Minnesota Department of Natural Resources
Division of Minerals
William C. Brice, Director

# Glacial Drift Geochemistry for Strategic Minerals;

## Duluth Complex, Lake County, Minnesota

*By:*
*R. L. Buchheit, K. L. Malmquist, and J. R. Niebuhr*

A
Legislative Commission on Minnesota Resources
Project

1989

Report 262
Part I of II

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# FOREWORD

This regional geochemical orientation and reconnaissance survey report for a portion of Lake County, Minnesota, has been made possible by the Minnesota Legislature's determination to promote a diversification of Minnesota's mineral resources base. With a favorable recommendation by the Minnesota Minerals Coordinating Committee and financial support provided by the Legislative Commission on Minnesota Resources, this non-ferrous metallic mineral investigation has been conducted by geologists and technicians in the Minerals Division of the Department of Natural Resources.

Bedrock in the four-hundred square mile study area is dominated by mafic intrusive rocks of the Duluth Complex, long known to host occurrences of copper, nickel, magnetic iron and titanium. Mineral exploration by mining companies for these metals over the past forty years has confirmed the existence of several mineral deposits of varying size and significance, but none have yet passed the economic tests for development and production.

Comparisons with similar intrusive bodies worldwide have suggested potential within the Duluth Complex for mineral deposits containing chrome, cobalt and platinum group elements (PGE's). The first platinum mineral identification was made in 1983; and a narrow, ore grade concentration of PGE's was identified in archived drill core that was re-examined in 1985.

Despite the attractive geological setting and mineral assemblage, this study area remains largely unevaluated and underexplored due to a general blanketing of bedrock by glacial drift that has a complex history of deposition. The locality provides an excellent opportunity for the application of a regional scale geochemical survey, using a variety and combination of evaluation techniques that have not previously been used in Minnesota. Analytical data that has been generated will constitute a large, new source of information to all who have interest in the mineral resource potential for this part of the Duluth Complex. It is hoped that the descriptions and discussions of the geochemical techniques applied to this study will stimulate and encourage wider use of these tools for mineral evaluation and exploration activities elsewhere in Minnesota.

# ACKNOWLEDGEMENTS

The authors wish to thank those many people whose contributions, great and small, were necessary for the successful completion of this project and report.

Being located within the Superior National Forest, the cooperation rendered by U.S. Forest Service personnel was critical to the execution of field work required by the project. Especially helpful were Stuart Behling, Zone Geologist in Duluth, and our working contacts in the district offices including: Paul Haggard (Isabella District), Robert Kari (Kawishiwi District), and Darryl Richards (Aurora District).

Howard Hobbs of the Minnesota Geological Survey provided a current Pleistocene description of the project area, its glacial history and deposit types. The spinels and other minerals in thirty-nine representative heavy mineral concentrates were reported on by Dr. Penelope Morton, University of Minnesota-Duluth and the Natural Resources Research Institute. The latter organization provided space and equipment for our use in sample preparation and processing at their Coleraine research facility.

Special recognition is given to contributions by our colleagues north of the border whose individual comments and numerous publications on Canadian geochemical investigations have been invaluable to the conceptualization and execution of this project. We are especially indebted to Dr. Colin E. Dunn of the Geological Survey of Canada who traveled to Hibbing to review the raw data with the authors, supported our confidence in the results, and suggested effective techniques for the report format and data presentation.

John Hoshal and Al Epp of the Land Management Information Service Bureau (LMIC), a division of the State Planning Agency's Planning Information Center, provided valuable assistance in presentation of our analytical results. Their computers and expertise allowed for the timely and cost effective production of the 62 geochemical maps that report the results of this reconnaissance program in forceful and convincing displays.

Within the Division of Minerals, numerous persons contributed to the success of the project. Special thanks go to the Hibbing staff, including Diane Williams for word processing and typing, accounting by Sue Saban, drafting services by Greg Walsh and Earl Mailhot, geophysical support by Thomas Lawler, computer services by Rick Ruhanen and Jacki Jiran, and vegetation recognition by Steve Dewar. Dennis Martin provided conceptual and technical advice, Mike McKenna contributed editorial suggestions, and E. Henk Dahlberg lent professional expertise in addition to critically reviewing the draft of this report.

Last, but not least, the Minnesota Minerals Coordinating Committee, the Legislative Commission on Minnesota Resources and Marty Vadis, Assistant Director - Division of Minerals, are to be commended for their support, promotion and funding of the program.

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## GEOCHEMICAL MAPS (cont.)

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## GEOCHEMICAL MAPS (cont.)



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## APPENDIX

# ABSTRACT

A multi-media, regional, reconnaissance geochemical survey was conducted over a four-hundred square mile area of Lake County, Minnesota. The pilot study was funded by the Legislative Commission on Minnesota Resources for the 1987-1989 biennium, with the Minnesota Department of Natural Resources, Division of Minerals as operator. Objective of the project was to determine, through the use of new or improved techniques of geochemistry and analytical processes, whether anomalous values of strategic metals were present in an area underlain by mafic igneous rocks of the Duluth Complex and North Shore Volcanic Group. In addition to the detection of platinum, palladium, chrome, cobalt, vanadium, titanium and associated or pathfinder elements, a second important goal was to learn whether the varied and complex glacial overburden would mask or distort the bedrock mineral content and geochemical signatures. The ultimate interpretation of data obtained would provide a basis for determining whether the applied techniques may be used for mineral resource evaluations elsewhere in Minnesota.

Taking 195 man-days or 78 calendar days from April 25 to October 14, 1988, overburden, A and B-soils and humus samples were collected at 1,162 sample sites at quarter-mile intervals along existing roads and trails. During the two weeks in October, 715 vegetation samples were collected from 327 of those sites; three species per site when available, including black spruce, white spruce, jack pine, balsam fir and alder.

Multi-element geochemical analyses were obtained on 566 partial heavy mineral concentrates, 567 clay/silt samples, 312 humus samples and 715 vegetation samples. Initial standard assay packages for the eight sampled media were all for 19 elements. Common elements were reported when possible, including Pt, Pd, Cr, Co, Ni, Zn, As, Ag, Au, Sb and Se. Heavy minerals and silt/clays also included V, $TiO_2$, Cu, Pb, MgO, $Fe_2O_3$, Bi and Te. For humus and vegetation, the additional elements were Ba, Br, Ir, Mo, Ta, Th, U and W. Later analyses, arriving too late for evaluation, were $SiO_2$, $Al_2O_3$, CaO, MnO, $Na_2O$, $K_2O$, Ba, Sc, Sr and Zr for heavy minerals and silt/clays, $P_2O_5$ and Y for heavy minerals only, and Fe and Hg for humus and vegetation.

Visual interpretations of selected elements have been illustrated by 62 computer generated geochemical contour maps for the eight sample media, with Pt, Pd, Cr, Co, Ni, Zn and As common to all of them. The results suggest that three anomalous localities exist across the project area, with internal sub-areas of interest. It is also concluded that the geochemical survey does reflect bedrock lithologies, despite variable thicknesses of glacial overburden of several deposit types and complex depositional history. The western anomalous locality is expressed best in heavy minerals, silt/clays and humus with a diagnostic element assemblage of Cr, Pt, Pd, Co, Ni and MgO. The central locality responds best with Co, V, $TiO_2$, $Fe_2O_3$ and Zn in the heavies; As, Sb and Br in humus and/or vegetation. The eastern locality is best expressed in silt/clays by Pt and $TiO_2$; in humus by Cr, Pt, Ir and Zn; and by Cr, Pd and sometimes Ni, Zn, Br and Ba in vegetation.

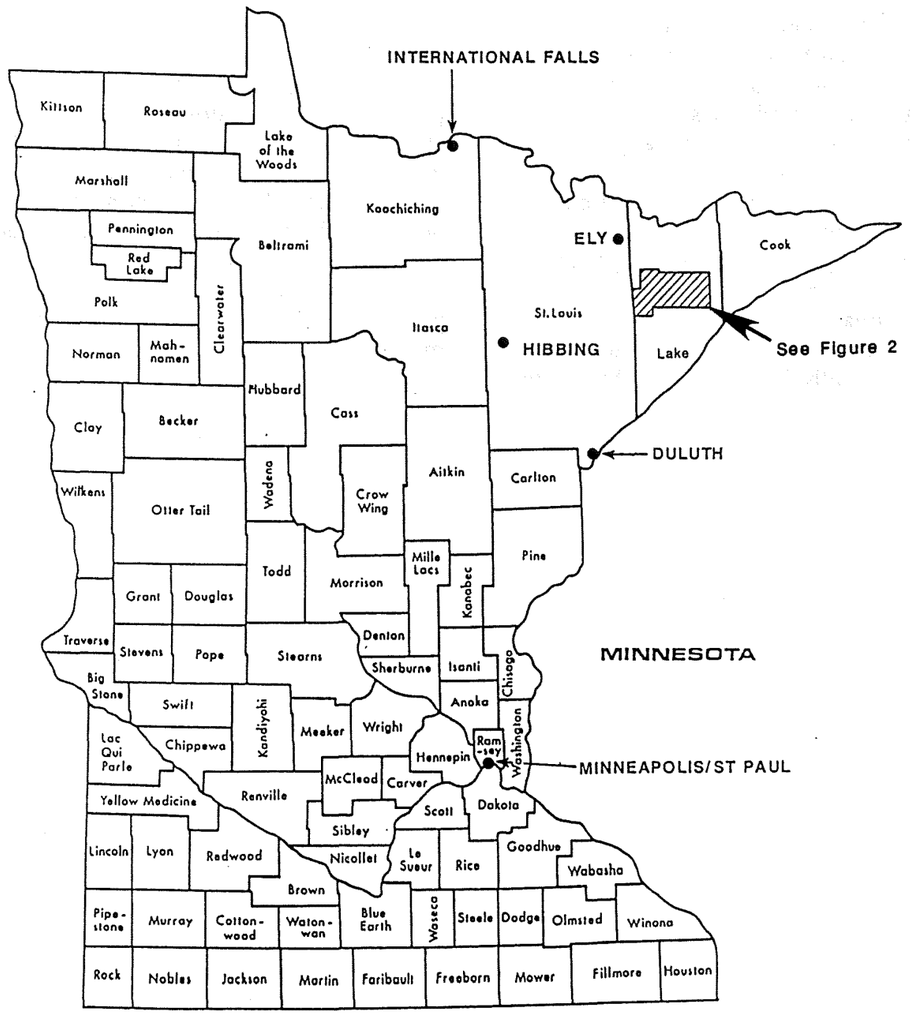
The multi-media approach was appropriate for the scope of the project, was very effective in areas with 50 feet of overburden, and useful, with caution, in the 50-125 foot overburden range. Further investigation of strategic mineral potential is suggested in the western area (T.59-61N., R.10-11W.); and the eastern locality, east of Isabella (T.59-60N., R.7-8W.).

# PURPOSE

This regional geochemical reconnaissance program by the DNR, Division of Minerals is an orientation pilot project. Its twofold purpose is to stimulate and encourage the diversified exploration and development of non-ferrous metallic minerals in the State of Minnesota, and to demonstrate that constantly improving and expanding techniques of geochemical prospecting are appropriate tools for identifying areas worthy of further evaluation. The investigation is intentionally focused on the interior of the Duluth Complex in Lake County, an area which has seen very little exploration activity, and on those minerals for which, until recently, Minnesota was thought to have little potential for hosting.

Our hopes and expectations were to find and recognize significant indications of the presence of strategic metals such as platinum, palladium, chrome, cobalt, vanadium, and their associated minerals, through the application of geochemical survey methods using several sample media. By demonstrating the effectiveness of such methods and media, we hope to encourage explorers for Minnesota minerals to include geochemistry in their inventory of exploration tools as they search for mineable mineral deposits in the State.

## LOCATION MAP




STUDY AREA – PROJECT 262, LAKE COUNTY

*figure 1*

# INTRODUCTION

Lake County, Minnesota, is located on the southern edge of the Canadian Shield and underlain by rocks of Precambrian age. Because of their wide distribution, diversity and economic significance to the north in Canada, these rocks have been studied and explored formany years. The search for mineral deposits has had some technical success but little economic reward. Approximately 1.5 million tons of iron ore were mined east of Ely from 1910 to 1923, and a large copper-nickel resource has been explored for years along a 12-mile strike length at Birch Lake and the South Kawishiwi River. Since the early 1980's, the focus for mineral potential in this area has shifted from base metals to other strategic metals including platinum, palladium, chrome, cobalt and titanium.

## Location

The area of this geochemical investigation encompasses approximately 400 square miles in the central portion of Lake County (Figures 1 and 2). It includes the N1/2 of T.59N., R.7-10W.; all of T.59N., R.11W. and T.60N., R.7-10W.; all of T.60N., R.11W. except the NW; those portions of T.61N., R.7-10W. lying outside of the Boundary Waters Canoe Area Wilderness; and the E1/2 of T.61N., R.11W. (Plate 1). All of the study area lies within the boundaries of the Superior National Forest.

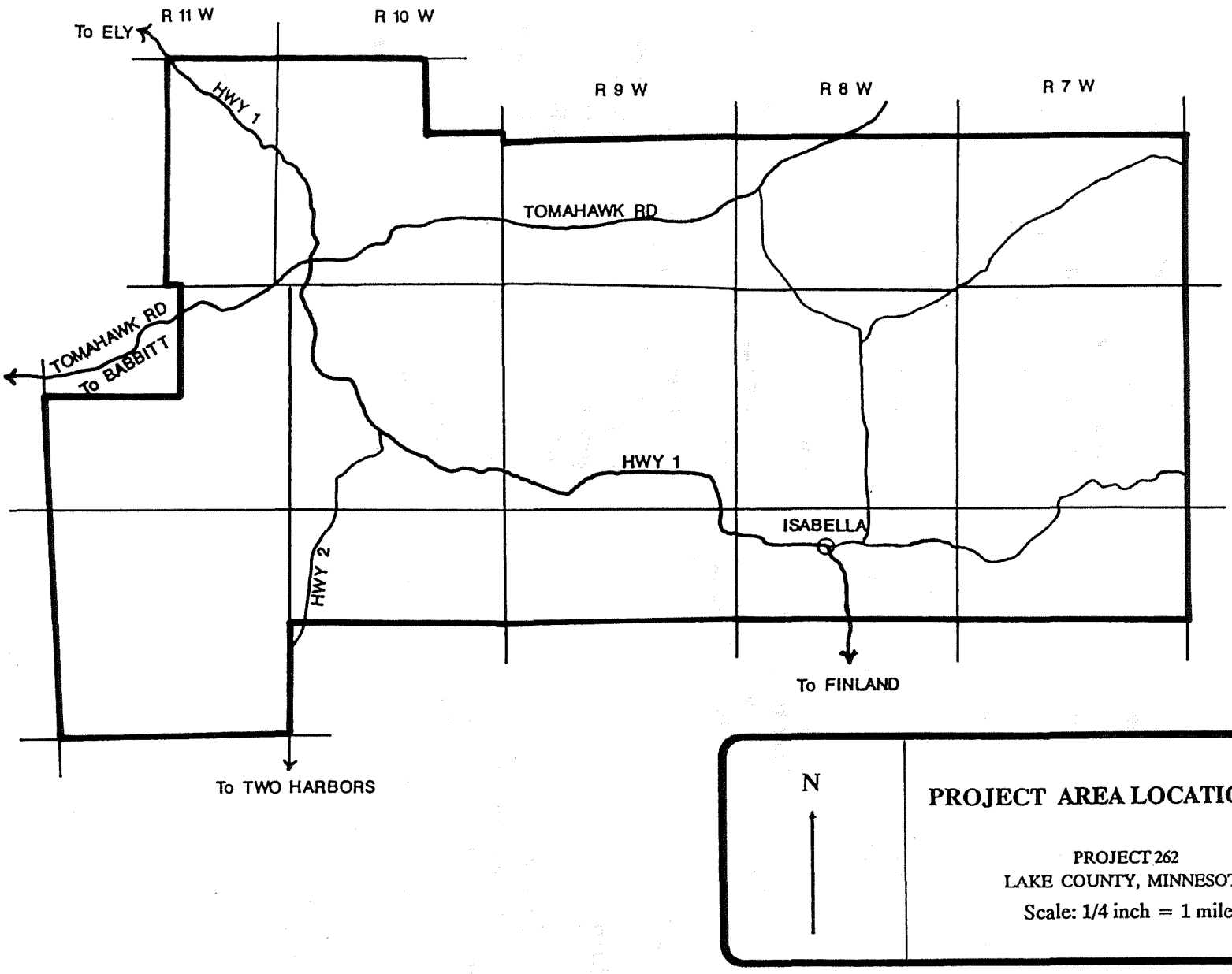
## Access

Road access is reasonably well developed, including blacktopped State Highway 1 and County Highway 2. There is an established system of improved, gravel, forest roads maintained by the U.S. Forest Service, traversing the area in east-west and north-south directions. From these, numerous secondary gravel roads and lesser primitive roads and trails extend into more remote portions of the area. Navigation for this investigation was provided from the Superior National Forest recreational map and U.S.G.S. 7.5 minute topographic quadrangle maps (Figure 3). Fully 90% of existing roads are passable with two-wheel drive vehicles in normal conditions. Winter access is more restricted when certain roads are left unplowed and are used as part of a system of snowmobile and ski trails.

## Land Status

Because the project area lies within the Superior National Forest, the predominant surface owner and land manager is the Federal government. A breakdown of surface ownership shows approximately 77% is Federal, 11% is State-owned, 11% belongs to private interests, and 1% is Lake County ownership. Without title examinations at the County Courthouse in Two Harbors, the exact mineral ownership status can not be determined. It is reasonable to assume, however, that Federal mineral ownership is in the 60-70% range, with remaining ownership divided between the State and private interests.

There are no State leases currently in effect in the project area. Superior National Forest records show that 1,246 acres are under lease in T.61N., R.11W. An additional 420 acres in T.61N., R.10W. and 435 acres in T.61N., R11W. are under Federal prospecting permits. Leases on private mineral interests, if any, are unknown.


To ELY
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R 8 W
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T 61 N
T 60 N
T 59 N
HWY 1
TOMAHAWK RD
TOMAHAWK RD
To BABBITT
HWY 1
HWY 2
ISABELLA
To FINLAND
To TWO HARBORS
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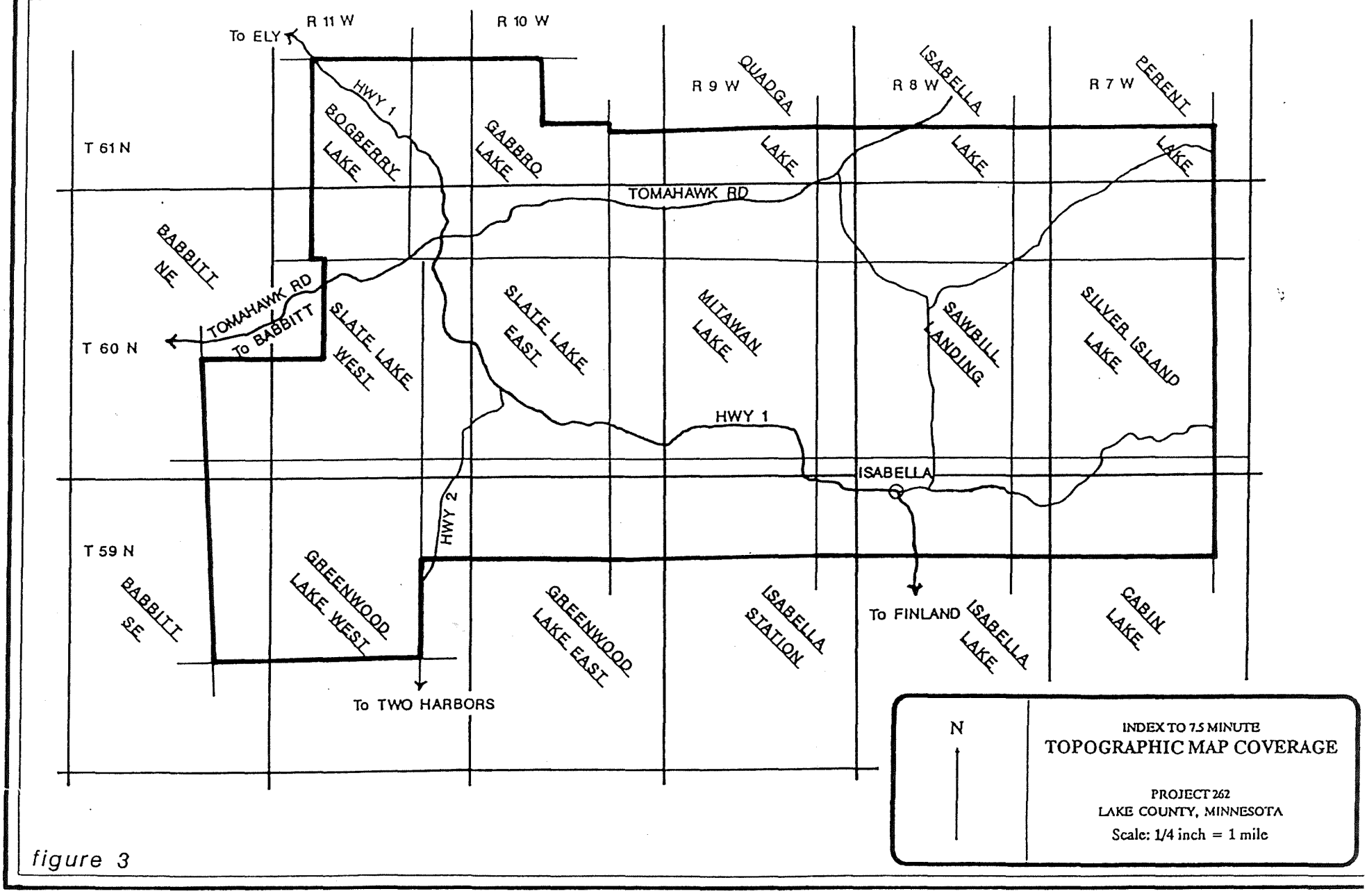
PROJECT AREA LOCATION MAP
PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

*figure 2*


R 11 W
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R 9 W
R 8 W
R 7 W
To ELY
HWY 1
BOGBERRY LAKE
GABBRO LAKE
QUADGA LAKE
ISABELLA LAKE
PERENT LAKE
T 61 N
TOMAHAWK RD
BABBITT NE
TOMAHAWK RD
To BABBITT
T 60 N
SLATE LAKE WEST
SLATE LAKE EAST
MITAWAN LAKE
SAWBILL LANDING
SILVER ISLAND LAKE
HWY 1
ISABELLA
HWY 2
T 59 N
BABBITT SE
GREENWOOD LAKE WEST
GREENWOOD LAKE EAST
ISABELLA STATION
To FINLAND
ISABELLA LAKE
CABIN LAKE
To TWO HARBORS
N
INDEX TO 7.5 MINUTE
TOPOGRAPHIC MAP COVERAGE
PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

figure 3

## Physiography

The area of this report is centrally located within the Arrowhead Region of Minnesota. It lies north of the Laurentian Divide except for about 14 square miles in the extreme southwest and about 20 square miles at the southeast corner of the project area. Three physiographic regions converge in this area, including the Border Lakes area, North Shore Highland and Toimi Drumlin area (Wright, 1956 & 1972). The Border Lakes area is situated north of the Laurentian Divide and, therefore, dominates the project area.

