5
C402-48	26	<5	<5	<20	16	<5	19
C92-4	9	<5	16	<20	71	79	<5
C92-5	17	<5	<5	<20	66	74	<5
C92-7	77	<5	6	<20	33	41	14
C92-8A	14	<5	<5	<20	44	55	14
C92-8B	10	<5	<5	<20	43	45	<5
C92-9A	17	<5	<5	<20	58	62	9
C92-9B	40	<5	<5	<20	50	49	15
C HT NoS	19	<5	<5	<20	57	56	19
C HT SoM	56	<5	<5	<20	3	<5	<5

Sample	Ti %	Al %	Fe %	Mn ppm	Mg %	Ca %	Na %	K %	Li ppm
C L A	0.01	0.38	0.31	295	8.38	>10.00	0.03	0.22	9
C LS	<0.01	0.23	0.33	320	4.35	>10.00	0.03	0.18	13
C MI	<0.01	0.17	0.15	153	9.46	>10.00	0.03	0.11	5
C Z	<0.01	0.12	0.26	124	>10.00	>10.00	0.34	0.15	10
C105-7	0.06	1.69	0.63	219	7.18	>10.00	0.16	0.38	24
C164	0.02	0.32	0.18	308	1.13	>10.00	0.03	0.15	10
C207	0.01	0.42	0.32	234	0.87	>10.00	0.25	0.17	21
C001	<0.01	0.41	0.38	127	5.31	>10	0.01	0.09	5
C011B	<0.01	0.09	0.03	165	2.35	>10	0.02	0.06	4
C020A	<0.01	0.1	0.11	112	6.14	>10	0.2	0.12	<2
C021	<0.01	0.09	0.07	71	0.78	>10	0.27	0.11	<2
C102B	<0.01	0.17	0.25	222	6.32	>10	0.01	0.12	8
C107G	<0.01	0.08	0.06	207	0.37	>10	0.23	0.1	11
C130	0.01	0.23	0.3	232	9.36	>10	0.34	0.18	7
C162A	0.02	0.32	0.37	168	9.93	>10	0.27	0.21	9
C174A	<0.01	0.32	0.19	216	2.22	>10	0.26	0.31	<2
C808	0.01	0.32	0.29	183	5.34	>10	0.27	0.31	3
C811	<0.01	0.1	0.07	102	0.98	>10	0.29	0.11	7
C815	0.02	0.54	0.38	228	5.52	>10	0.22	0.33	<2
C818	<0.01	0.15	0.12	84	3.84	>10	0.25	0.16	4
C822	0.01	0.25	0.16	133	3.7	>10	0.03	0.21	8
C824	0.02	2.39	0.39	169	5.91	>10	0.29	0.42	17
C2014	0.01	0.22	0.18	237	1.37	>10	0.28	0.26	2
C2032	0.02	0.55	0.37	362	2.31	>10	0.03	0.12	4
C2052	<0.01	0.18	0.52	378	5.95	>10	0.3	0.18	<2
C2059	0.01	0.31	0.2	246	3.07	>10	0.27	0.21	<2
C2103	<0.01	0.31	0.29	183	>10	>10	0.31	0.17	<2
C2125	<0.01	0.17	0.24	140	>10	>10	0.37	0.2	<2
C3048	0.01	0.23	0.33	204	8.88	>10	0.3	0.24	<2
C3049	0.02	0.5	0.24	80	>10	>10	0.37	0.4	4

Sample	Sc ppm	V ppm	Cr ppm	Co ppm	Ni ppm	Cu ppm	Zn ppm	Ga ppm	Sr ppm
C L A	<1	8	26	5	7	4	3	<10	135
C LS	<1	5	23	5	7	3	5	<10	88
C MI	<1	4	24	4	5	2	5	<10	61
C Z	<1	5	14	<1	6	<1	<1	92	38
C105-7	2	9	19	3	14	4	16	<10	28
C164	<1	6	31	6	5	4	6	<10	137
C207	<1	3	13	<1	<1	<1	10	66	82
C001	<1	2	21	4	<1	1	<1	<10	139
C011B	<1	2	23	5	4	<1	<1	<10	141
C020A	<1	3	<2	<1	<1	1	<1	102	98
C021	<1	<2	<2	<1	<1	<1	<1	72	218
C102B	<1	4	21	3	4	3	1	<10	116
C107G	<1	<2	4	<1	<1	<1	<1	70	216
C130	<1	3	4	<1	5	<1	<1	103	117
C162A	<1	<2	5	<1	<1	<1	<1	104	156
C174A	<1	<2	3	<1	<1	<1	<1	77	177
C808	<1	4	9	<1	<1	2	<1	95	210
C811	<1	<2	<2	<1	<1	3	<1	78	193
C815	<1	<2	5	<1	<1	6	<1	87	153
C818	<1	<2	<2	<1	<1	2	<1	89	142
C822	<1	7	27	7	5	3	<1	<10	168
C824	<1	11	28	6	10	7	5	<10	87
C2014	<1	<2	4	<1	<1	<1	<1	79	248
C2032	<1	7	27	7	6	3	1	<10	142
C2052	<1	<2	<2	<1	<1	2	<1	93	87
C2059	<1	<2	4	<1	<1	<1	<1	76	164
C2103	<1	<2	4	<1	12	3	<1	101	64
C2125	<1	2	<2	<1	<1	3	<1	105	39
C3048	<1	6	<2	<1	<1	3	<1	105	68
C3049	<1	<2	2	<1	<1	<1	<1	104	45