Topography varies from gently sloping to rolling to steep. Elevation variations between low and high ground may differ by as little as 20-50 feet over long distances, or change abruptly by 100-150 feet over short distances of a few hundred feet. This local relief is superimposed on regional slope to the north of approximately 600 feet over 12-14 miles.

There are numerous lakes, streams, ponds and bogs in this area which is part of the Birch Lake - South Kawishiwi River watershed, with all waters flowing northward. A deranged drainage pattern, developed subsequent to glacial retreat, is present. This pattern is characterized by irregular stream courses flowing into and out of lakes, few short tributaries, and frequently swampy interstream areas where the streams are mere water movement through the swamps. Bedrock control of the drainage pattern is only evident in the northwest quadrant and along the northern edge of the study area where rock outcrops and thin overburden are common.

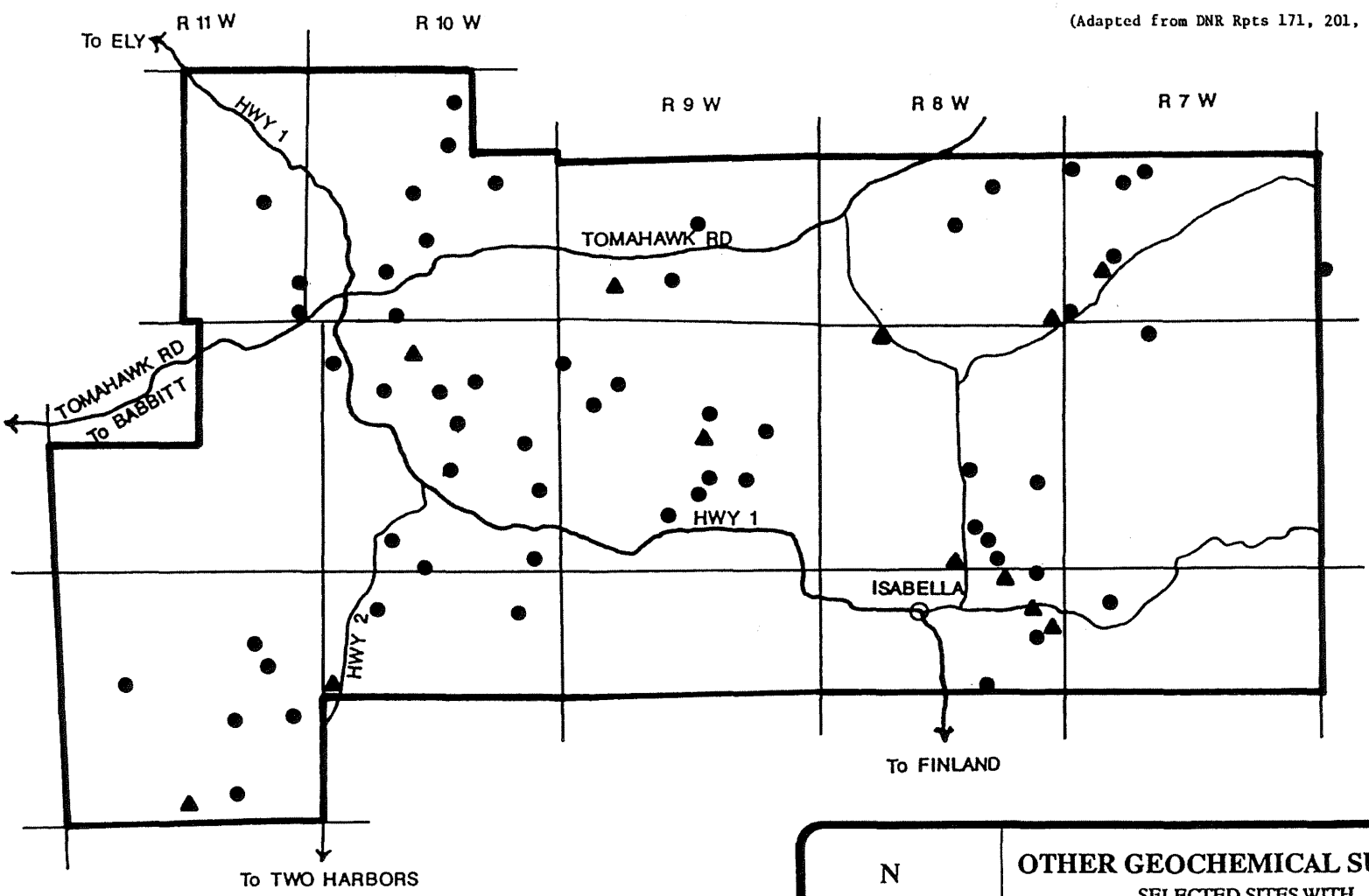
Overburden is glacially derived material of varying thickness. Depth to bedrock is widely variable over the area due to both the glacial geomorphology and topography of the bedrock surface, ranging from 0 to greater than 125 feet at the Isabella office of the U.S.F.S. According to Minnesota Soils Atlas (1981), area soils are variably thick to thin; may be silty, loamy or sandy; are normally light colored and drain well. Peat bogs are ever-present. The glacial deposits represent all variations of tills, ice contact and outwash types. All are sandy to greater or lesser degrees, frequently gravelly, sometimes clayey, and all but the outwash sands generally contain cobbles in quantities ranging from a few percent up to 80-90% of the deposit type.

Forest vegetation is representative of the boreal coniferous forest that originally covered the northeastern third of Minnesota. Red and white pine are in successional growth with white spruce and balsam fir, while jack pine is abundant in sandy outwash areas. Aspen, birch, balsam and spruce are the most frequent second-growth species. Bogs are dominated by black spruce and tamarack; with ash, willow and alder found in adjacent swampy terrain.

## Previous Work

Modern investigations of the geology and non-ferrous mineral potential for the project area date back to the recognition of copper-nickel occurrences along the basal contact of the Duluth Complex in the late 1940's (Ojakangas, 1982). Early information, published in the 1950's and 1960's, included joint MGS-USGS GP-series aeromagnetic survey maps, MGS summary reports on copper-nickel prospects (Schwartz, 1952 and Harris, 1954), and the first MGS geologic quadrangle map of the Gabbro Lake Quadrangle (Green, 1966) with discussions written by Weiblen (1965)and Phinney (1969).

Another generation of regional geological, geophysical and glacial maps was published during the 1970's and 1980's by the MGS and USGS. Listerud and Meineke (1977) of the Division of Minerals reported on mineral resources along the basal zone of the Complex.




(Adapted from DNR Rpts 171, 201, 231 & 246)

*figure 4*

DNR reports 171, 201 and 246 also presented the results of a number of pilot and regional geochemical surveys in and around the project area (Figure 4).

With few exceptions, mineral exploration within the Duluth Complex has always concentrated on copper, nickel and titanium in the "basal zone." As a result, very little of this project area has been examined in detail and most of that activity has been concentrated north of the Tomahawk Trail in T.61N., R.10-11W. Figure 5 indicates just how minimal information is on drill holes and mineral occurrences for this area. Little is known of any geological, geophysical or geochemical results that may have been developed by private exploration programs, at a time when disclosure of data was not required.

The Duluth Complex is once again becoming a focal point for non-ferrous mineral resource exploration and evaluation. Some chrome occurrences have been reported in years past (Weiblen, 1965; Stevenson, 1974; Fukui, 1976; Mainwaring, 1977; Ross, 1985; Miller, 1986) and reviewed by Sabelin (1987). This interest has been further spurred by Ryan's (1984) identification of a platinum mineral in massive sulfide ore from the Minnamax deposit, and by subsequent discoveries of chrome and PGE's in other gabbro drill cores from old copper-nickel exploration drill holes (Weiblen, 1988). The information to date suggests that the Noril'sk, Sudbury, Stillwater and Bushveld PGE distributions may have rough analogs in the Duluth Complex. Weiblen (1988) further suggests that PGE exploration targets in the Complex may include: 1) the copper-nickel ores; 2) associations with chrome-spinel rich rocks; and 3) possible concentrations in anorthositic rocks.

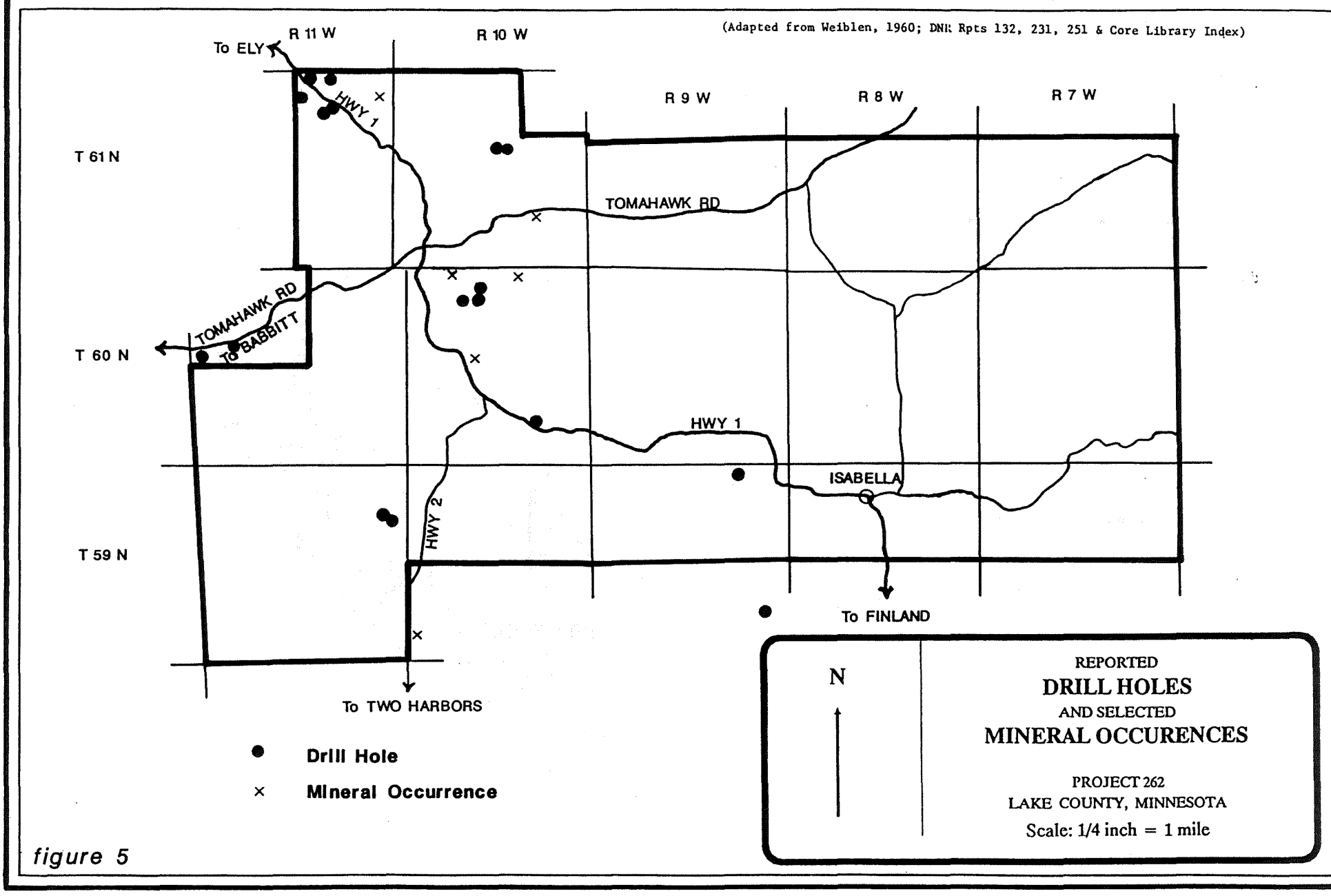
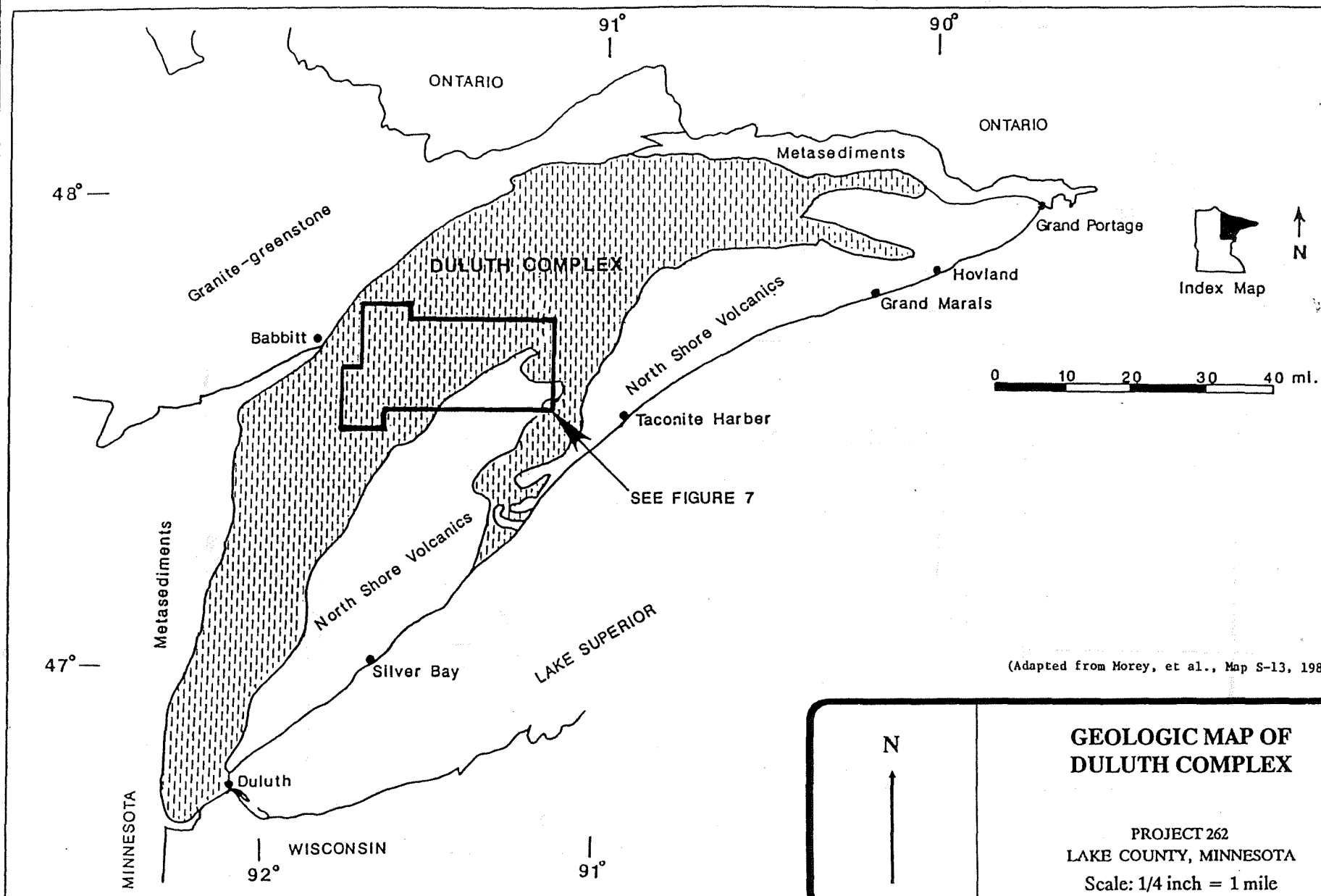

(Adapted from Weiblen, 1960; DNR Rpts 132, 231, 251 & Core Library Index)
R 11 W
R 10 W
R 9 W
R 8 W
R 7 W
To ELY
HWY 1
T 61 N
TOMAHAWK RD
TOMAHAWK RD
To BABBITT
T 60 N
HWY 1
ISABELLA
HWY 2
T 59 N
To FINLAND
To TWO HARBORS
Drill Hole
Mineral Occurrence
N
REPORTED
DRILL HOLES
AND SELECTED
MINERAL OCCURENCES
PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

*figure 5*




(Adapted from Morey, et al., Map S-13, 1982)

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**GEOLOGIC MAP OF DULUTH COMPLEX**

PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

*figure 6*

# REGIONAL SETTING

Lying halfway between Ely, Minnesota, and the North Shore of Lake Superior, the study area of this investigation reflects a complexity of both bedrock geology and glacial geology. Rock units of the Duluth Complex form bedrock under 90% of the area, while the southeastern 10% is underlain by rock units that include the extrusive Keweenawan Volcanics and other rock of less certain composition and origin that are simply categorized as Middle Proterozoic (Green, 1982). There are, similarly, glacial deposits from two major ice lobes of the last (Wisconsin) continental glaciation. Deposits of the Rainy Lobe cover basement rocks of the Duluth Complex and Superior Lobe deposits cover the Keweenawan-Proterozoic rocks; with perhaps a 20% overlap of outwash and mixed Superior-Rainy materials onto Rainy Lobe deposits over "Complex" rocks.

## Bedrock Geology

The Duluth Complex is a large, arcuate-shaped, mafic intrusive body of Middle Proterozoic age, extending from Duluth northeastward toward Hovland and Grand Portage as illustrated in Figure 6 (Green, 1979; Morey, 1982). Rock types are primarily anorthositic and troctolitic gabbros, with lesser amounts of normal gabbros, ultramafic, intermediate and felsic rocks (Phinney, 1972; Weiblen, 1980).

The Duluth Complex is generally characterized as a sill-like, multiple intrusive body (Taylor, 1964; Phinney, 1969), that intruded along the contact between underlying Lower Proterozoic and Archean rocks and overlying volcanics of the North Shore Volcanic Group (Green, 1972a). The geology of the Complex in the study area, as published in the Two Harbors sheet, is shown by Figure 7 (Green, 1982) and Plate 2 of this report.

The rocks of the North Shore Volcanic Group are present in only a small part of the southeast corner of the study area. They have been extensively reported on by Green (1972a&b, 1982). Rock types are mafic, extrusive varieties overlying the Duluth Complex, with their origins believed to be related to magmatic events associated with the formation of the Midcontinent Rift System (Van Schmus, 1985).

## Glacial Geology

The Quaternary history for the study area is described by Wright (1972), and the generalized glacial geology is illustrated by the Hobbs and Goebel map (1982). Three unpublished Master's theses, by Fenelon (1986), Friedman (1981) and Stark (1977), provide additional detail which has been compiled, modified and reinterpreted by Hobbs (1988).

The glacial geology, after Hobbs, is contained in Plate 3 of the report and illustrates the glacial deposit types of the Rainy and Superior lobes and their relationships. An approximate distribution of Rainy lobe versus Superior lobe deposits, interpreted from Hobb's work, is shown by Figure 8.

The glacial depositional history, which might logically be presumed to affect the geochemical interpretations for the study area, has been described in detail by the Hobbs report. The land forms and glacial features resulting from this depositional chronology are illustrated by Figure 9, and the glacial history is summarized as follows:

"*The Superior lobe advanced into the area from*

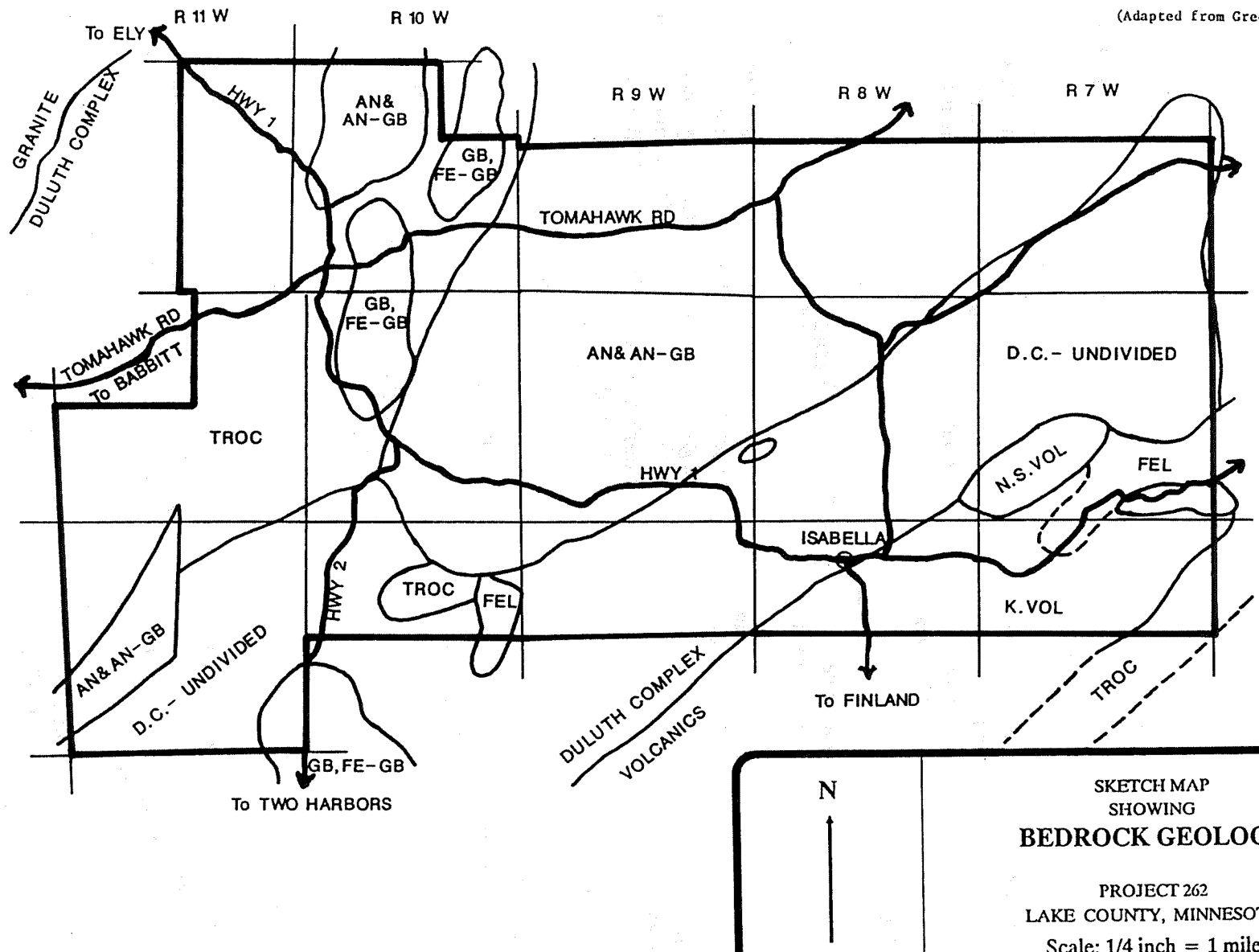
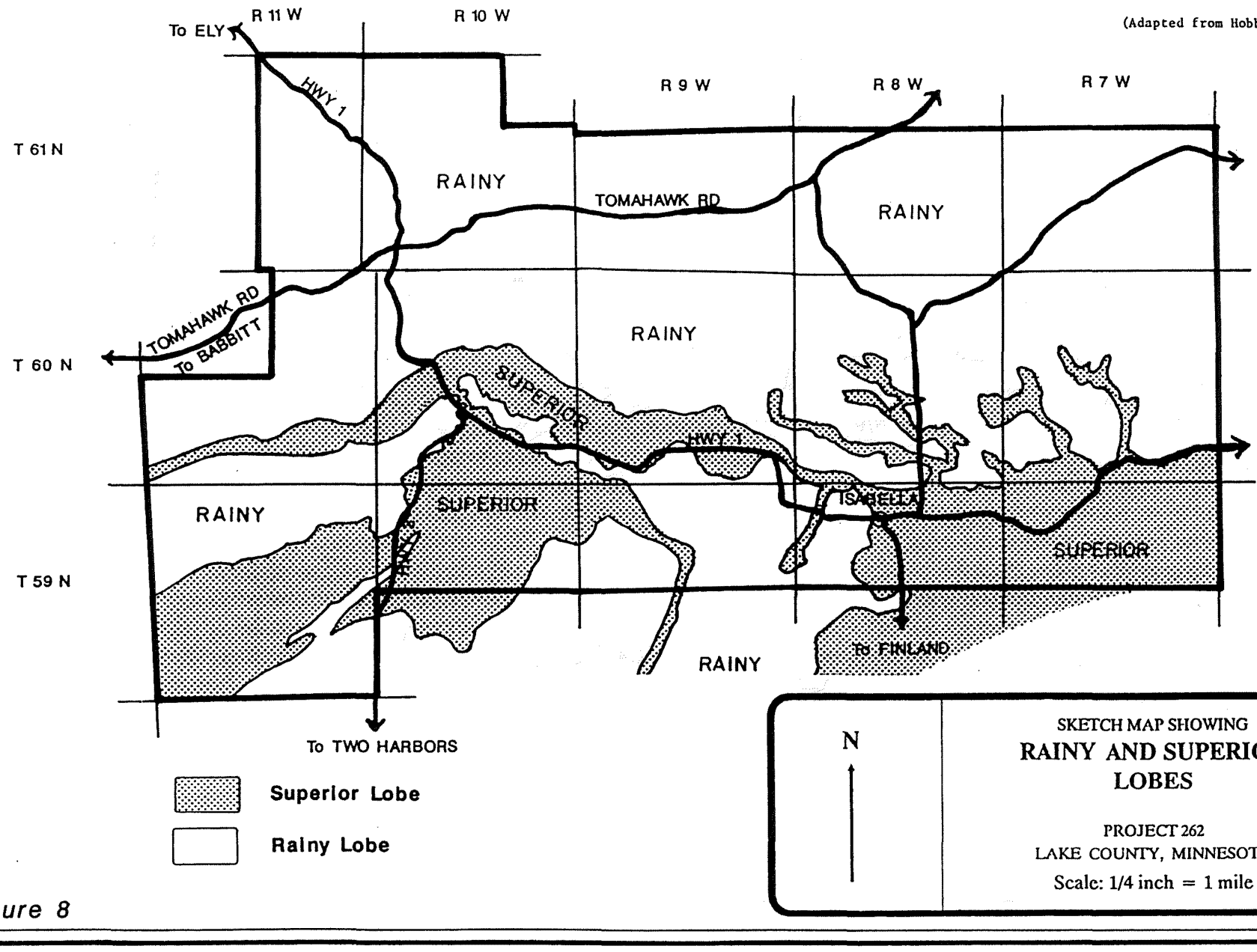

(Adapted from Green, 1982)
R 11 W
R 10 W
R 9 W
R 8 W
R 7 W
To ELY
GRANITE
DULUTH COMPLEX
HWY 1
AN&
AN-GB
GB,
FE-GB
TOMAHAWK RD
T 61 N
T 60 N
T 59 N
TOMAHAWK RD
To BABBITT
TROC
AN& AN-GB
D.C.- UNDIVIDED
HWY 2
TROC
FEL
HWY 1
ISABELLA
N.S.VOL
FEL
K.VOL
To FINLAND
DULUTH COMPLEX
VOLCANICS
TROC
GB, FE-GB
To TWO HARBORS
N
SKETCH MAP
SHOWING
BEDROCK GEOLOGY
PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

*figure 7*


(Adapted from Hobbs, 1988)
To ELY
R 11 W
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T 61 N
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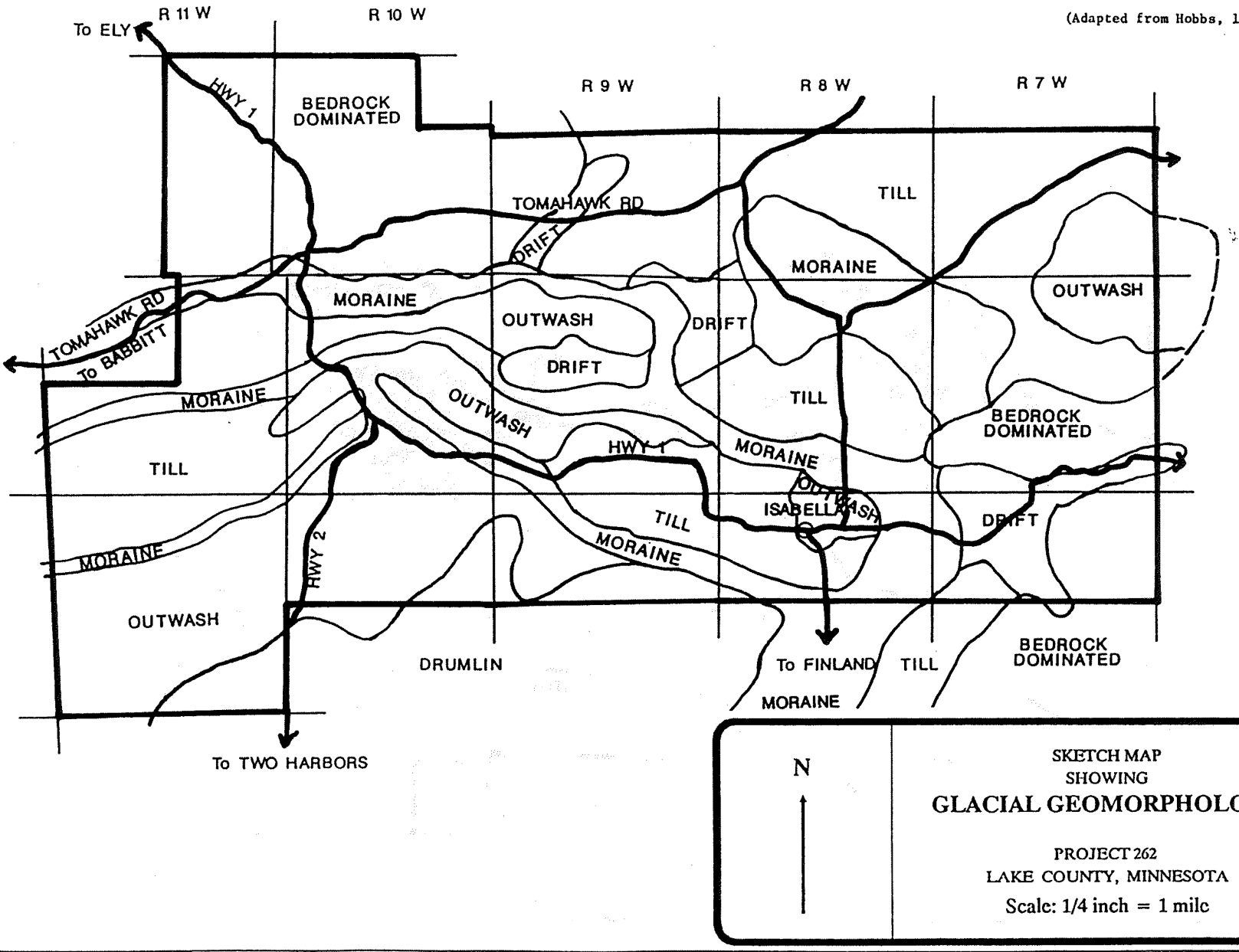
T 59 N
HWY 1
RAINY
TOMAHAWK RD
TOMAHAWK RD
To BABBITT
SUPERIOR
HWY 1
ISABELLA
SUPERIOR
To FINLAND
To TWO HARBORS
Superior Lobe
Rainy Lobe
N
SKETCH MAP SHOWING
RAINY AND SUPERIOR LOBES
PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

*figure 8*


(Adapted from Hobbs, 1988)
To ELY
R 11 W
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R 9 W
R 8 W
R 7 W
T 61 N
T 60 N
T 59 N
HWY 1
BEDROCK DOMINATED
TOMAHAWK RD
To BABBITT
TOMAHAWK RD
DRIFT
MORAINE
OUTWASH
DRIFT
TILL
MORAINE
OUTWASH
BEDROCK DOMINATED
DRIFT
TILL
OUTWASH
HWY 1
MORAINE
TILL
ISABELLA
OUTWASH
DRIFT
MORAINE
TILL
MORAINE
HWY 2
OUTWASH
DRUMLIN
To FINLAND
TILL
BEDROCK DOMINATED
MORAINE
To TWO HARBORS
N
SKETCH MAP
SHOWING
GLACIAL GEOMORPHOLOGY
PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

*figure 9*

*the southeast and built a broad moraine, at which it remained until the final melting episode. The Rainy lobe and its sublobe behaved much differently; they advanced from the northwest and northeast, and built a series of narrow moraines which reflect much shorter periods of stability. There appears to be a general contrast between the Rainy and Superior lobes, which explains their shapes: the Superior lobe was narrow and thick, because it occupied the Lake Superior basin, and so it reacted conservatively to changes in ice flow and ablation. The Rainy lobe was wide but thin, because its base was higher, even though its surface may have been roughly as high as that of the Superior lobe; thus it was more sensitive to changes in ablation and ice flow.*"

## Geophysics

Only regional geophysical maps are available for the study area. The magnetics are interpreted from a number of airborne surveys by the Minnesota Geological Survey and/or the U.S. Geological Survey (Bath, 1965; USGS, 1969; Chandler, 1983 and Chandler, 1984). The general magnetic pattern for the area is illustrated by Figure 10, and shows both correlations and contrasts with bedrock geology as presently mapped; however, actual practice has shown that ground magnetic surveys can provide useful insight into the geological interpretation when applied at a suitable scale and density of data.

Simple Bouguer gravity maps are also available (Ikola, 1968 and 1970). On the broader area scale of Figure 11, the interpretations generally define the contact zone between troctolitic and anorthositic gabbroic rocks. Again, actual practice has shown that a close order survey can assist on bedrock interpretations when combined with available bedrock and magnetic survey information.

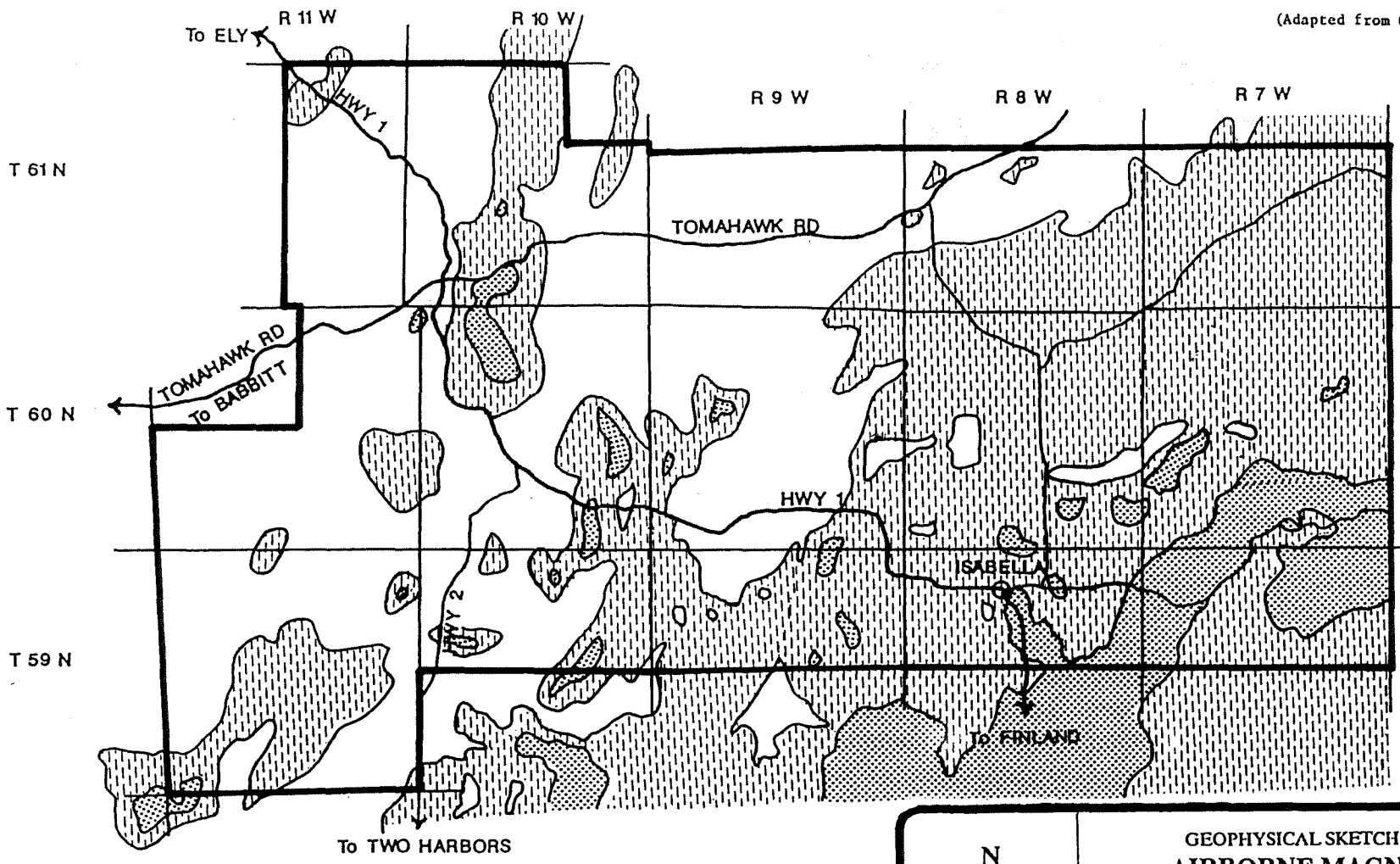

(Adapted from Chandler, 1983)
R 11 W
R 10 W
R 9 W
R 8 W
R 7 W
To ELY
HWY 1
T 61 N
TOMAHAWK RD
TOMAHAWK RD
To BABBITT
T 60 N
HWY 1
ISABELLA
HWY 2
T 59 N
To FINLAND
To TWO HARBORS
< 0 gammas
0–1000 gammas
1000–3000 gammas
N
GEOPHYSICAL SKETCH MAP OF
AIRBORNE MAGNETICS
INTERPRETATION
PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

*figure 10*

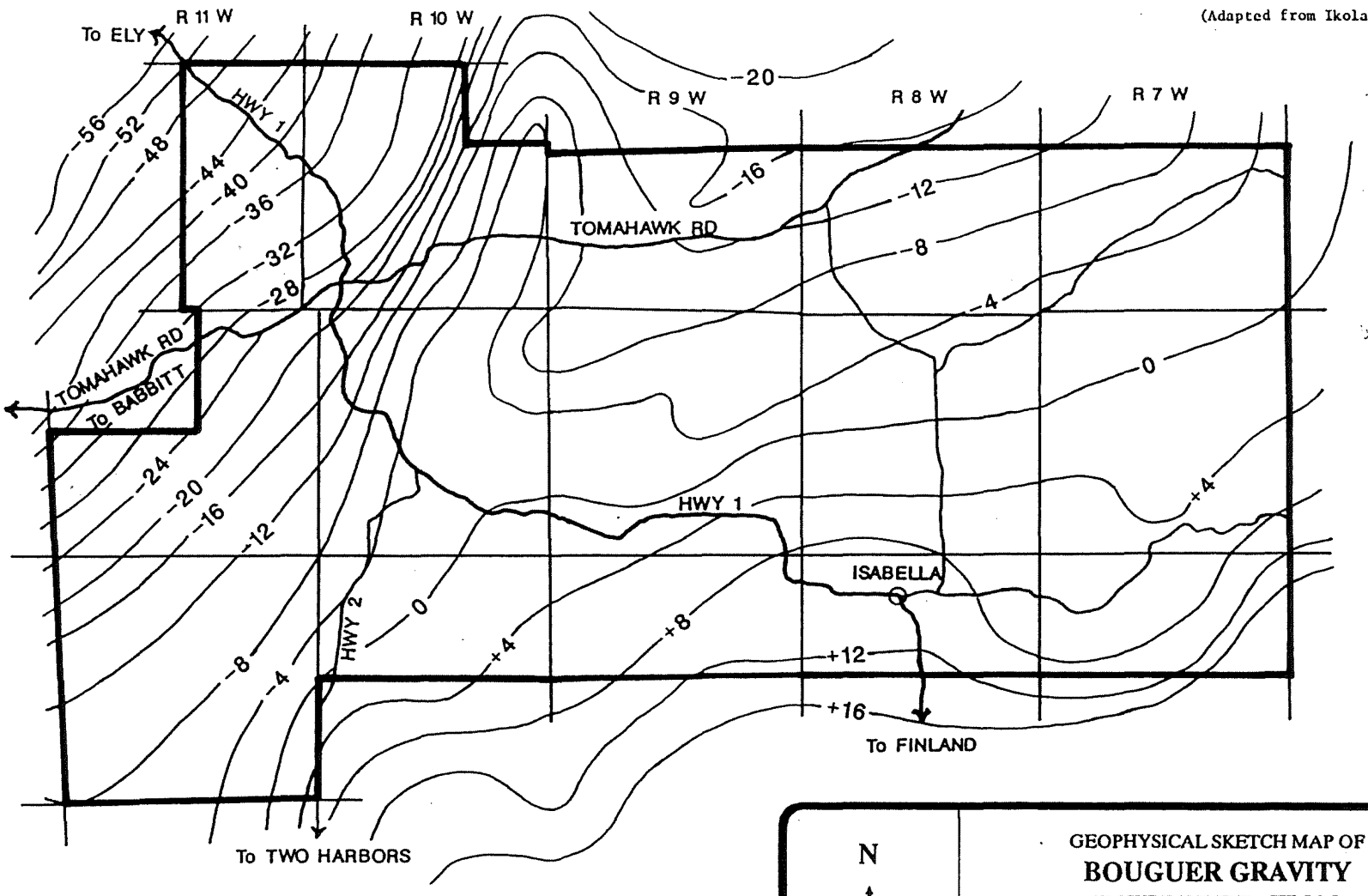

(Adapted from Ikola, 1970)
To ELY
R 11 W
R 10 W
R 9 W
R 8 W
R 7 W
T 61 N
T 60 N
T 59 N
HWY 1
TOMAHAWK RD
TOMAHAWK RD
To BABBITT
HWY 1
HWY 2
ISABELLA
To FINLAND
To TWO HARBORS
-56
-52
-48
-44
-40
-36
-32
-28
-24
-20
-16
-12
-8
-4
0
+4
+8
+12
+16
-20
-16
-12
-8
-4
0
+4
N
GEOPHYSICAL SKETCH MAP OF
BOUGUER GRAVITY
INTERPRETATION
PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

*figure 11*

# PROJECT CONCEPTS

## Goals

The aim of this investigation is to demonstrate a simple, rapid, cost-effective, regional geochemical survey plan that has produced a statistically reliable set of samples and analytical results and that adequately reflects and represents the mineral potential for the 400 square mile area that has been evaluated. If successful, the execution of the program should be able to narrow down the area for further exploration and should provide a basis for assessment of expectations for those occurrences that are found.

The geochemical analyses for the several types of sample media are to be determined, in so far as possible, from the standardized element packages regularly offered by recognized commercial laboratories. The element detection limits must be as low as can be commercially obtained by normal analytical procedures and methods in order to produce values of sufficient contrast that cause background or threshold element values to be distinguished from anomalous ones. All media varieties from the sampled locations are to be analyzed in order to determine the presence, persistence and magnitude for the element values of those media and to determine whether any, all, or which of the media types will act as reliable geochemical indicators in the study area.

Bedrock and glacial geology are to be compiled for the study. The compilation will be used to insure a sample site distribution that produces geochemical results which may reasonably be presumed to be reflective of the bedrock and overlying glacial deposit responses. Correlations of geochemical values or element clusters may reflect bedrock types and/or glacial deposit types, permit extrapolation of possible source locations and define specific target areas for further investigation.

## Objectives

Execution of this geochemical investigation should provide results that permit qualified remarks on a number of questions that are generated by geochemical surveys.

1. Were sampling and processing procedures appropriate and effective? Could they be improved?
2. Was the analytical package employed adequate for the investigation?
3. Can bedrock source areas be identified and mineral concentrations characterized on the basis of a geochemical signature?
4. Did glacial processes and history influence the geochemical results?
5. What geochemical anomalies exist in the study area?
6. Do the survey methodologies and interpretive techniques characterize the geochemical anomalies that are present?
7. What is, or is there, a preferred sample media or size fraction of material for use in a geochemical reconnaissance survey of the type conducted?
8. What are comparable element analysis values when translating from one sample media to another?
9. Is it appropriate to apply the conceptual approach and methodology of this pilot study to other Minnesota locations with differing bedrock geology and glacial history?

# GEOCHEMICAL PROGRAM

This geochemical survey was designed to locate strategic mineral occurrences, utilizing a geochemical method or methods that would (1) test a variety of sample medias and analytical procedures, (2) require minimal specialized skills or knowledge in order to collect and process samples, and (3) economically evaluate a large area with a sample density that is statistically meaningful.

The survey was comprised of three major phases. These were:

*I. Planning*
- *A. Review of Previous Work/Literature*
- *B. Program Selection/Development*

*II. Execution*
- *A. Sample Collection*
- *B. Sample Processing*
- *C. Laboratory Analysis*
- *D. Data Manipulation*

*III. Results*
- *A. Presentation of Data*
- *B. Discussion of Results*

## Planning

The initial planning process included researching the most recent bedrock and glacial geologic interpretations, and evaluating the geochemical methods and results of previous surveys within the study area. The sources for this information are provided in the list of references cited. A broader examination of geochemical texts and reports was also conducted to identify current geochemical practices in similar terraine, with emphasis on chrome, platinum and other related minerals possible in an environment of mafic host rocks. These latter publications (listed as Selected Bibliography) provided information on techniques and methodology, but were frequently inappropriate for application to this project because of their site-specific nature and focus on known mineral occurrences within the surveyed areas.

The review of previous work in the project area indicated a presence of unusual chemical values for certain elements, but no definitive geochemical anomalies within the study area. This lack of specific targets resulted in the conclusion that a regional, multimedia geochemical survey would be appropriate for the objectives of the project. A geographical review revealed an extensive network of county and forest service roads. This ready access, coupled with the presence of relatively shallow glacial cover and occasional bedrock exposures, allowed the design of an extensive surface sampling program. Of all the sampling media considered, glacial overburden, soil, humus and five species of vegetation were selected because they would best meet the project objectives. A cost effective program was devised, using technical personnel, to collect eight sample media from approximately 1,162 sample sites in a rapid and standardized routine.

## Execution

To insure an efficient, yet standardized collection of samples, care was taken to match methods, personnel and equipment with the geochemical medias being sampled. The selection of all sample site locations was done in the office from 7.5 minute, topographic, quadrangle maps. This impartial site selection procedure was used to eliminate any sampler bias in the field, and to insure impartiality on both the sample location and the nature of the sample media collected. Standardized approaches to recording of field notes were

MINNESOTA DEPARTMENT OF NATURAL RESOURCES
MINERALS DIVISION
SAMPLE SHEET

PROJECT NO: 262 | SAMPLE NO: 21446
PROJECT NAME: T60N-R9W-Sec 12 SW-SE
SAMPLER: JM-AR | DATE: 8/16/88 | SAMPLE NO. RANGE:
SAMPLE DEPTH OR INTERVAL: | SAMPLE TYPE: S R SS LS
SAMPLING METHOD: P PA FAh FAp ST T S H LSS
DESCRIPTION OF SAMPLE SITE | SLOPE: L G M S VS
TOPOGRAPHY: HC U L S | VEGETATION: DF CF MF GC GPF
DRAINAGE: F I P WL | BOULDERS:
ELEVATION: | OUTCROPS:
STRIATIONS: | WATER COLOR:
REMARKS:

Ag Ti As V Au Zn Cd Al Co C Cr Ca Cu Fe Hg K Mo Mg Ni Mn Pb Na S P Sn Si LOI

SOIL HORIZON: L F H Ah Ae AB B BC C
TEXTURE: g s z c o f Fn M Cr G S Z C O F P
COLOR: L M D____ G B R Y Bl Bk W Gn DEPTH TO WATER TABLE:____
SOIL TYPE: P GPc BPc GBPc GlP GlPc PP PPc G HG S Pt
GLACIAL TYPE: IC T M D GL WWT E O
CLAST TYPES: CLAST ANGULARITY: A SA SR R
REMARKS:

ROCK ROCK TYPE:____ T.S.____ P.S.____
STRUCTURE & TEXTURE:

| MINERAL | % | DESCRIPTION |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

REMARKS:

SEDIMENT STREAM FLOW: W ST SL M F SEDIMENT TYPE: Lake Stream Other
BANK OR SHORELINE MATERIAL: IC T M D GL WWT E P O CHANNEL DEPTH & WIDTH:____
TEXTURE: g s z c o f Fn M Cr G S Z C O F P SORTING: G F P
COLOR: L M D____ G B R Y Bl Bk W Gn ANGULARITY: A SA SR R
PERCENT: S M W N QUALITY: G F P GELATINOUS: G S SU N
SEDIMENT: T°C____ pH____ Eh____ SURFACE WATER: T°C____ pH____ Eh____
REMARKS:

M-406 05/79 NA-02306-01

figure 12

Sample # 21446

| Code | Type | Sampled | Depth | Assay Method | Elmts. Assayed | Loc. Retained Samples | Type Processed Samples |
|---|---|---|---|---|---|---|---|
| A | Wilfley Heavies | X | | 1,2,3,4 | 4 | 1,2 | |
| B | Wilfley Lights | X | | | | 1 | |
| C | Clay(-2um) Prep | X | | 1,3,4,7 | 3 | 2 | |
| D | | | | | | | |
| E | Black Spruce | | | | | | |
| F | White Spruce | X | | | 5 | 2 | |
| G | Jack Pine | X | | | 5 | 2 | |
| H | Balsam Fir | X | | | 5 | 2 | |
| I | Alder | | | | | | |
| J | Representative | X | | | | 1 | |
| K | Humus | X | | | | 1 | |
| L | A-Soil Horizon | X | | | | 1 | |
| M | B-Soil Horizon | X | | | | 1 | |
| N | Auger | X | 6' | | | 1 | 1,2,6,7,8,4 |
| O | Shovel | | | | | | |
| P | Bedrock | X | | | 2 | 1,2 | 9 |
| Q | OB Outcrop | | | | | | |
| R | Eskers | | | | | | |
| S | Stream Sediments | | | | | | |
| T | Other Cobbles | 10# | | | | | |

Outwash Sands: Medium to Coarse Grained, Slightly oxidized.
Bedrock Knob 100 yards to S.E. (Gabbro)

| Assay Methods | Elmts. Assayed | Loc. Retained Samples | Type Processed Samples |
|---|---|---|---|
| 1-FA-ICP | 1-Granitoid Package | 1-DNR Core Library | 1-Pebbles |
| 2-WR | 2-Ultramafics Package | 2-Assay Lab | 2-Granules |
| 3-AA | 3--63 or -2 Micron Pkg | 3-Project Geol. File | 3-Coarse HM Conc. |
| 4-ICP-Hydride | 4-Pan Concentrate Pkg | 4-Discarded | 4-Fine HM Conc. |
| 5-LECO | 5-Veg. Biogeochem Pkg | 5- | 5--63um Sample |
| 6-SP 10N EL | 6- | 6- | 6-Coarse Sd: |
| 7-INAA | | | 7-Very Coarse Sd |
| | | | 8-Med Sd. |
| | | | 9-Pulp |

developed and used throughout the project (Figure 12).

Statistical distribution of sample locations within the project area averaged 2.9 sites per square mile. Geochemical sampling at each site for humus, A and B soils, and glacial overburden commenced on April 25, 1988, and was complete by September 22, 1988. At a few locations, bedrock samples were taken where no overburden was available. Vegetation sampling of up to three of five possible species at 327 sites was accomplished over a two-week period from October 3-14, 1988.

Overburden was collected at 95% of the sites using a truck-mounted "Giddings Soil Probe" equipped with a 3 1/2" (diameter) spiral auger, with the remainder coming from shoveled, five-foot channel samples in roadcuts. Auger sites were located just off the roadway in undisturbed sediments. A continuous sample from surface to a maximum depth of five feet including soils and glacial sediments was collected and stored in a five-gallon plastic bucket. Cobbles and boulders were noted and then discarded. Sample weights averaged fifty pounds. Augering conditions were often difficult but the rig was adequate and operated with minimal down time. Soil samples were collected from shallow shovel pits, one square foot in area by 18 inches deep. This was adequate to obtain samples of both humus and the A and B soil horizons. The soil sites were located within a 100 foot radius of the auger site. Each site was marked with a 1" x 3 1/2" aluminum tag bearing the sample site number. This number was plotted on field topographic maps, recorded in the field notebook, and assigned to identify every sample type collected at that location.

The sampling techniques were rapid and completed with few problems. The daily sampling rate ranged between 10 and 34 sites, with an overall average of 20 sites per day. Actual time spent at a site averaged only twenty minutes. Initially, sampling and data recording were performed by two geologists and one technician. As the program progressed, all sampling and data recording were accomplished by the technician and one laborer.

The second phase of sample collecting, vegetation sampling in October, was also accomplished with a rapid yet standardized approach. Five vegetation species were sampled from 327 selected sites across the study area. These were as follows:

| | |
|---|---|
| White Spruce | *Picea glauca* |
| Black Spruce | *Picea mariana* |
| Jack Pine | *Pinns banksiana* |
| Balsam Fir | *Abies balsamifera* |
| Alder | *Alnus rugosa* |

A maximum of three species were sampled at each site. Twelve branch tips, approximately 45 cm. long, were selected from three trees of a given species. The branch tips were bagged and identified with the sample site number and a sample type code to identify the species.

During the conception of this project, sample collecting was expected to be an expensive, time consuming and laborious experience. Actual practice proved otherwise. Within five and one-half months, approximately 6,750 samples were collected from 1,162 sites in 153 man-days. Expenses, other than salary, lodging, meals and fuel, were limited to sample bucket purchases and minor repairs to the soil auger.

## Sample Processing

To insure a consistency and reliability in the resulting analytical data, standardized processing methods were developed and have

# GLACIAL TILL SAMPLE PROCESSING

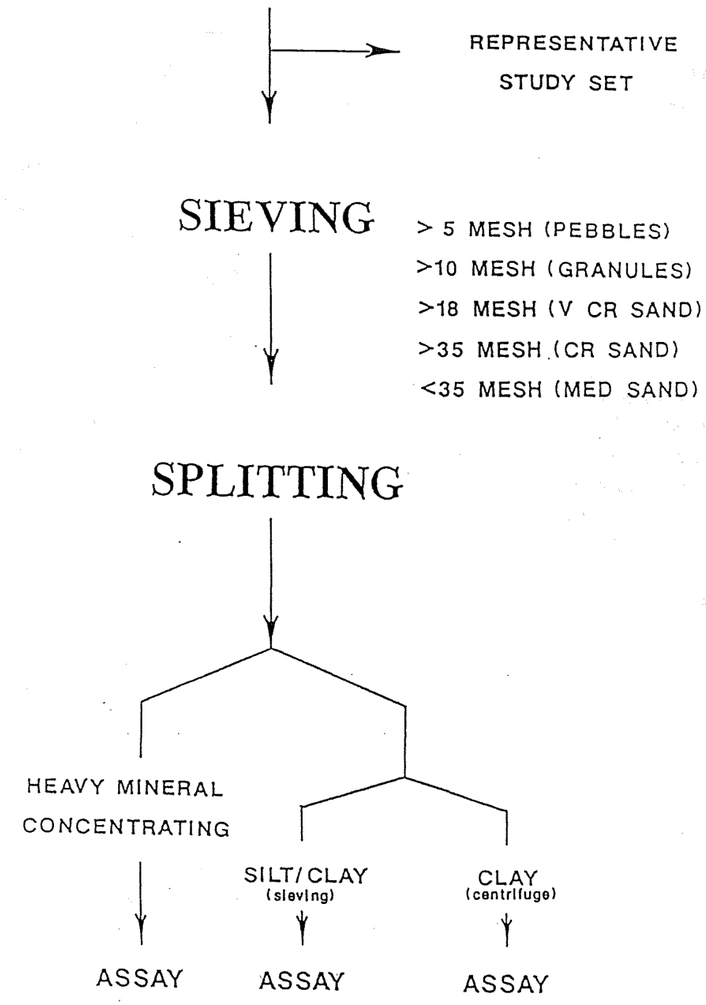



*figure 13*

been used throughout the program. The preparation of samples is described according to sample media type.

Processing of vegetation and humus at the DNR laboratory included sample drying, to prevent decay during shipment, and the removal of needles or leaves. This task was completed by two individuals over a three week period. Further processing at Technical Service Laboratories (TSL) included washing, macerating, blending, pressing and shrink wrapping the samples into 8 gram briquettes for neutron activation analysis. The remainder of the sample, approximately 80 grams, was ashed and analyzed for platinum and palladium by the Inductively Coupled Argon Plasma (ICP) method.

The preparation of heavy mineral concentrates, silt and clay fractions from glacial drift is depicted in Figure 13. Samples were sorted, dried and sieved through 5, 10, 18 and 35 mesh plastic or steel screens. All fractions greater than 35 mesh were weighed, bagged and stored for future reference. The minus 35 mesh fraction was then passed through a riffle splitter and portions were bagged for heavy mineral concentrating, silt and clay separation, and for future reference.

Partial heavy mineral concentrating was accomplished using a No. 13 Wilfley shaking table at the Natural Resources Research Institute (NRRI) in Coleraine. Following a series of test samples, the table's slope, speed, travel distance and feed rate were set and remained constant throughout the project. Water pressure was monitored and attempts were made to maintain this variable at a constant rate. Concentrates and light mineral rejects were dried, bagged and weighed. Concentrates were split, 1/2 was submitted for assay, 1/2 was placed in storage.

Separation of the silt and clay fractions from the minus 35 mesh fraction was accomplished using a two-step process of sieving and centrifuging at Technical Service Laboratories. Initially, the silt and clay (minus 63 micron) fractions were separated from the minus 35 mesh fraction by sieving. The resulting silt and clay fraction was then processed to separate the clay (minus 2 micron) portion using a centrifuge method developed by P. J. Higgins of the Geological Survey of Canada, as follows:

# PROCEDURE FOR CLAY SEPARATIONS
# BY
# P. J. HIGGINS
# TERRAIN SCIENCE DIVISION
# GEOLOGICAL SURVEY OF CANADA

This procedure utilizes bulk material, with no sample preparation required, to yield approximately 50 clay sized samples per day, along with accompanying washed coarser grain sizes.

Samples are suspended in a dispersant on a milkshake mixer and then centrifuged to bring down the desired grain sizes according to calculated times and RPM's (*equation for time needed for sedimentation under centrifugal acceleration for a given diameter). Coarse material remaining in the mixer bucket is washed and retained for other tests.

* Jackson, M. L., Soil Chemical Analysis - Advanced Course 1956

## Procedure

Sample is washed in the mixer with approximately 600 ml of metaphosphate solution. Three washings of 200 ml each work well. The amount of original sample material required will vary depending on the percentage of fines present but, normally 300-400 gms is sufficient. After each washing, the suspension is allowed to settle for 5 seconds and then decanted into the 1000 ml centrifuge bottle. By the third washing the supernatant should be fairly clean, indicating the proper amount of original sample was used.

After four samples are mixed, opposing centrifuge bottles are balanced to within 1 gm and spun for 3 minutes at 750 rpm on the centrifuge. This leaves particles less than 2 um (ESD) still in suspension while the silt is brought down. (Centrifuge bottles should be shaken prior to this run to be sure that all material can reach suspension). The supernatant (less than/or equal to 2 um) is decanted into a second series of centrifuge bottles, balanced, and spun at 2800 RPM for 14 minutes. Although some fines remain in suspension after this run, further centrifuging does not appreciably alter the amount of clay brought down. Using this method, the clay particles removed range from 0.3 um - 2.0 um ESD.

Throughout the procedure the following observations are noted:

a) colour of the raw till (Using the Munsell colour chart)

b) texture: clay, silt, etc.

c) consistency: crumbly, sticky, etc.

d) pebbles: how many?, size, shape, etc.

e) other features of the till: roots, rotted pebbles, etc.

f) any colour banding that may be developed in the clay residue.

Fine particles remaining in suspension after the 14 minute run are discarded and a long-handled stainless steel spatula is used to scrape the settled clay from the bottom of the centrifuge bottle into 100 ml nalgene cups. Distilled water is added to facilitate scraping. The clays are then dried in an oven overnight and ground or disaggregated to a powder the following day with an agate mortar and pestle.

Because neither the stainless mixer bucket nor the centrifuge bottles can be labelled easily, an index card with the sample number and a brief description, as well as a labelled 250 ml beaker accompany each sample throughout the process. A simple digit on the corner of the card (1-4) can be readily identified with the same digit ion the corresponding centrifuge bottles.

Silt, which settled out in the first series of centrifuge bottles after the 3 minute run, is discarded. The sand and gravel which settles in the mixer bucket is washed into the 250 ml beaker. Further washing and/or sieving of this material is done at convenience. Heavy minerals can be separated from the "clean" sand fraction that results from this washing and pebble counts can be performed on the 2-6 mm fractions, if desired.

There were some difficulties encountered during preparation of samples from the glacial drift. In order to minimize shipping costs, it was decided to produce the partial heavy mineral concentrates prior to shipment for analysis. Preparation of these concentrates on the Wilfley Table was influenced by a fluctuating water pressure. While it turned out that this fluctuation did not have an adverse affect on assay quality, solutions to this problem would have been to either develop a steady-state tank feeding the system, or to have the samples processed by a commercial laboratory. Separation of the clay fraction (minus two micron) was accomplished using a centrifuge method which was labor intensive and became a substantial bottle neck at TSL's facility. An alternative to this method is to assay silt plus clay rather than silt and clay separates. Drying of fifty-pound glacial drift samples was a major problem. The best drying results were accomplished by using flat wooden boxes (16" x 32" x 4") stacked with spacers (2" x 2" x 48") for air circulation. During the summer months, stacks of boxes were placed in the sun to promote drying. Drying times decreased sharply during November when all boxes were stacked indoors and subjected to the lower humidities resulting from forced air heat.

## Laboratory Analysis

All analytical work was performed by Technical Service Laboratories of Mississauga, Ontario. Methods are outlined on the following pages.

A. HMC - Partial Heavy Mineral Concentrates

| Element | Detection Limit | Sample Weight Assayed (gm) | Extraction | Assay Method |
|---|---|---|---|---|
| Pt | 10 ppb | 30 | Unknown | FA-ICP |
| Pd | 2 ppb | 30 | Unknown | FA-ICP |
| Cr | 5 ppm | .2 | Unknown | WR |
| Au | 1 ppb | 30 | Unknown | FA-ICP |
| Ag | 0.5 ppm | 1 | Unknown | AA |
| Co | 1 ppm | .2 | Unknown | WR |
| Y | 1 ppm | .2 | Unknown | WR |
| TiO | .01% | .2 | Unknown | WR |
| Cu | 5 ppm | .2 | Unknown | WR |
| Ni | 5 ppm | .2 | Unknown | WR |
| Pb | 5 ppm | 1 | Unknown | AA |
| Zn | 5 ppm | .2 | Unknown | WR |
| Bi | 1 ppm | 1 | Unknown | ICP-Hydride |
| Sb | 0.5 ppm | 1 | Unknown | ICP-Hydride |
| Se | 1 ppm | 1 | Unknown | ICP-Hydride |
| Te | 1 ppm | 1 | Unknown | ICP-Hydride |
| As | 1 ppm | 1 | Unknown | ICP-Hydride |
| MgO | .01% | .2 | Unknown | WR |
| Fe O | .01% | .2 | Unknown | WR |

Additional elements assayed:
$SiO_2$, $Al_2O_3$, CaO, MnO, $Na_2O$, $TiO_2$, $K_2O$, $P_2O_5$, Ba, Sr, Zr, Sc, Y

B. Silt/Clays - Silt and Clay Fractions ( -63 and -2 micron)

| Element | Detection Limit | Sample Weight Assayed (gm) | Extraction | Assay Method |
|---|---|---|---|---|
| Pt | 10 ppb | 30 | Unknown | FA-ICP |
| Pd | 2 ppb | 30 | Unknown | FA-ICP |
| Cr* | 5 ppm | .2 | Unknown | WR |
| Au | 5 ppb | 30 | Unknown | FA-ICP |
| Ag | 0.5 ppm | 1 | Unknown | AA |
| Co | 1 ppm | .2 | Unknown | WR |
| Y | 1 ppm | .2 | Unknown | WR |
| TiO | .01% | .2 | Unknown | WR |
| Cu | 5 ppm | .2 | Unknown | WR |
| Ni | 5 ppm | .2 | Unknown | WR |
| Pb | 5 ppm | .2 | Unknown | WR-AA |
| Zn | 5 ppm | .2 | Unknown | WR |
| Bi | 1 ppm | 1 | Unknown | ICP-Hydride |
| Sb | 0.5 ppm | 1 | Unknown | ICP-Hydride |
| Se | 5 ppm | 1 | Unknown | ICP-Hydride |
| Te | 1 ppm | 1 | Unknown | ICP-Hydride |
| As | 1 ppm | 1 | Unknown | ICP-Hydride |
| MgO | .01% | .2 | Unknown | WR |
| Fe O | .01% | .2 | Unknown | WR |

Additional elements assayed:
$SiO_2$, $Al_2O_3$, CaO, $Na_2O$, $K_2O$, MnO, $P_2O_5$, Ba, Sr, Zr, Sc

C. Humus and Vegetation

| Element | Detection Limit | Sample Weight Assayed (gm) | Extraction | Assay Method |
|---|---|---|---|---|
| Au | .1 ppb | 8 | Unknown | INAA |
| Sb | .01 ppm | 8 | Unknown | INAA |
| As | .01 ppm | 8 | Unknown | INAA |
| Ba | 20 ppm | 8 | Unknown | INAA |
| Br | .01 ppm | 8 | Unknown | INAA |
| Cd | 0.5 ppm | 8 | Unknown | INAA |
| Cr | .3 ppm | 8 | Unknown | INAA |
| Co | .3 ppm | 8 | Unknown | INAA |
| Ir | 5 ppb | 8 | Unknown | INAA |
| Mo | .05 ppm | 8 | Unknown | INAA |
| Ni | 2 ppm | 8 | Unknown | INAA |
| Se | .5 ppm | 8 | Unknown | INAA |
| Ag | 0.5 ppm | 8 | Unknown | INAA |
| Ta | 0.1 ppm | 8 | Unknown | INAA |
| Th | 0.1 ppm | 8 | Unknown | INAA |
| W | .05 ppm | 8 | Unknown | INAA |
| U | 0.02 ppm | 8 | Unknown | INAA |
| Zn | 2 ppm | 8 | Unknown | INAA |
| Pt | 10 ppb | 1 (ash) | Unknown | ICP |
| Pd | 2 ppb | 1 (ash) | Unknown | ICP |

Additional elements assayed:
Fe, Hg

## Data Manipulation

IBM compatible computers using Watfile, Infosys, Displaywrite 4, Word Perfect, Ventura, SuperCalc 4, Mineral Interpretation Program (MIPS), Arc Info and Epple 7 were used in the manipulation of data. Watfile and Infosys were most helpful for organizing and using the master sample list and analytical results. Displaywrite 4 was used as an editing intermediary between the ASCII formatted Infosys and the Wat formatted Watfile. All analytical results were printed using Word Perfect. Ventura produced many of the title pages and map legends. Statistics, line graphs and correlation matrices were developed with MIPS. Histograms were plotted using SuperCalc 4. Arc Info and Epple 7 were used in the plotting of geochemical maps.