Sample	Y ppm	Zr ppm	Nb ppm	Mo ppm	Ag ppm	Cd ppm	Sn ppm	Sb ppm	Te ppm
C L A	<5	7	<5	<1	<0.2	<0.5	<20	<5	<25
C LS	<5	6	<5	<1	<0.2	<0.5	<20	<5	<25
C MI	<5	4	<5	<1	<0.2	<0.5	<20	<5	<25
C Z	<5	17	28	6	<0.2	<0.5	<20	29	70
C105-7	<5	33	<5	<1	<0.2	<0.5	<20	8	<25
C164	<5	9	<5	<1	<0.2	<0.5	<20	6	<25
C207	<5	15	26	6	<0.2	1.1	<20	19	<25
C001	<5	21	<5	<1	<0.2	<0.5	<20	<5	<25
C011B	<5	1	<5	<1	<0.2	<0.5	<20	<5	<25
C020A	<5	10	29	2	<0.2	5.6	<20	28	<25
C021	<5	8	26	<1	<0.2	<0.5	<20	<5	<25
C102B	<5	4	<5	<1	<0.2	<0.5	<20	<5	<25
C107G	<5	7	25	<1	<0.2	<0.5	<20	<5	<25
C130	<5	14	29	<1	<0.2	7.3	<20	24	<25
C162A	<5	13	31	<1	<0.2	7.2	<20	35	<25
C174A	<5	8	25	<1	<0.2	6.8	<20	16	<25
C808	<5	15	31	<1	<0.2	3.4	<20	23	<25
C811	<5	8	26	<1	<0.2	2.9	<20	<5	<25
C815	<5	16	29	2	<0.2	<0.5	<20	21	<25
C818	<5	10	27	2	<0.2	<0.5	<20	19	<25
C822	<5	3	<5	<1	<0.2	1.3	<20	<5	<25
C824	<5	9	<5	<1	<0.2	<0.5	<20	<5	<25
C2014	<5	8	26	<1	<0.2	2.1	<20	<5	<25
C2032	<5	5	<5	<1	<0.2	0.6	<20	<5	<25
C2052	<5	9	28	3	<0.2	<0.5	<20	27	<25
C2059	<5	13	26	2	<0.2	1.5	<20	16	<25
C2103	<5	13	31	2	<0.2	1.6	<20	42	<25
C2125	<5	12	31	<1	<0.2	6.8	<20	38	<25
C3048	<5	10	30	<1	<0.2	4.1	<20	38	<25
C3049	<5	12	29	<1	<0.2	<0.5	<20	40	<25

Sample	Ba ppm	La ppm	Ta ppm	W ppm	Pb ppm	Bi ppm	As ppm
C L A	22	<5	<5	<20	14	<5	<5
C LS	33	6	<5	<20	18	12	<5
C MI	9	<5	<5	<20	8	<5	<5
C Z	14	<5	15	<20	57	69	8
C105-7	51	<5	<5	<20	10	7	<5
C164	25	8	<5	<20	21	5	<5
C207	112	<5	<5	<20	17	7	9
C001	40	<5	<5	<20	23	10	8
C011B	5	<5	<5	<20	16	8	6
C020A	8	<5	8	<20	32	40	<5
C021	10	<5	<5	<20	2	6	<5
C102B	16	<5	<5	<20	11	6	6
C107G	13	<5	<5	<20	<2	6	<5
C130	20	<5	<5	<20	40	52	35
C162A	21	<5	11	<20	42	44	<5
C174A	344	<5	<5	<20	13	10	<5
C808	33	<5	5	<20	27	33	<5
C811	10	<5	13	<20	2	12	<5
C815	1933	<5	<5	<20	21	37	<5
C818	14	<5	10	<20	20	26	<5
C822	13	<5	<5	<20	17	11	20
C824	35	5	<5	<20	16	9	121
C2014	15	<5	<5	<20	<2	10	<5
C2032	42	<5	<5	<20	18	9	21
C2052	14	<5	9	<20	25	31	<5
C2059	19	<5	21	23	13	18	<5
C2103	23	<5	<5	<20	41	52	<5
C2125	13	<5	<5	<20	46	48	<5
C3048	13	<5	<5	<20	35	50	25
C3049	38	<5	<5	30	39	66	<5