# GEOCHEMICAL INTERPRETATION

The broad objectives of this geochemical discussion are to: 1) identify localities within the study area interpreted to be favorable for the occurrence of platinum, palladium, chrome, cobalt, vanadium and titanium; 2) present the base line data generated by that search; 3) discuss the method of multimedia sampling and how it can be modified for future applications; and 4) discuss how follow-up manipulation of the data can highlight anomalous values within geochemical regions or localities.

## Presentation of Results

An abundance of baseline data for strategic minerals within the Duluth Complex has been assembled. Not all of the data generated could be included within this report; however, examples of the data have been included with the text in this Part I or as additional compiled information in Part II.

A master sample list is contained in Part II which identifies each sample site by number and location and indicates bedrock units, glacial deposit types and geomorphic character according to the following number system.

## BEDROCK UNITS

| | | |
|---|---|---|
| 1 | (Ku) | Keweenawan undivided, extrusive volcanics. |
| 2 | (Df) | Duluth Complex red, granophyre & adamellite. |
| 3 | (Di) | Duluth Complex intermediate intrusives. |
| 4 | (Da) | Duluth Complex anorthositic gabbro, anorthosite. |
| 5 | (Dto) | Duluth Complex cumulate troctolite, layered. |
| 6 | (Dt) | Duluth Complex troctolite, anorthositic troctolite, layered. |
| 7 | (Dg) | Duluth Complex gabbro & Fe-gabbro. |
| 8 | (Du) | Duluth Complex intrusive rocks, undivided. |
| 9 | (Hm) | Middle Proterozoic contact-metamorphic, mafic volcanics. |
| 10 | (Nsu) | North Shore volcanics, undivided. |

## GLACIAL DEPOSITS

| | | |
|---|---|---|
| 1 | (rt) | Rainy, till. |
| 2 | (ra) | Rainy, reworked till. |
| 3 | (ri) | Rainy, ice-contact deposits. |
| 4 | (ro) | Rainy, outwash. |
| 5 | (rtd) | Rainy, drumlinized till. |
| 6 | (st) | Superior, till. |
| 7 | (rst) | Superior & Rainy, till. |
| 8 | (sa) | Superior, reworked till. |
| 9 | (rsa) | Superior & Rainy, reworked till. |
| 10 | (si) | Superior, ice-contact deposits. |
| 11 | (rsi) | Superior & Rainy, ice-contact deposits. |
| 12 | (so) | Superior, outwash. |
| 13 | (uo) | Undivided, outwash. |
| 14 | (ul) | Undivided, lag deposits. |

## GEOMORPHOLOGY

| | | |
|---|---|---|
| 1 | (1A) | Bedrock-dominated, ice-molded. |
| 2 | (1B) | Drumlins, ice-molded. |
| 3 | (1C) | Rogen moraine, ice-molded. |
| 4 | (1D) | Other-basal till, ice-molded. |
| 5 | (2A) | Outwash, super & extra glacial. |
| 6 | (2B) | End moraines, super & extra glacial. |
| 7 | (2C) | Other-till & drift, super & extra glacial. |

This three-way subdivision of sampled sites makes it possible to subdivide the report database into similar, but smaller, populations which can be statistically evaluated in greater detail.

The master list also indicates that just slightly over 50% of the various media at the sampled sites in the study area were analyzed to provide the basis for this report. The remaining materials that were not analyzed have been preserved and stored by the Division of Minerals in Hibbing, Minnesota, and are available for examination and analysis by all interested parties.

Also included in Part II are the multi-element analyses for the 2,160 individual samples from the eight types of sample media collected. From these results, the averages, standard deviations, threshold values and correlation matrices have been calculated for thirteen elements within each of the eight media. All of this information is presented on the following six pages as Tables 1-8 and 9-16, respectively. The geochemical contour maps, Maps 1 through 62 of the text, are the final products derived from this vast accumulation of analytical results. They graphically illustrate the distribution of 18 elements across the project area and individually, or in combinations, identify locations where more detailed geochemical investigations may be worthwhile.

In the course of trying to interpret all of the analytical results obtained, more than 200 histograms were produced in order to sort and view the data according to bedrock, glacial deposit and geomorphic type at each sample site. The designations were pulled from the master list and plotted using the SuperCalc 4 program. Except for representative samples, these histograms have not been made a part of the report; instead, Part II provides a listing of these graphs which may be examined on open file at the Division of Minerals, Hibbing.

Figures 14 and 15 are examples of these histograms that exhibit features worth noting. Elevated values of titanium oxide, iron oxide, cobalt and vanadium are observed over anorthosites of rock unit 4 in Figure 14. These elements are present but somewhat less abundant over rock unit 6, the troctolites. Figure 15 illustrates chrome assays peaking sharply over bedrock units 6, 7 and 8. Palladium peaks in bedrock units 1, 2, part of 4, 6 and 8. The total effect of inspection of all the histograms, sorted by bedrock, glacial and geomorphic types, indicates that the geochemical element concentrations reflect the bedrock lithologies and not the overlying glacial deposits.

Numerical sample distributions according to bedrock, glacial and geomorphic types are displayed by Figure 16.

Figures 17 through 20 display complete assay values encountered across the study area in a west to east sequence, as plotted using the Mineral Interpretation Program (MIP's) supplied by Technical Service Laboratories. These graphs are intended to show the comparative orders of magnitude and variations at which elements occur within the eight media and bedrock types. Element scales have been standardized where possible, to allow for a direct comparison between several sample media. As an example, note that the scales on the heavy mineral concentrate graph of Figure 17 and silt and clay fraction graphs of Figure 18 are identical. This allows for a direct visual comparison of data between the two media. Chrome, cobalt, vanadium and titanium oxide are highly variable and produce strong values within the partial heavy mineral concentrates. Assays of these same elements, from the silt and clay media, are subdued in variability and amplitude. Conversely, nickel and arsenic are more variable and yield higher peaks within the silt and clay media. Also note how lead reacts within these media, with the silt and clay assays showing highly variable lead results. Lead assays from the partial heavy mineral concentrates produce subdued results, except for the presence of two anomalous intervals.

The vegetation assays on Figure 20 are also displayed using identical scales. White spruce and black spruce twig assays give highly variable chrome, nickel and bromine assay results. The balsam fir assays are relatively subdued but display marked anomalies in chrome, zinc, bromine, barium and palladium. Humus assays, as illustrated by Figure 19, can not be compared directly with any of the other vegetation medias. The interpretation of this data set is presently inconclusive, perhaps due to inherent difficulty in collecting consistent

Table 1 Heavy Mineral Concentrates, Basic Statistics and Determination of Threshold Values for Selected Elements.

| Element | Max. | Min. | Detection Level | Average | Standard Deviation | Threshold |
|---|---|---|---|---|---|---|
| Pt | 75 | 0 | 10 | 1.4 | 6.5 | 14.4 |
| Pd | 92 | 0 | 1 | 8.5 | 12.7 | 33.8 |
| Cr | 7141 | 6 | 5 | 753.5 | 698.5 | 2150.4 |
| Co | 292 | 4 | 1 | 123.1 | 38.4 | 199.9 |
| V | 2197 | 8 | 1 | 767.4 | 335.9 | 1439.1 |
| $TiO_2$ | 26.81 | 1.14 | 0.01 | 7.9 | 3.7 | 15.3 |
| Cu | 726 | 0 | 5 | 48.5 | 52.5 | 153.5 |
| Ni | 897 | 0 | 5 | 198.0 | 125.0 | 448.1 |
| Pb | 80 | 0 | 5 | 1.7 | 5.2 | 12.1 |
| Zn | 409 | 0 | 5 | 196.1 | 59.5 | 315.2 |
| As | 5 | 0 | 1 | 1.0 | 1.6 | 4.1 |
| $Fe_2O_3$ | 51.74 | 0 | 0.01 | 26.8 | 8.0 | 42.8 |
| MgO | 23.96 | 0 | 0.01 | 7.2 | 3.0 | 13.3 |

Note: Results in ppm; Pt, Pd in ppb; Oxides in %
Note: Threshold = 2 x Standard Deviation + Average



Table 2 Silt and Clay Fraction, Basic Statistics and Determination of Threshold Values for Selected Elements.

| Element | Max. | Min. | Detection Level | Average | Standard Deviation | Threshold |
|---|---|---|---|---|---|---|
| Pt | 47 | 0 | 10 | 1.1 | 5.2 | 11.5 |
| Pd | 97 | 0 | 1 | 3.1 | 5.9 | 15.0 |
| Cr | 479 | 0 | 5 | 101.6 | 48.1 | 197.3 |
| Co | 190 | 0 | 1 | 47.9 | 16.9 | 81.6 |
| V | 891 | 0 | 1 | 129.7 | 55.1 | 239.9 |
| $TiO_2$ | 1.47 | 0.16 | 0.01 | 0.7 | 0.2 | 1.0 |
| Cu | 2496 | 0 | 5 | 228.1 | 167.2 | 562.5 |
| Ni | 1237 | 0 | 5 | 191.7 | 175.5 | 542.8 |
| Pb | 100 | 0 | 5 | 20.9 | 12.8 | 46.5 |
| Zn | 365 | 0 | 5 | 104.4 | 46.3 | 197.0 |
| As | 100 | 0 | 1 | 4.1 | 5.0 | 14.1 |
| $Fe_2O_3$ | 39.69 | 3.89 | 0.01 | 10.2 | 2.9 | 16.0 |
| MgO | 10.0 | 0.7 | 0.01 | 2.2 | 0.9 | 4.0 |

Note: Results in ppm; Pt, Pd in ppb; Oxides in %
Note: Threshold = 2 x Standard Deviation + Average

Table 3 Humus Samples, Basic Statistics and Determination of Threshold Values for Selected Elements.

| Element | Max. | Min. | Detection Level | Average | Standard Deviation | Threshold |
|---|---|---|---|---|---|---|
| Pt | 20 | 0 | 10 | 0.5 | 2.8 | 6.1 |
| Pd | 16 | 0 | 1 | 1.5 | 2.8 | 7.1 |
| Cr | 400 | 0 | .3 | 51.2 | 51.5 | 154.2 |
| Co | 30 | 1 | .3 | 7.6 | 4.8 | 17.2 |
| Ni | 130 | 0 | 2 | 14.8 | 20.2 | 55.2 |
| Zn | 240 | 0 | 2 | 74.4 | 37.0 | 148.4 |
| As | 6.1 | 0.43 | 0.01 | 2.4 | 1.2 | 4.8 |
| Ir | 0.7 | 0 | 5 | 0.0 | 0.03 | 0.06 |
| Sb | 73 | 0.06 | 0.01 | 0.5 | 3.0 | 6.5 |
| Mo | 2.2 | 0 | 0.05 | 0.07 | 0.28 | .63 |
| Br | 14 | 1.9 | 0.01 | 5.4 | 1.9 | 9.2 |
| Ba | 470 | 53.0 | 20 | 195.3 | 80.8 | 356.9 |

Note: Results in ppm; Pt, Pd, Ir in ppb
Note: Threshold = 2 x Standard Deviation + Average

Table 4 Black Spruce Twigs, Basic Statistics and Determination of Threshold Values for Selected Elements.

| Element | Max. | Min. | Detection Level | Average | Standard Deviation | Threshold |
|---|---|---|---|---|---|---|
| Pt | 10 | 0 | 10 | 0.1 | 1.2 | 2.5 |
| Pd | 21 | 0 | 1 | 1.0 | 2.8 | 6.6 |
| Cr | 28 | 1.7 | .3 | 6.1 | 4.6 | 15.3 |
| Co | 1.5 | 0.1 | .3 | 0.4 | 0.2 | 0.8 |
| Ni | 10 | 0 | 2 | 1.7 | 2.4 | 6.5 |
| Zn | 54 | 20 | 2 | 36.2 | 6.6 | 49.4 |
| As | 0.20 | 0.02 | 0.01 | 0.08 | 0.04 | 0.16 |
| Ir | 0 | 0 | 5 | - | - | - |
| Sb | 0.03 | 0 | 0.01 | 0.01 | 0.01 | 0.13 |
| Mo | 0.45 | 0 | 0.05 | 0.03 | 0.08 | 0.19 |
| Br | 4.4 | 0.74 | 0.01 | 1.77 | 0.63 | 3.03 |
| Ba | 110 | 17 | 20 | 62.0 | 18.4 | 98.8 |

Note: Results in ppm; Pt, Pd, Ir in ppb
Note: Threshold = 2 x Standard Deviation + Average

Table 5 White Spruce Twigs, Basic Statistics and Determination of Threshold Values for Selected Elements.

| Element | Max. | Min. | Detection Level | Average | Standard Deviation | Threshold |
|---|---|---|---|---|---|---|
| Pt | 40 | 0 | 10 | 0.4 | 3.7 | 7.8 |
| Pd | 25 | 0 | 1 | 2.6 | 4.5 | 11.6 |
| Cr | 30 | 1.2 | .3 | 4.8 | 4.6 | 14.0 |
| Co | 1.1 | 0 | .3 | 0.3 | 0.2 | 0.7 |
| Ni | 11 | 0 | 2 | 1.1 | 2.3 | 5.7 |
| Zn | 65 | 26 | 2 | 41.5 | 9.3 | 60.1 |
| As | 2 | .02 | 0.01 | 0.10 | 0.18 | 0.46 |
| Ir | 0 | 0 | 5 | - | - | - |
| Sb | 0.04 | 0 | 0.01 | 0.00 | 0.01 | 0.02 |
| Mo | 0.39 | 0 | 0.05 | 0.03 | 0.06 | 0.15 |
| Br | 3.8 | 0.98 | 0.01 | 2.00 | 0.53 | 3.06 |
| Ba | 120 | 25 | 20 | 66.8 | 19.2 | 105.2 |

Note: Results in ppm; Pt, Pd, Ir in ppb
Note: Threshold = 2 x Standard Deviation + Average

Table 6 Jack Pine Twigs, Basic Statistics and Determination of Threshold Values for Selected Elements.

| Element | Max. | Min. | Detection Level | Average | Standard Deviation | Threshold |
|---|---|---|---|---|---|---|
| Pt | 30 | 0 | 10 | 0.9 | 4.8 | 10.5 |
| Pd | 17 | 0 | 1 | 3.3 | 4.5 | 12.3 |
| Cr | 25 | 0.5 | .3 | 3.2 | 4.3 | 11.8 |
| Co | 0.5 | 0 | .3 | 0.2 | 0.1 | 0.4 |
| Ni | 8 | 0 | 2 | 0.6 | 1.7 | 4.0 |
| Zn | 42 | 13 | 2 | 24.4 | 5.3 | 35.0 |
| As | 2.9 | 0 | 0.01 | 0.09 | 0.32 | 0.73 |
| Ir | .1 | 0 | 5 | 0.0 | 0.01 | 0.02 |
| Sb | 12 | 0 | 0.01 | 0.14 | 1.25 | 2.64 |
| Mo | .21 | 0 | 0.05 | 0.02 | 0.04 | 0.10 |
| Br | 1.9 | 0.6 | 0.01 | 1.1 | 0.23 | 1.56 |
| Ba | 88 | 0 | 20 | 3.4 | 10.4 | 24.2 |

Note: Results in ppm; Pt, Pd, Ir in ppb
Note: Threshold = 2 x Standard Deviation + Average

Table 7 Balsam Fir Twigs, Basic Statistics and Determination of Threshold Values for Selected Elements.

| Element | Max. | Min. | Detection Level | Average | Standard Deviation | Threshold |
|---|---|---|---|---|---|---|
| Pt | 20 | 0 | 10 | 0.2 | 1.7 | 3.6 |
| Pd | 52 | 0 | 1 | 1.1 | 4.2 | 9.5 |
| Cr | 9.4 | 0.7 | .3 | 2.2 | 1.4 | 5.0 |
| Co | 0.5 | 0 | .3 | 0.2 | 0.1 | 0.4 |
| Ni | 4 | 0 | 2 | 0.1 | 0.4 | 0.9 |
| Zn | 110 | 17 | 2 | 30.8 | 9.6 | 50.0 |
| As | .12 | 0 | 0.01 | 0.03 | 0.02 | 0.07 |
| Ir | 0 | 0 | 5 | - | - | - |
| Sb | .07 | 0 | 0.01 | 0.0 | 0.01 | 0.02 |
| Mo | .17 | 0 | 0.05 | 0.01 | 0.03 | 0.07 |
| Br | 2.4 | .5 | 0.01 | 0.8 | 0.2 | 1.2 |
| Ba | 210 | 6 | 20 | 66.3 | 22.7 | 111.7 |

Note: Results in ppm; Pt, Pd, Ir in ppb
Note: Threshold = 2 x Standard Deviation + Average

Table 8 Alder Twigs, Basic Statistics and Determination of Threshold Values fo Selected Elements.

| Element | Max. | Min. | Detection Level | Average | Standard Deviation | Threshold |
|---|---|---|---|---|---|---|
| Pt | 20 | 0 | 10 | 0.4 | 2.3 | 5.0 |
| Pd | 16 | 0 | 1 | 1.1 | 3.1 | 7.3 |
| Cr | 1.6 | 0 | .3 | 0.2 | 0.3 | 0.8 |
| Co | .7 | 0 | .3 | 0.1 | 0.1 | 0.3 |
| Ni | 4 | 0 | 2 | 0.0 | 0.4 | 0.8 |
| Zn | 220 | 0 | 2 | 14.4 | 19.8 | 54.0 |
| As | 1.9 | 0 | 0.01 | 0.0 | 0.18 | 0.36 |
| Ir | 0 | 0 | 5 | - | - | - |
| Sb | 2.5 | 0 | 0.01 | 0.0 | 0.27 | 0.54 |
| Mo | 1 | 0 | 0.05 | 0.04 | 0.1 | 0.06 |
| Br | 1.8 | .28 | 0.01 | 1.05 | 0.36 | 1.77 |
| Ba | 69 | 0 | 20 | 8.4 | 8.53 | 25.46 |

Note: Results in ppm; Pt, Pd, Ir in ppb
Note: Threshold = 2 x Standard Deviation + Average

*Table 9*

## CORRELATION MATRIX PARTIAL HEAVY MINERAL CONCENTRATES

| | Pt | Pd | Cr | Co | V | $TiO_2$ | Cu | Ni | Pb | Zn | As | $Fe_2O_3$ | MgO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pt | 1.00 | 0.04 | 0.14 | -0.06 | -0.02 | -0.05 | -0.02 | -0.02 | 0.03 | -0.03 | 0.10 | -0.04 | -0.02 |
| Pd | 0.04 | 1.00 | 0.10 | -0.05 | -0.04 | -0.12 | 0.00 | -0.10 | 0.00 | -0.11 | 0.12 | -0.08 | -0.10 |
| Cr | 0.14 | 0.10 | 1.00 | 0.47 | 0.15 | 0.15 | -0.14 | 0.76 | 0.07 | 0.23 | -0.06 | 0.22 | 0.64 |
| Co | -0.06 | -0.05 | 0.47 | 1.00 | 0.77 | 0.82 | -0.10 | 0.41 | -0.10 | 0.80 | -0.40 | 0.89 | 0.43 |
| V | -0.02 | -0.04 | 0.15 | 0.77 | 1.00 | 0.92 | -0.10 | -0.10 | -0.07 | 0.89 | -0.26 | 0.94 | -0.12 |
| $TiO_2$ | -0.05 | -0.12 | 0.15 | 0.82 | 0.92 | 1.00 | -0.10 | -0.10 | -0.09 | 0.85 | -0.33 | 0.92 | -0.09 |
| Cu | -0.02 | 0.00 | -0.14 | -0.10 | -0.10 | -0.10 | 1.00 | -0.10 | 0.00 | -0.05 | 0.05 | -0.08 | -0.07 |
| Ni | -0.02 | -0.10 | 0.76 | 0.41 | -0.10 | -0.10 | -0.10 | 1.00 | 0.08 | 0.03 | -0.12 | 0.07 | 0.92 |
| Pb | 0.03 | 0.00 | 0.07 | -0.10 | -0.07 | -0.09 | 0.00 | 0.08 | 1.00 | -0.04 | 0.12 | -0.11 | -0.01 |
| Zn | -0.03 | -0.11 | 0.23 | 0.80 | 0.89 | 0.85 | -0.05 | 0.03 | -0.04 | 1.00 | -0.27 | 0.92 | 0.04 |
| As | 0.10 | 0.12 | -0.06 | -0.40 | -0.26 | -0.33 | 0.05 | -0.12 | 0.12 | -0.27 | 1.00 | -0.33 | -0.16 |
| $Fe_2O_3$ | -0.04 | -0.08 | 0.22 | 0.89 | 0.94 | 0.92 | -0.08 | 0.07 | -0.11 | 0.92 | -0.33 | 1.00 | 0.12 |
| MgO | -0.02 | -0.10 | 0.64 | 0.43 | -0.12 | -0.09 | -0.07 | 0.92 | -0.01 | 0.04 | -0.16 | 0.12 | 1.00 |

*Table 10*

## CORRELATION MATRIX SILT AND CLAY FRACTION

| | Pt | Pd | Cr | Co | V | $TiO_2$ | Cu | Ni | Pb | Zn | As | $Fe_2O_3$ | MgO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pt | 1.00 | -0.05 | -0.02 | 0.03 | -0.05 | -0.01 | -0.01 | 0.03 | -0.08 | 0.05 | -0.06 | -0.02 | 0.05 |
| Pd | -0.05 | 1.00 | -0.03 | 0.05 | -0.05 | -0.13 | 0.10 | 0.05 | -0.03 | -0.07 | 0.02 | -0.05 | 0.01 |
| Cr | -0.02 | -0.03 | 1.00 | 0.27 | 0.39 | 0.33 | 0.03 | 0.08 | -0.03 | 0.38 | -0.01 | 0.38 | 0.36 |
| Co | 0.03 | 0.05 | 0.27 | 1.00 | 0.01 | -0.21 | 0.15 | 0.70 | -0.09 | 0.30 | -0.05 | 0.35 | 0.57 |
| V | -0.05 | -0.05 | 0.39 | 0.01 | 1.00 | 0.60 | -0.01 | -0.26 | 0.21 | 0.35 | 0.12 | 0.56 | -0.15 |
| $TiO_2$ | -0.01 | -0.13 | 0.33 | -0.21 | 0.60 | 1.00 | -0.01 | -0.47 | 0.15 | 0.37 | 0.08 | 0.26 | -0.11 |
| Cu | -0.01 | 0.10 | 0.03 | 0.15 | -0.01 | -0.01 | 1.00 | -0.03 | 0.08 | 0.08 | 0.14 | 0.10 | 0.09 |
| Ni | 0.03 | 0.05 | 0.08 | 0.70 | -0.26 | -0.47 | -0.03 | 1.00 | -0.34 | 0.16 | -0.17 | 0.13 | 0.63 |
| Pb | -0.08 | -0.03 | -0.03 | -0.09 | 0.21 | 0.15 | 0.08 | -0.34 | 1.00 | -0.09 | 0.24 | 0.06 | -0.22 |
| Zn | 0.05 | -0.07 | 0.38 | 0.30 | 0.35 | 0.37 | 0.08 | 0.16 | -0.09 | 1.00 | 0.01 | 0.48 | 0.32 |
| As | -0.06 | 0.02 | -0.01 | -0.05 | 0.12 | 0.08 | 0.14 | -0.17 | 0.24 | 0.01 | 1.00 | 0.08 | -0.06 |
| $Fe_2O_3$ | -0.02 | -0.05 | 0.38 | 0.35 | 0.56 | 0.26 | 0.10 | 0.13 | 0.06 | 0.48 | 0.08 | 1.00 | 0.24 |
| MgO | 0.05 | 0.01 | 0.36 | 0.57 | -0.15 | -0.11 | 0.09 | 0.63 | -0.22 | 0.32 | -0.06 | 0.24 | 1.00 |

*Table 11*

## CORRELATION MATRIX HUMUS SAMPLES

| | Pt | Pd | Au | Cr | Co | Ni | Zn | Mo | As | Br | Ba | Ir | Sb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pt | 1.00 | 0.35 | 0.09 | 0.16 | 0.17 | 0.18 | -0.05 | -0.03 | -0.05 | -0.11 | -0.05 | -0.01 | 0.20 |
| Pd | 0.35 | 1.00 | 0.04 | -0.04 | -0.07 | -0.08 | 0.09 | 0.03 | -0.04 | 0.04 | -0.03 | -0.02 | 0.03 |
| Au | 0.09 | 0.04 | 1.00 | 0.01 | 0.12 | 0.04 | 0.07 | 0.02 | 0.11 | 0.06 | 0.10 | -0.03 | 0.25 |
| Cr | 0.16 | -0.04 | 0.01 | 1.00 | 0.71 | 0.83 | -0.19 | 0.40 | 0.01 | -0.20 | 0.27 | -0.03 | -0.08 |
| Co | 0.17 | -0.07 | 0.12 | 0.71 | 1.00 | 0.67 | -0.17 | 0.13 | 0.27 | -0.10 | 0.43 | -0.04 | -0.04 |
| Ni | 0.18 | -0.08 | 0.04 | 0.83 | 0.67 | 1.00 | -0.19 | 0.30 | -0.09 | -0.17 | 0.07 | -0.02 | -0.12 |
| Zn | -0.05 | 0.09 | 0.07 | -0.19 | -0.17 | -0.19 | 1.00 | -0.01 | 0.12 | 0.17 | 0.37 | -0.05 | 0.24 |
| Mo | -0.03 | 0.03 | 0.02 | 0.40 | 0.13 | 0.30 | -0.01 | 1.00 | 0.10 | 0.02 | 0.20 | -0.01 | 0.09 |
| As | -0.05 | -0.04 | 0.11 | 0.01 | 0.27 | -0.09 | 0.12 | 0.10 | 1.00 | 0.54 | 0.54 | 0.01 | 0.38 |
| Br | -0.11 | 0.04 | 0.06 | -0.20 | -0.10 | -0.17 | 0.17 | 0.02 | 0.54 | 1.00 | 0.12 | 0.02 | 0.23 |
| Ba | -0.05 | -0.03 | 0.10 | 0.27 | 0.43 | 0.07 | 0.37 | 0.20 | 0.54 | 0.12 | 1.00 | 0.04 | 0.25 |
| Ir | -0.01 | -0.02 | -0.03 | -0.03 | -0.04 | -0.02 | -0.05 | -0.01 | 0.01 | 0.02 | -0.04 | 1.00 | -0.01 |
| Sb | 0.20 | 0.03 | 0.25 | -0.08 | -0.04 | -0.12 | 0.24 | 0.09 | 0.38 | 0.23 | 0.25 | -0.01 | 1.00 |

*Table 12*

## CORRELATION MATRIX ALDER TWIGS

| | Pt | Pd | Au | Cr | Co | Ni | Zn | Mo | As | Br | Ba | Ir | Sb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pt | 1.00 | 0.21 | -0.03 | 0.00 | -0.07 | -0.01 | -0.01 | -0.03 | -0.02 | 0.08 | 0.12 | 0.00 | -0.02 |
| Pd | 0.21 | 1.00 | 0.00 | 0.05 | 0.01 | -0.03 | -0.03 | -0.01 | -0.04 | -0.01 | -0.05 | 0.00 | -0.04 |
| Au | -0.03 | 0.00 | 1.00 | 0.26 | 0.17 | -0.04 | 0.17 | -0.03 | 0.05 | -0.04 | 0.09 | 0.00 | -0.05 |
| Cr | 0.00 | 0.05 | 0.26 | 1.00 | 0.51 | -0.06 | 0.33 | 0.05 | 0.28 | 0.35 | 0.06 | 0.00 | 0.08 |
| Co | -0.07 | 0.01 | 0.17 | 0.51 | 1.00 | 0.07 | 0.18 | -0.05 | 0.50 | 0.45 | 0.07 | 0.00 | 0.03 |
| Ni | -0.01 | -0.03 | -0.04 | -0.06 | 0.07 | 1.00 | -0.01 | 0.14 | 0.20 | 0.16 | 0.08 | 0.00 | 0.58 |
| Zn | -0.01 | -0.03 | 0.17 | 0.33 | 0.18 | -0.01 | 1.00 | 0.02 | 0.11 | 0.26 | 0.67 | 0.00 | -0.01 |
| Mo | -0.03 | -0.01 | -0.03 | 0.05 | -0.05 | 0.14 | 0.02 | 1.00 | 0.13 | 0.14 | -0.04 | 0.00 | 0.42 |
| As | -0.02 | -0.04 | 0.05 | 0.28 | 0.50 | 0.20 | 0.11 | 0.13 | 1.00 | 0.04 | 0.01 | 0.00 | 0.37 |
| Br | 0.08 | -0.01 | -0.04 | 0.35 | 0.45 | 0.16 | 0.26 | 0.14 | 0.04 | 1.00 | 0.40 | 0.00 | 0.12 |
| Ba | 0.12 | -0.05 | 0.09 | 0.06 | 0.07 | 0.08 | 0.67 | -0.04 | 0.01 | 0.40 | 1.00 | 0.00 | 0.05 |
| Ir | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sb | -0.02 | -0.04 | -0.05 | 0.08 | 0.03 | 0.58 | -0.01 | 0.42 | 0.37 | 0.12 | 0.05 | 0.00 | 1.00 |

*Table 13*

## CORRELATION MATRIX BLACK SPRUCE TWIGS

| | PT | PD | AU | CR | CO | NI | ZN | MO | AS | BR | BA | IR | SB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PT | 1.00 | 0.00 | -0.03 | 0.10 | 0.04 | 0.06 | -0.04 | -0.05 | -0.05 | -0.10 | -0.15 | 0.00 | -0.11 |
| PD | 0.00 | 1.00 | 0.07 | 0.35 | 0.34 | 0.18 | 0.26 | 0.39 | -0.10 | 0.09 | 0.10 | 0.00 | -0.05 |
| AU | -0.03 | 0.07 | 1.00 | 0.01 | 0.02 | -0.13 | -0.09 | 0.08 | 0.02 | -0.04 | -0.04 | 0.00 | 0.10 |
| CR | 0.10 | 0.35 | 0.01 | 1.00 | 0.82 | 0.75 | 0.08 | 0.48 | 0.10 | -0.15 | 0.07 | 0.00 | 0.24 |
| CO | 0.04 | 0.34 | 0.02 | 0.82 | 1.00 | 0.63 | 0.02 | 0.46 | 0.18 | 0.04 | 0.05 | 0.00 | 0.29 |
| NI | 0.06 | 0.18 | -0.13 | 0.75 | 0.63 | 1.00 | 0.06 | 0.29 | 0.15 | -0.21 | 0.04 | 0.00 | 0.08 |
| ZN | -0.04 | 0.26 | -0.09 | 0.08 | 0.02 | 0.06 | 1.00 | 0.01 | 0.07 | 0.07 | 0.19 | 0.00 | 0.07 |
| MO | -0.05 | 0.39 | 0.08 | 0.48 | 0.46 | 0.29 | 0.01 | 1.00 | -0.11 | -0.01 | 0.07 | 0.00 | 0.20 |
| AS | -0.05 | -0.10 | 0.02 | 0.10 | 0.18 | 0.15 | 0.07 | -0.11 | 1.00 | 0.03 | 0.11 | 0.00 | 0.05 |
| BR | -0.10 | 0.09 | -0.04 | -0.15 | 0.04 | -0.21 | 0.07 | -0.01 | 0.03 | 1.00 | 0.30 | 0.00 | 0.03 |
| BA | -0.15 | 0.10 | -0.04 | 0.07 | 0.05 | 0.04 | 0.19 | 0.07 | 0.11 | 0.30 | 1.00 | 0.00 | 0.07 |
| IR | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SB | -0.11 | -0.05 | 0.10 | 0.24 | 0.29 | 0.08 | 0.07 | 0.20 | 0.05 | 0.03 | 0.07 | 0.00 | 1.00 |

*Table 14*

## CORRELATION MATRIX WHITE SPRUCE TWIGS

| | PT | PD | AU | CR | CO | NI | ZN | MO | AS | BR | BA | IR | SB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PT | 1.00 | 0.33 | 0.18 | 0.28 | 0.28 | 0.26 | 0.08 | 0.27 | 0.04 | 0.11 | -0.12 | 0.00 | -0.14 |
| PD | 0.33 | 1.00 | 0.09 | 0.12 | 0.17 | 0.17 | 0.14 | 0.06 | 0.13 | -0.03 | -0.09 | 0.00 | -0.00 |
| AU | 0.18 | 0.09 | 1.00 | 0.18 | 0.15 | 0.13 | -0.03 | 0.13 | 0.06 | 0.10 | 0.05 | 0.00 | 0.13 |
| CR | 0.28 | 0.12 | 0.18 | 1.00 | 0.84 | 0.66 | 0.11 | 0.61 | 0.13 | 0.15 | 0.05 | 0.00 | 0.13 |
| CO | 0.28 | 0.17 | 0.15 | 0.84 | 1.00 | 0.63 | 0.16 | 0.44 | 0.39 | 0.31 | 0.07 | 0.00 | 0.22 |
| NI | 0.26 | 0.17 | 0.13 | 0.66 | 0.63 | 1.00 | 0.19 | 0.52 | 0.36 | 0.17 | 0.04 | 0.00 | 0.30 |
| ZN | 0.08 | 0.14 | -0.03 | 0.11 | 0.16 | 0.19 | 1.00 | 0.09 | 0.14 | 0.07 | 0.41 | 0.00 | -0.11 |
| MO | 0.27 | 0.06 | 0.13 | 0.61 | 0.44 | 0.52 | 0.09 | 1.00 | -0.01 | 0.10 | 0.07 | 0.00 | 0.05 |
| AS | 0.04 | 0.13 | 0.06 | 0.13 | 0.39 | 0.36 | 0.14 | -0.01 | 1.00 | -0.00 | -0.04 | 0.00 | 0.50 |
| BR | 0.11 | -0.03 | 0.10 | 0.15 | 0.31 | 0.17 | 0.07 | 0.10 | -0.00 | 1.00 | 0.12 | 0.00 | 0.15 |
| BA | -0.12 | -0.09 | 0.05 | 0.05 | 0.07 | 0.04 | 0.41 | 0.07 | -0.04 | 0.12 | 1.00 | 0.00 | -0.02 |
| IR | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SB | -0.14 | -0.00 | 0.13 | 0.13 | 0.22 | 0.30 | -0.11 | 0.05 | 0.50 | 0.15 | -0.02 | 0.00 | 1.00 |

*Table 15*

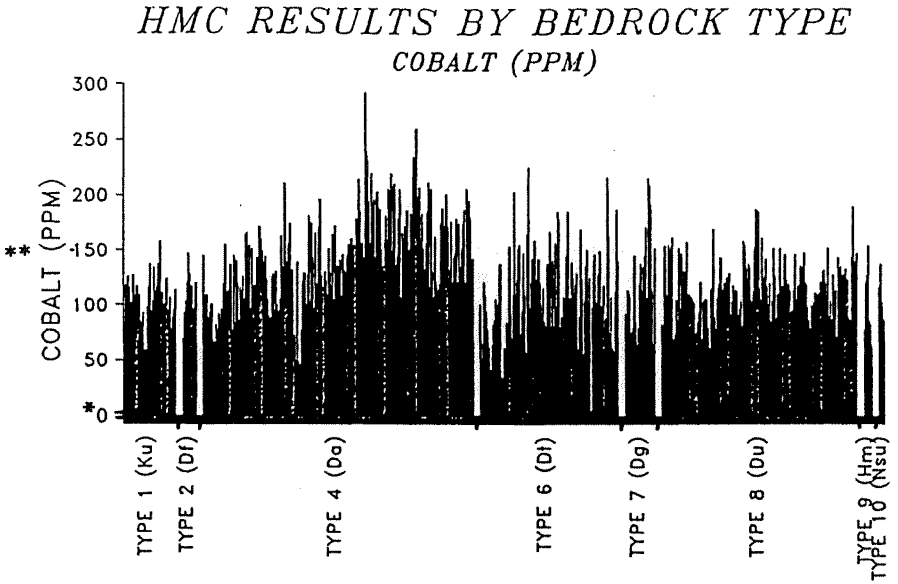
## CORRELATION MATRIX JACK PINE TWIGS

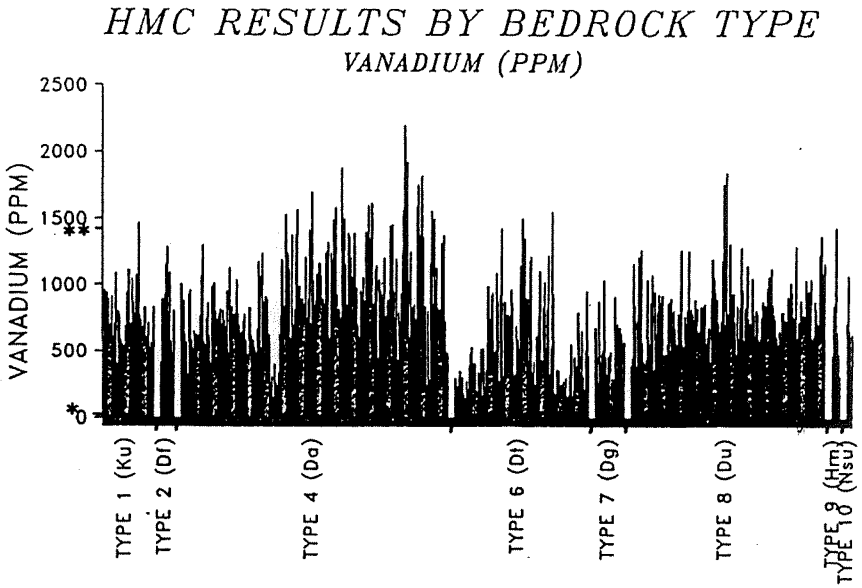
| | PT | PD | AU | CR | CO | NI | ZN | MO | AS | BR | BA | IR | SB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PT | 1.00 | 0.17 | -0.06 | 0.20 | 0.09 | 0.21 | 0.06 | -0.07 | -0.02 | -0.06 | 0.03 | -0.02 | -0.01 |
| PD | 0.17 | 1.00 | -0.08 | 0.04 | 0.02 | 0.02 | -0.02 | -0.09 | -0.10 | -0.01 | -0.13 | 0.06 | -0.07 |
| AU | -0.06 | -0.08 | 1.00 | 0.28 | 0.21 | 0.33 | -0.14 | 0.15 | 0.13 | -0.06 | -0.04 | 0.10 | 0.10 |
| CR | 0.20 | 0.04 | 0.28 | 1.00 | 0.65 | 0.89 | -0.11 | 0.63 | 0.00 | 0.06 | 0.03 | -0.04 | -0.02 |
| CO | 0.09 | 0.02 | 0.21 | 0.65 | 1.00 | 0.56 | 0.11 | 0.40 | 0.13 | 0.21 | 0.10 | -0.05 | -0.05 |
| NI | 0.21 | 0.02 | 0.33 | 0.89 | 0.56 | 1.00 | -0.09 | 0.60 | -0.02 | 0.02 | 0.04 | -0.04 | -0.04 |
| ZN | 0.06 | -0.02 | -0.14 | -0.11 | 0.11 | -0.09 | 1.00 | 0.04 | 0.04 | -0.04 | 0.27 | 0.03 | -0.11 |
| MO | -0.07 | -0.09 | 0.15 | 0.63 | 0.40 | 0.60 | 0.04 | 1.00 | -0.03 | -0.05 | -0.03 | -0.04 | -0.04 |
| AS | -0.02 | -0.10 | 0.13 | 0.00 | 0.13 | -0.02 | 0.04 | -0.03 | 1.00 | -0.02 | -0.02 | -0.01 | 0.91 |
| BR | -0.06 | -0.01 | -0.06 | 0.06 | 0.21 | 0.02 | -0.04 | -0.05 | -0.02 | 1.00 | 0.39 | -0.10 | 0.01 |
| BA | 0.03 | -0.13 | -0.04 | 0.03 | 0.10 | 0.04 | 0.27 | -0.03 | -0.02 | 0.39 | 1.00 | -0.03 | -0.03 |
| IR | -0.02 | 0.06 | 0.10 | -0.04 | -0.05 | -0.04 | 0.03 | -0.04 | -0.01 | -0.10 | -0.03 | 1.00 | -0.01 |
| SB | -0.01 | -0.07 | 0.10 | -0.02 | -0.05 | -0.04 | -0.11 | -0.04 | 0.91 | 0.01 | -0.03 | -0.01 | 1.00 |

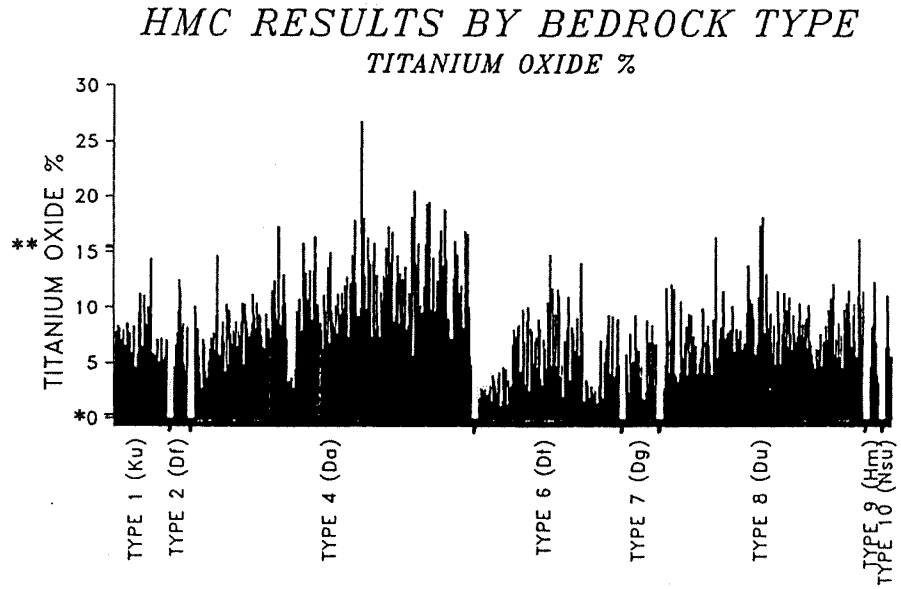
*Table 16*

## CORRELATION MATRIX BALSAM FIR TWIGS

| | PT | PD | AU | CR | CO | NI | ZN | MO | AS | BR | BA | IR | SB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PT | 1.00 | -0.01 | -0.05 | 0.02 | -0.04 | -0.02 | -0.05 | 0.02 | -0.03 | -0.02 | 0.04 | 0.00 | -0.04 |
| PD | -0.01 | 1.00 | -0.10 | -0.04 | 0.12 | 0.24 | 0.05 | -0.08 | 0.01 | 0.05 | 0.02 | 0.00 | 0.07 |
| AU | -0.05 | -0.10 | 1.00 | 0.01 | 0.04 | -0.11 | -0.03 | 0.11 | 0.01 | 0.01 | 0.03 | 0.00 | 0.05 |
| CR | 0.02 | -0.04 | 0.01 | 1.00 | 0.65 | 0.20 | 0.32 | 0.05 | 0.40 | 0.41 | 0.26 | 0.00 | 0.23 |
| CO | -0.04 | 0.12 | 0.04 | 0.65 | 1.00 | 0.19 | 0.32 | -0.03 | 0.45 | 0.46 | 0.20 | 0.00 | 0.22 |
| NI | -0.02 | 0.24 | -0.11 | 0.20 | 0.19 | 1.00 | 0.02 | -0.05 | 0.17 | 0.05 | 0.07 | 0.00 | -0.06 |
| ZN | -0.05 | 0.05 | -0.03 | 0.32 | 0.32 | 0.02 | 1.00 | -0.08 | 0.28 | 0.53 | 0.67 | 0.00 | 0.29 |
| MO | 0.02 | -0.08 | 0.11 | 0.05 | -0.03 | -0.05 | -0.08 | 1.00 | 0.06 | 0.02 | 0.01 | 0.00 | -0.00 |
| AS | -0.03 | 0.01 | 0.01 | 0.40 | 0.45 | 0.17 | 0.28 | 0.06 | 1.00 | 0.45 | 0.22 | 0.00 | 0.25 |
| BR | -0.02 | 0.05 | 0.01 | 0.41 | 0.46 | 0.05 | 0.53 | 0.02 | 0.45 | 1.00 | 0.47 | 0.00 | 0.26 |
| BA | 0.04 | 0.02 | 0.03 | 0.26 | 0.20 | 0.07 | 0.67 | 0.01 | 0.22 | 0.47 | 1.00 | 0.00 | 0.25 |
| IR | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SB | -0.04 | 0.07 | 0.05 | 0.23 | 0.22 | -0.06 | 0.29 | -0.00 | 0.25 | 0.26 | 0.25 | 0.00 | 1.00 |


HMC RESULTS BY BEDROCK TYPE
COBALT (PPM)
COBALT (PPM)
300
250
200
150
100
50
0
**
*
TYPE 1 (Ku)
TYPE 2 (Df)
TYPE 4 (Da)
TYPE 6 (Dt)
TYPE 7 (Dg)
TYPE 8 (Du)
TYPE 9 (Hm)
TYPE 10 (Nsu)


HMC RESULTS BY BEDROCK TYPE
VANADIUM (PPM)
VANADIUM (PPM)
2500
2000
1500
1000
500
0
**
*
TYPE 1 (Ku)
TYPE 2 (Df)
TYPE 4 (Da)
TYPE 6 (Dt)
TYPE 7 (Dg)
TYPE 8 (Du)
TYPE 9 (Hm)
TYPE 10 (Nsu)


HMC RESULTS BY BEDROCK TYPE
TITANIUM OXIDE %
TITANIUM OXIDE %
30
25
20
15
10
5
0
**
*
TYPE 1 (Ku)
TYPE 2 (Df)
TYPE 4 (Da)
TYPE 6 (Dt)
TYPE 7 (Dg)
TYPE 8 (Du)
TYPE 9 (Hm)
TYPE 10 (Nsu)

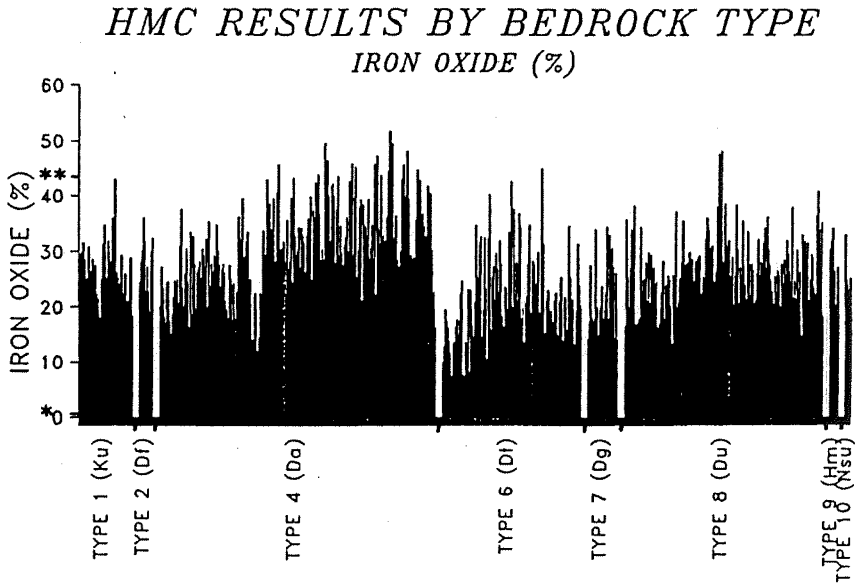
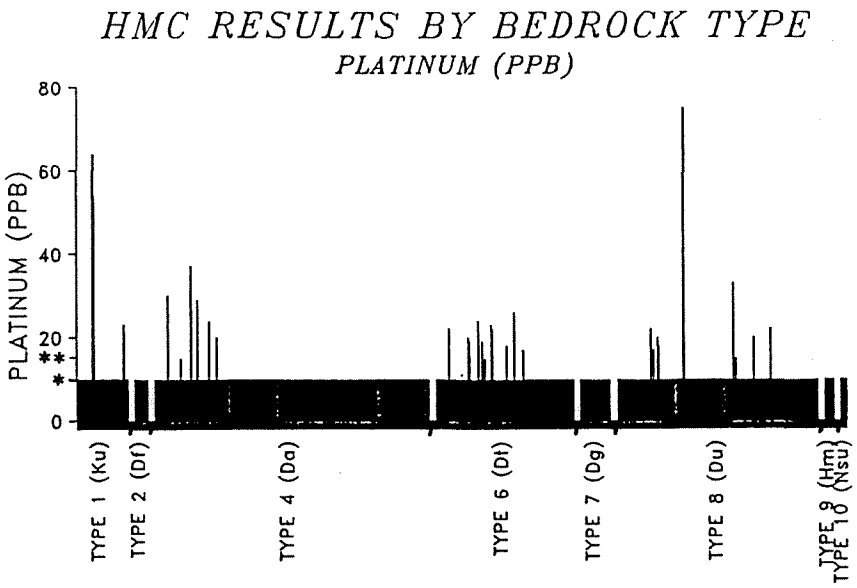
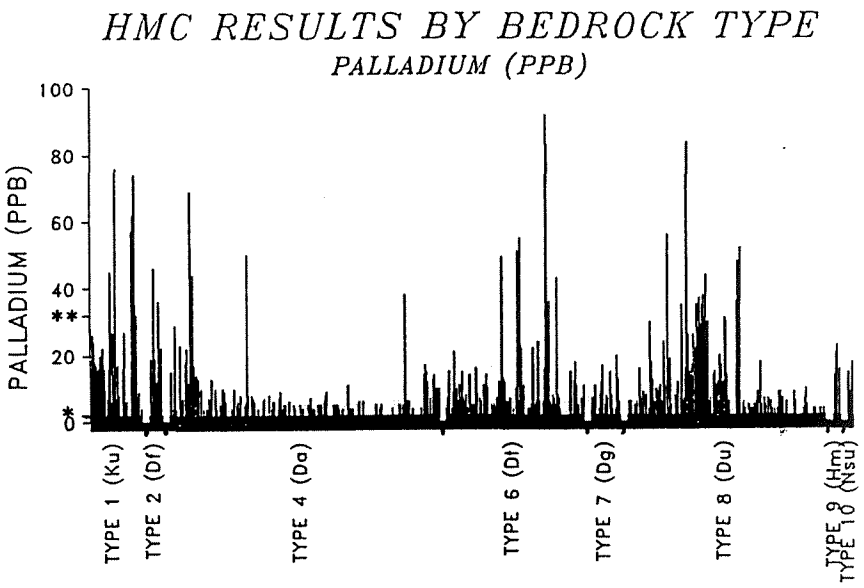

HMC RESULTS BY BEDROCK TYPE
IRON OXIDE (%)
IRON OXIDE (%)
60
50
40
30
20
10
0
**
*
TYPE 1 (Ku)
TYPE 2 (Df)
TYPE 4 (Da)
TYPE 6 (Dt)
TYPE 7 (Dg)
TYPE 8 (Du)
TYPE 9 (Hm)
TYPE 10 (Nsu)

*figure 14*



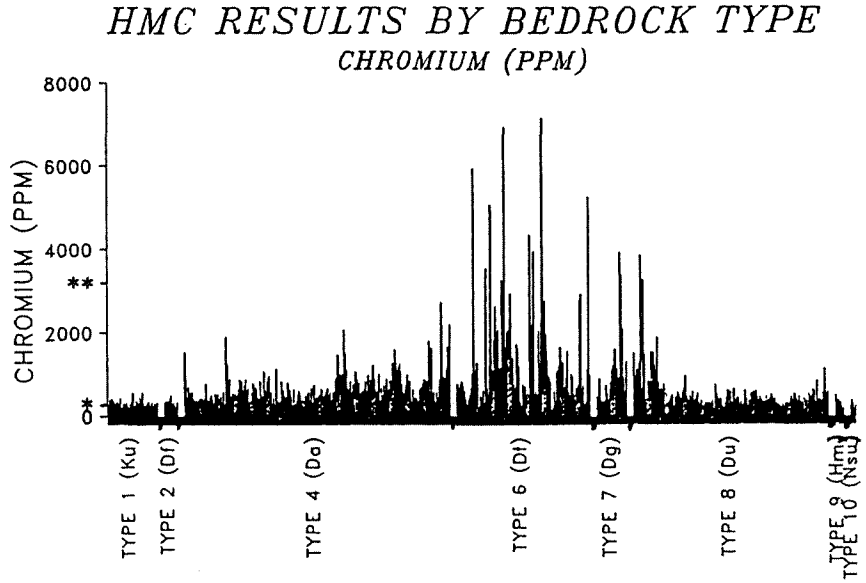
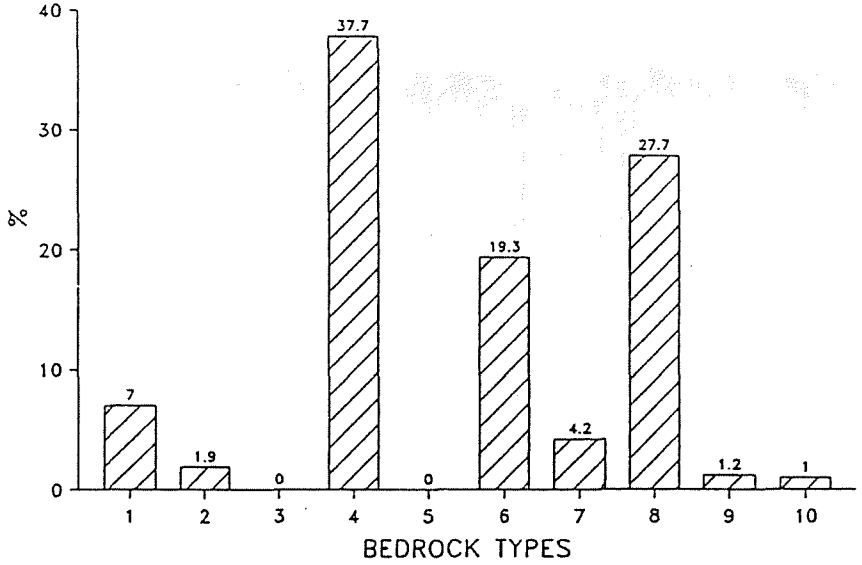




figure 15

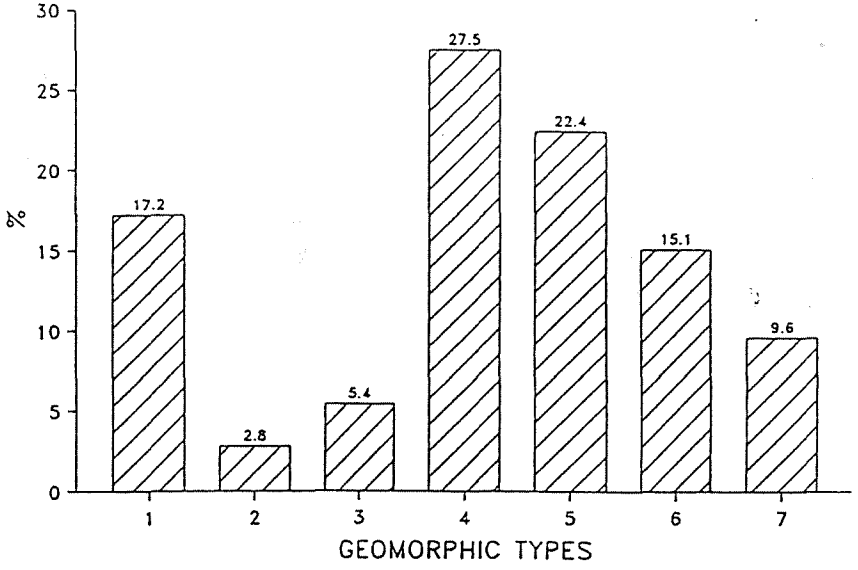
## BEDROCK UNITS

| | | |
|---|---|---|
| 1 | (Ku) | Keweenawan undivided, extrusive volcanics. |
| 2 | (Df) | Duluth Complex red, granophyre & adamellite. |
| 3 | (Di) | Duluth Complex intermediate intrusives. |
| 4 | (Da) | Duluth Complex anorthositic gabbro, anorthosite. |
| 5 | (Dto) | Duluth Complex cumulate troctolite, layered. |
| 6 | (Dt) | Duluth Complex troctolite, anorthositic troctolite, layered. |
| 7 | (Dg) | Duluth Complex gabbro & Fe-gabbro. |
| 8 | (Du) | Duluth Complex intrusive rocks, undivided. |
| 9 | (Hm) | Middle Proterozoic contact-metamorphic, mafic volcanics. |
| 10 | (Nsu) | North Shore volcanics, undivided. |
| | * | Detection Limit |
| | ** | Threshold |

## SAMPLE DISTRIBUTIONS
### BY BEDROCK TYPE




## SAMPLE DISTRIBUTIONS
### BY GEOMORPHIC TYPE




## SAMPLE DISTRIBUTIONS
### BY GLACIAL TYPE

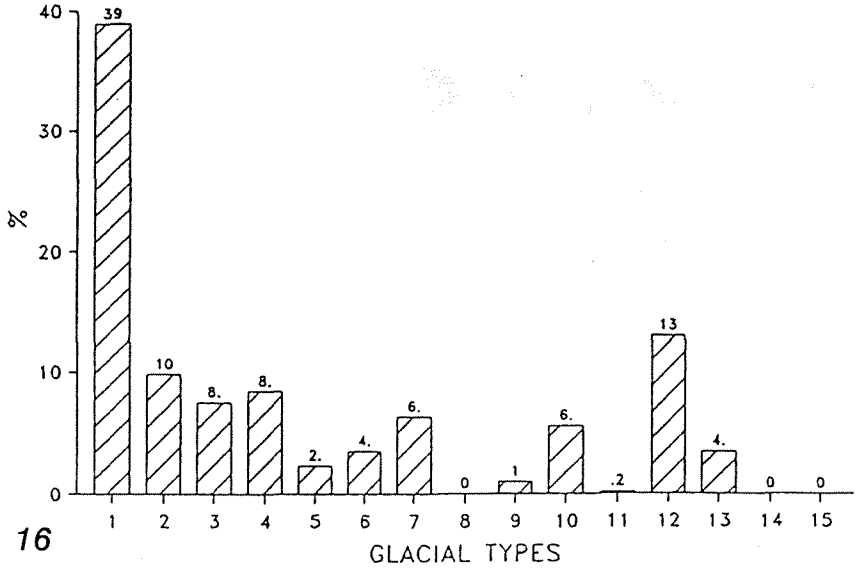



figure 16

**BEDROCK UNITS**

| | | |
|---|---|---|
| 1 | (Ku) | Keweenawan undivided, extrusive volcanics. |
| 2 | (Df) | Duluth Complex red, granophyre & adamellite. |
| 3 | (Di) | Duluth Complex intermediate intrusives. |
| 4 | (Da) | Duluth Complex anorthositic gabbro, anorthosite. |
| 5 | (Dto) | Duluth Complex cumulate troctolite, layered. |
| 6 | (Dt) | Duluth Complex troctolite, anorthositic troctolite, layered. |
| 7 | (Dg) | Duluth Complex gabbro & Fe-gabbro. |
| 8 | (Du) | Duluth Complex intrusive rocks, undivided. |
| 9 | (Hm) | Middle Proterozoic contact-metamorphic, mafic volcanics. |
| 10 | (Nsu) | North Shore volcanics, undivided. |

**GLACIAL DEPOSITS**

| | | |
|---|---|---|
| 1 | (rt) | Rainy, till. |
| 2 | (ra) | Rainy, reworked till. |
| 3 | (ri) | Rainy, ice-contact deposits. |
| 4 | (ro) | Rainy, outwash. |
| 5 | (rtd) | Rainy, drumlinized till. |
| 6 | (st) | Superior, till. |
| 7 | (rst) | Superior & Rainy, till. |
| 8 | (sa) | Superior, reworked till. |
| 9 | (rsa) | Superior & Rainy, reworked till. |
| 10 | (si) | Superior, ice-contact deposits. |
| 11 | (rsi) | Superior & Rainy, ice-contact deposits. |
| 12 | (so) | Superior, outwash. |
| 13 | (uo) | Undivided, outwash. |
| 14 | (ul) | Undivided, lag deposits. |

**GEOMORPH**

| | | |
|---|---|---|
| 1 | (1A) | Bedrock-dominated, ice-molded. |
| 2 | (1B) | Drumlins, ice-molded. |
| 3 | (1C) | Rogen moraine, ice-molded. |
| 4 | (1D) | Other-basal till, ice-molded. |
| 5 | (2A) | Outwash, super & extra glacial. |
| 6 | (2B) | End moraines, super & extra glacial. |
| 7 | (2C) | Other-till & drift, super & extra glacial. |

# HEAVY MINERAL CONCENTRATES

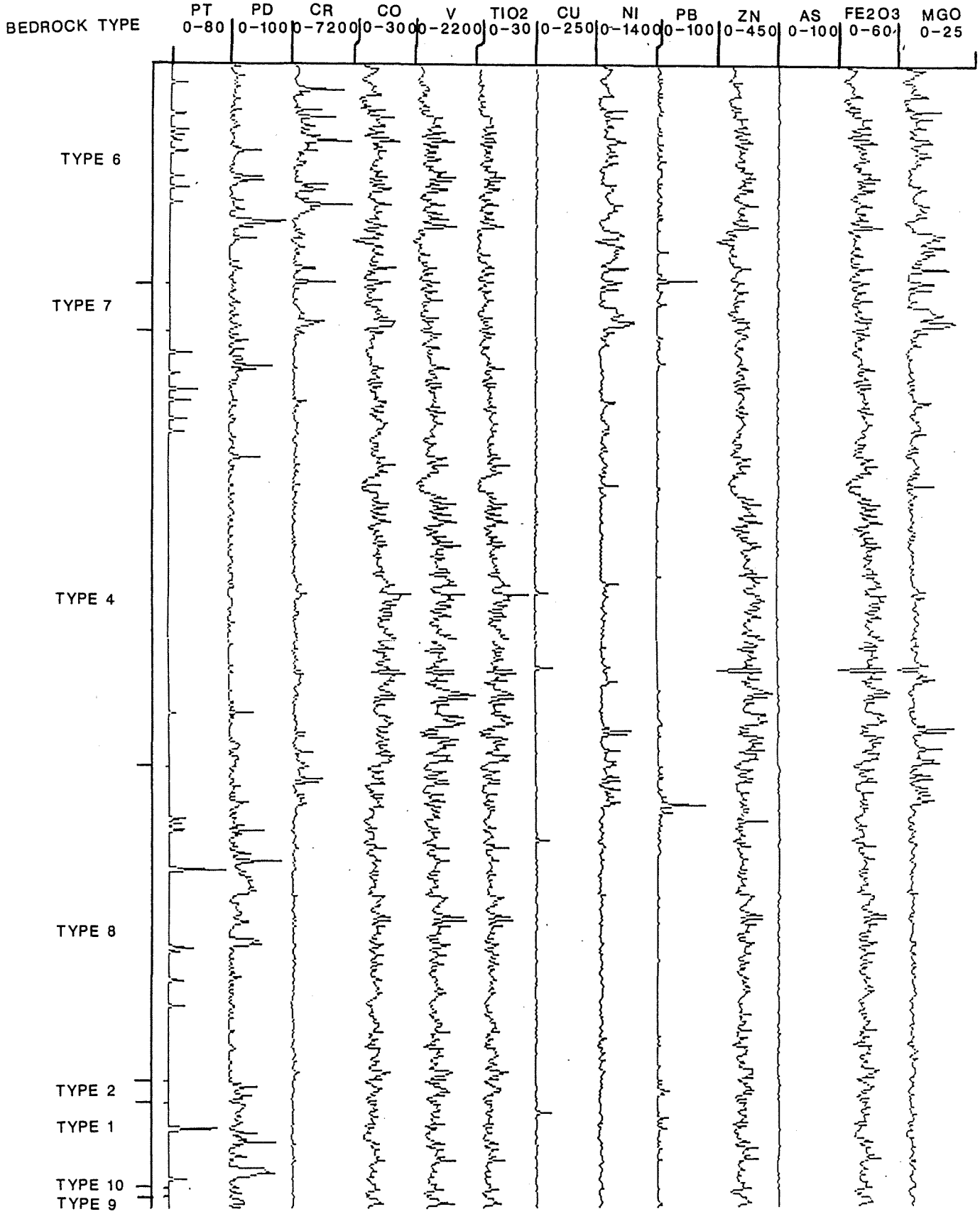



*figure 17*

## SILT AND CLAY FRACTIONS

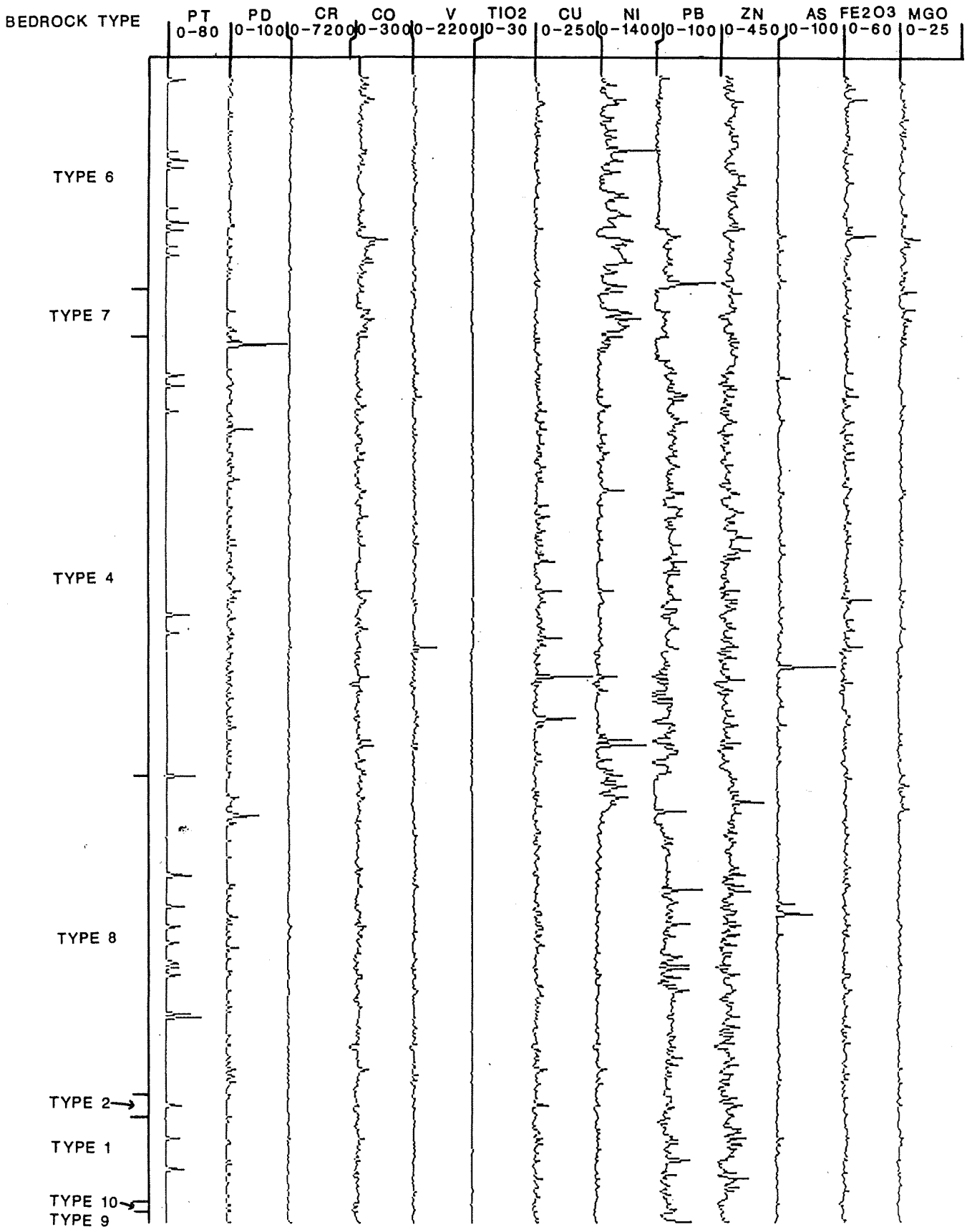



*figure 18*

RESULTS IN PPM, PT,PD IN PPB, OXIDES IN %

## HUMUS SAMPLES

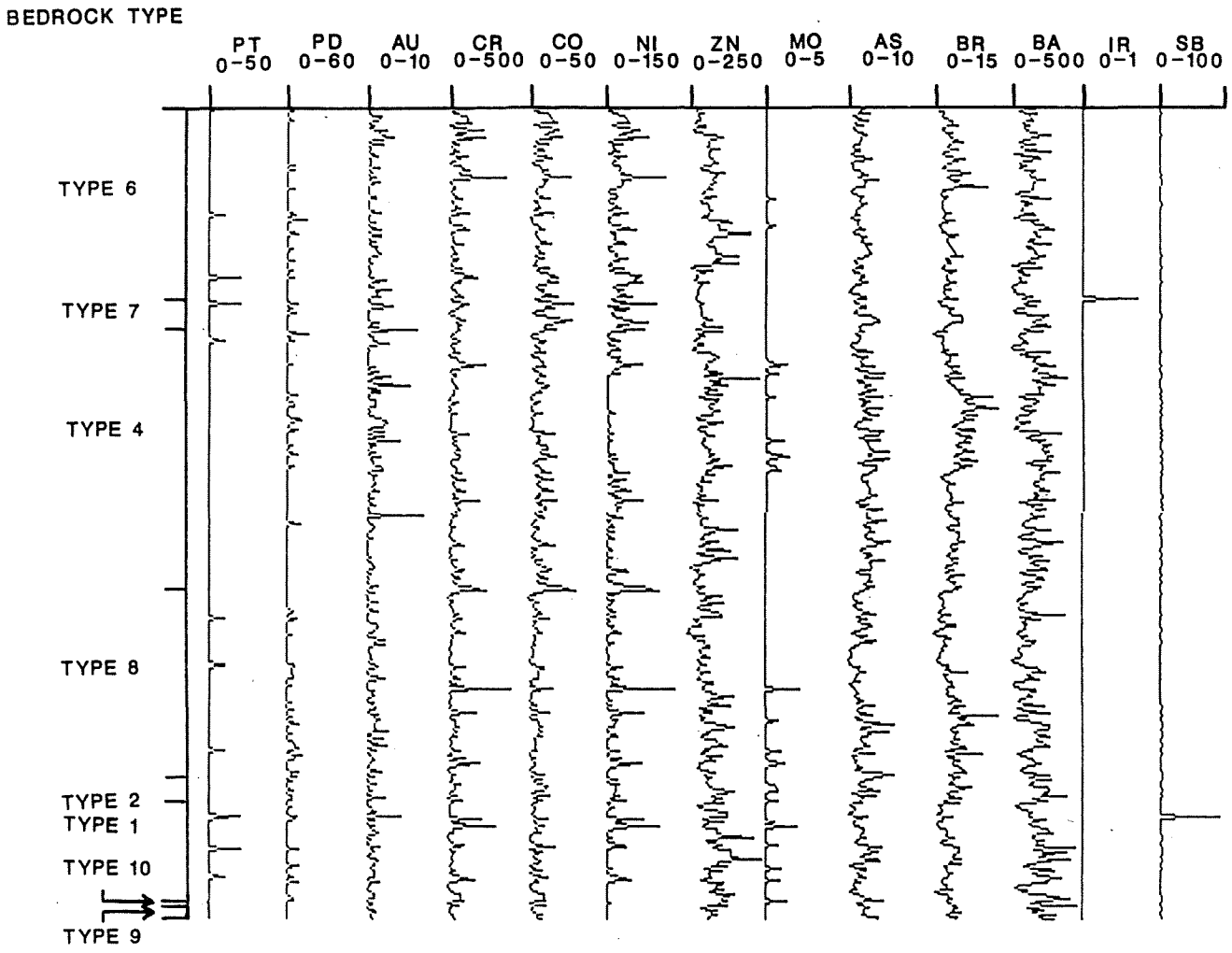



*figure 19*

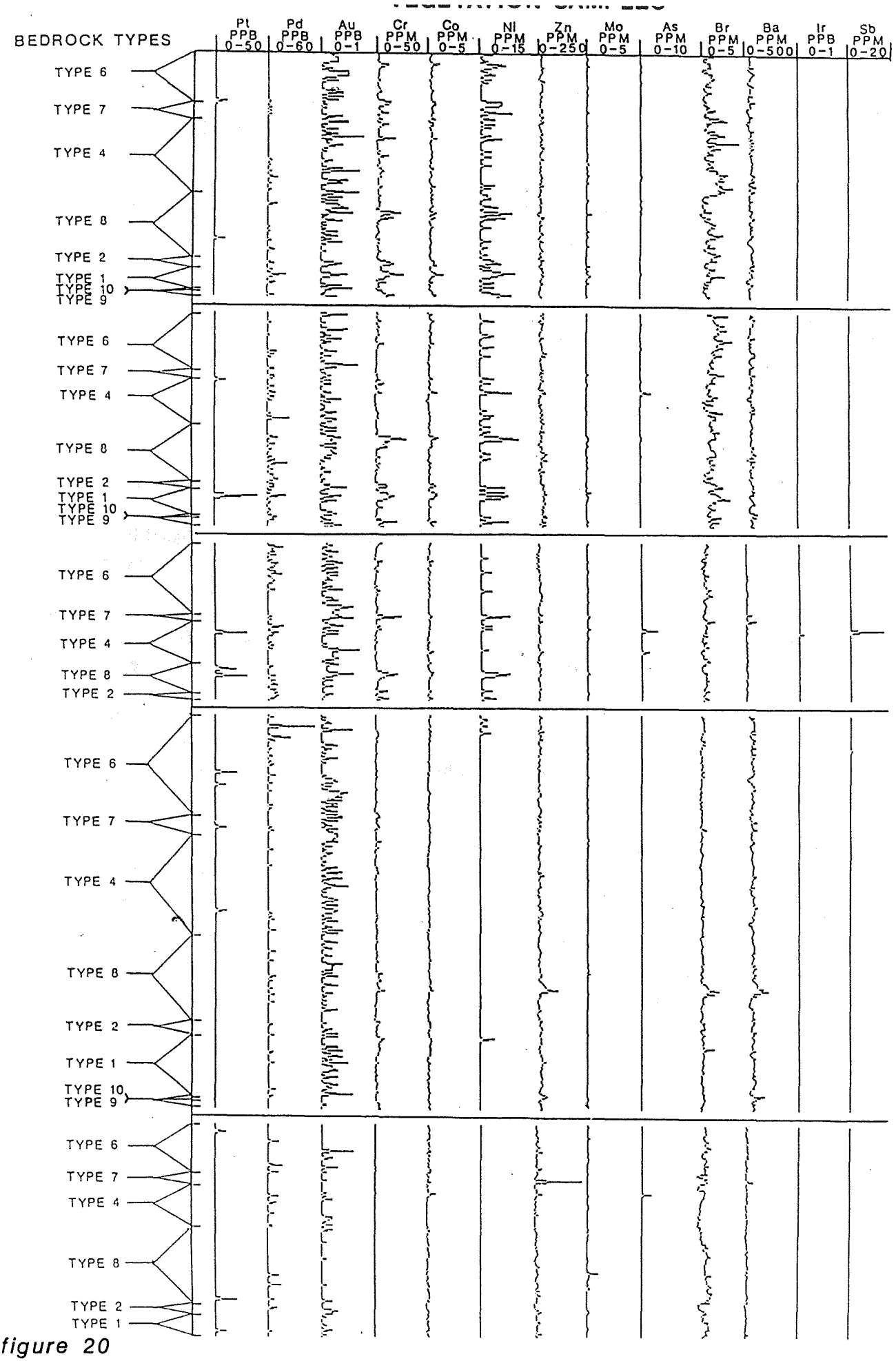

BEDROCK TYPES
Pt PPB 0-50
Pd PPB 0-60
Au PPB 0-1
Cr PPM 0-50
Co PPM 0-5
Ni PPM 0-15
Zn PPM 0-250
Mo PPM 0-5
As PPM 0-10
Br PPM 0-5
Ba PPM 0-500
Ir PPB 0-1
Sb PPM 0-20
TYPE 6
TYPE 7
TYPE 4
TYPE 8
TYPE 2
TYPE 1
TYPE 10
TYPE 9
BLACK SPRUCE
WHITE SPRUCE
JACK PINE
BALSAM FIR
ALDER

*figure 20*

samples in a regional setting (Dunn, personal communication).

The validity of surficial drift prospecting is frequently questioned due to concerns of whether geochemical patterns reflect the glacial drift, glacial transport or the underlying bedrock. The SuperCalc 4 histograms, the MIP's assay graphs, and the geochemical contour maps indicate that element signatures conform to bedrock boundaries. These graphs and maps also supply a wealth of information concerning what element concentrations can be expected in the various media and bedrock types.

Sieving and heavy mineral concentrating of the glacial drift samples produced an extensive tabulation of weights and weight percentages according to the sizes of particles within the processed samples. Sieve data are available for examination at the Division of Minerals in Hibbing. Heavy mineral concentrate weights, percentages and concentration ratios are listed in Part II. These data can be used to further characterize the glacial drift of the study area or may be useful in developing a sand and gravel resource map for the area.

Visual examination of the partial heavy mineral concentrates did indicate a degree of variability in the concentrate quality. While the concentrating procedures used were constant and uniform, this variability was caused by fluctuating water pressures at the laboratory as was mentioned earlier in this report in a discussion of sample processing methods. Figure 21 is a plot of chrome versus normalized chrome values. The normalized chrome values are a mathematically derived estimate of what the actual chrome values were in the table feed, calculated in the following manner:

$$\textit{Normalized Chrome Value} = \frac{\textit{HMC Weight x Assay Value}}{\textit{Wilfley Table Feed Weight}}$$

The calculation compensates for high assays which may be caused by an increase in the degree of concentration. The remarkable similarity between these plots indicates that fluctuating water pressure had little impact on variability of assay results. The assay results presented in this report are, therefore, not normalized.

DNR glacial drift projects (Martin, 1988 & Martin, 1989) have used the services of Overburden Drilling Management (ODM) of Nepean, Ontario, for tabling, heavy liquid and magnetic separations and for visual inspection of gold grains. Seven partial heavy mineral concentrates from this project were subjected to the same routine with hopes of locating platinum group minerals or indicator minerals. Their microscopic examination of the nonmagnetic fraction did not detect such minerals. ODM did find that the degree of oxidation of the concentrates ranged from slight to severe, and the degree of concentration was lower than concentrates they are accustomed to examining. The results of ODM's sample examinations and their comments on oxidation, concentrate quality and mineral assemblages are available for examination in the project files.

An additional characterization of eleven partial heavy mineral concentrates at the NRRI laboratory in Coleraine was accomplished by using heavy liquids with a specific gravity of 2.89. Concentrate feed, heavy liquid concentrate and light mineral reject weights and weight percents are summarized in Table 17.

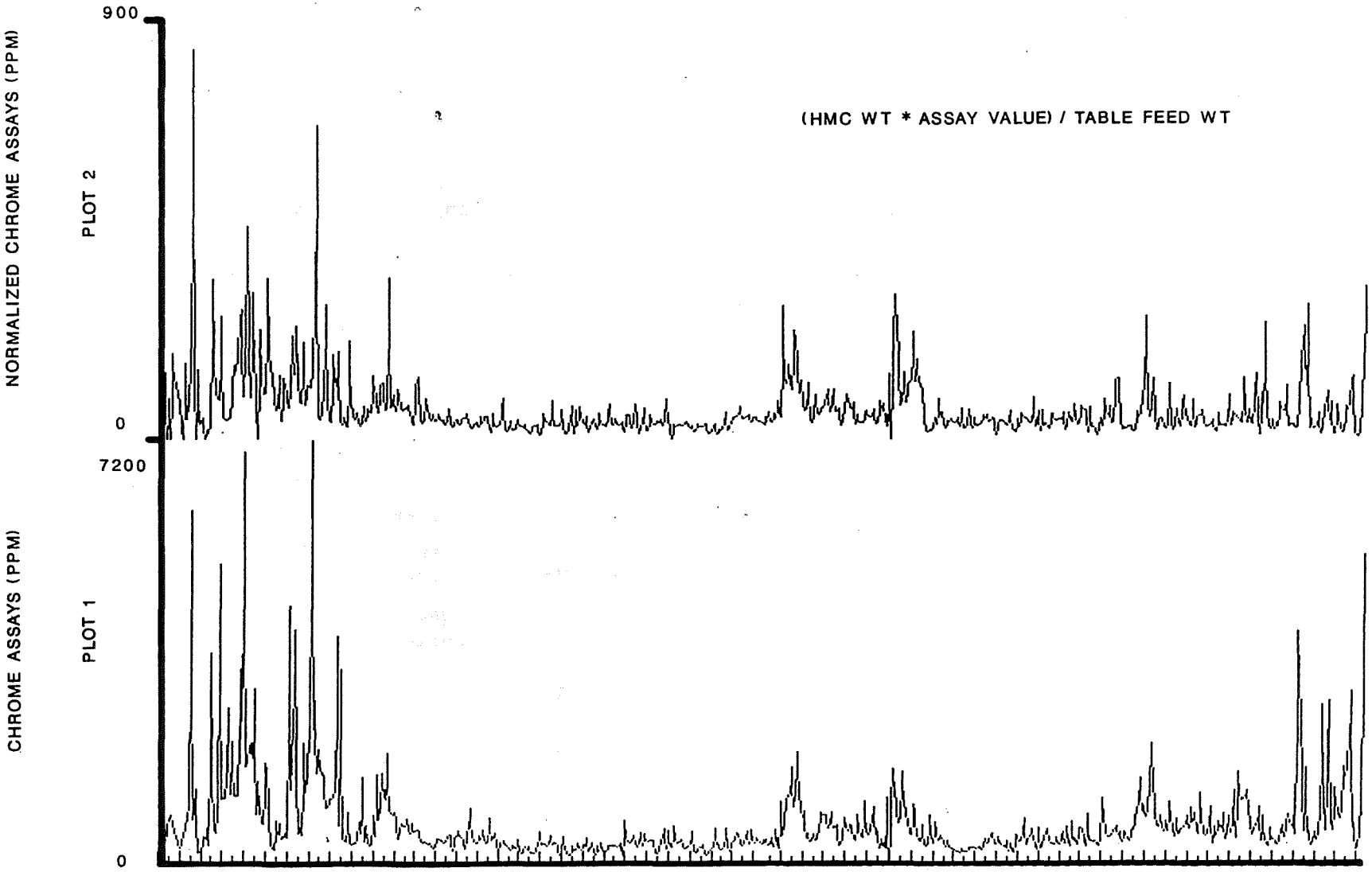



*figure 21* NORMALIZATION OF CHROME ASSAYS FROM PARTIAL HEAVY MINERAL CONCENTRATES.

Table 17. Heavy Liquid Separation of Wilfley Table Concentrates, Selected Samples.

| Sample | Order Processed[1] | Bedrock | Glacial | Degree of Darkness[2] | Degree of Oxidation[3] | Wilfley Table Concentrate, Wt. % of Table Feed | Heavies from Concentrates (% > 2.95S.G.) | Lights from Concentrates (% < 2.95S.G.) |
|---|---|---|---|---|---|---|---|---|
| 20437 | 1 | Troctolite | Rainy Ice Contact | 11 | 5 | 14% | 34% | 66% |
| 20423 | 2 | Troctolite | Rainy Till | 9 | 5 | 20% | 27% | 73% |
| 20474 | 3 | Troctolite | Rainy Till | 8 | 3 | 8% | 47% | 53% |
| 20591 | 4 | Duluth Complex Undivided | Superior Outwash | 2 | 1 | 5% | 86% | 14% |
| 20873 | 5 | Duluth Complex Undivided | Superior Outwash | 10 | 5 | 16% | 40% | 60% |
| 21114 | 6 | Troctolites | Superior Till | 5 | 1 | 7% | 25% | 75% |
| 21207 | 7 | Anorthosite | Rainy Reworked Till | 7 | 4 | 5% | 71% | 29% |
| 21267 | 8 | Anorthosite | Rainy Outwash | 4 | 2 | 4% | 83% | 17% |
| 21446 | 9 | Anorthosite | Rainy Ice Contact | 1 | 1 | 4% | 96% | 4% |
| 21698 | 10 | Gabbro & Ferro Gabbro | Undivided Outwash | 6 | 4 | 3% | 96% | 4% |
| 21537 | 11 | Anorthosite | Rainy Till | 3 | 2 | 7% | 94% | 6% |

[1] Order Processed, eleven samples selected at intervals throughout Wilfley table processing.

[2] Degree of Darkness, used as an indication of dark mineral content. Sliding scale #1 meaning very dark, #11 indicating very light.

[3] Degree of Oxidation, sliding scale #1 meaning unoxidized, #5 indicating oxidized.

## Chrome-Spinel and Chromite Investigation

Dr. Penelope Morton of NRRI/UMD has conducted a petrographic/microprobe examination of thirty-nine selected partial heavy mineral concentrates with emphasize on the chrome spinels and chromites. A summary of her results is directly reported in the following paragraphs, tables and figures.

# "ANALYSIS OF OPAQUE OXIDES IN PARTIAL HEAVY MINERAL CONCENTRATES FROM GLACIAL DRIFT SAMPLES, LAKE COUNTY, MINNESOTA"

by P. Morton and J. Reichoff

## SUMMARY

### Purpose:

Thirty-nine partial heavy mineral concentrate samples were submitted by Minnesota DNR to UMD geology and NRRI for identification, quantification and analysis of spinel, magnetite and ilmenite. These samples had been collected in a glacial drift geochemical sampling program for strategic minerals during the summer of 1988 in Lake County, NE Minnesota over parts of the basal, middle and upper zones of the Duluth Complex. Of these samples 12 had Cr contents less than 1000 ppm, 10 between 1000 and 2000 ppm, 9 between 2000 and 3000 ppm, 4 between 3000 and 4000 ppm and 4 in excess of 5000 ppm. One of the purposes of this project was to determine the mineral source of the higher Cr contents as well as determine if the types of Fe-Ti-Cr oxides were representative either of bedrock and/or glacial drift type. The Cr content of the partial heavy mineral concentrates is particularly interesting because of the known correlation of high Pt values with Cr spinels in diamond drill core of basal layered troctolite in DU-15 (Sabelin, 1985). It is hoped that Cr spinels such as those found associated with the high Pt values might prove to be good path finder minerals for Pt-Pd exploration.

Analysis of these samples was accomplished in two steps: 1. point countingof polished grain mounts and 2. electron microprobe analysis of representative magnetite, ilmenite and/or spinel phases. Point counts were made with the following mineral groups: 1. silicates, 2. magnetite, 3. magnetite with spinel lamellae, 4. ilmenite, 5. ilmenite, spinel and magnetite together, 6. magnetite with hematite alteration, 7. hematite, 8. ilmenite with spinel inclusions, 9. magnetite and ilmenite together either as lamellae in one another or as extremely fine-grained intergrowth (on the order of 2-3 um; these may be in fact magnetite-ulvospinel intergrowths), 10. simplectites of silicate and oxide, 11. sulfide grains, 12. composite grains composed of rounded chromite grains in silicate gangue, 13. ilmenite with hematite oxidation or lamellae and 14. spinel. An average of 678 grains were counted on each sample. Point count results are presented in Table 1.

Electron microprobe analysis of representative minerals was achieved using an updated MAC 400 electron microprobe equipped with a Krisel automation package. An average of 10 grains were analyzed on each sample and each grainwas analyzed for FeO, MgO, MnO, TiO2, SiO2, Al2O3, and Cr2O3. Fe2O3 content was calculated from stochiometry. In all, 500 grains were analyzed on 38 samples. These are presented in Table 2.

## Results:

The following represents a summary of results in point form. They are presented first in terms of the point counts with chemical analyses where applicable and then with respect to the chemical composition of the types of grains analyzed.

1. There is a positive correlation between the volume percent magnetite/spinel and chromite/spinel and the overall Cr content of the samples. Where no Cr-spinels were recognized in the point counts, and the sample had high Cr contents, it was found that in four cases (20541, 20591, 21552 and 21700) that the magnetite had a high Cr content (2-6 wt% Cr2O3) and there was a significant amount of magnetite in each sample. Samples 21307, 21641, and 21728 however have Cr contents that vary from 1188 to 2116 ppm, and no Cr-spinels were recognized nor do the magnetites analyzed have high Cr contents (generally less than 0.6 wt% Cr2O3). This really might represent the fact that not enough grains of magnetite were analyzed in these samples. In sample 21752 which contains 2929 ppm Cr, no Cr- spinels were recognized in the point count, however upon analysis of several magnetite grains, it was found that some of the magnetite had been misidentified as ferritchromit.

2. The samples that contain high contents of Cr are generally located in the western part of the sampling area (T60,R11; T61,R10; T60,R10; T59,R10) and likewise these are the samples that contain the Cr-spinels.

3. TiO2 content (in wt%) of the heavy mineral concentrate correlates well with the volume percent ilmenite. The V content (in ppm) correlates with both the volume percent magnetite and ilmenite in the sample. Of the 39 samples presented, 8 had volume percent pure ilmenite contents in excess of 15%. Of these, 5 come from T60R9, 2 from T61R8, and one (20515) from T60R10. With the exception of 20515, all overlie what are mapped as anorthositic series rocks in the Duluth Complex and all lie in a north-easterly trend. This ilmenite content may be representative of both the bedrock and the quaternary geology.

4. There is a good correlation between volume per cent ilmenite and volume per cent magnetite. However, there is no correlation between the volume per cent ilmenite and the volume per cent magnetite with spinel. This might indicate that the magnetite with spinel lamellae are of a different population than that of the magnetite without lamellae and the ilmenite. Chemically however they appear similar.

5. Grains of iron formation (IF) were recognized in 20 of the samples. The main criterion used to identify them was the granoblastic texture of magnetite and/or hematite with silicate (usually quartz). These are not tallied in Table 1 however. The greatest density of samples that contain IF grains are in the northwest section of the sampling area. This may be real or a function of the sampling density given to us for analysis. Analyses of these magnetite and hematite grains contain very little trace metal content. Ti, Cr, Mn Mg and Al contents are usually less than 0 .1 oxide %. This is not the case with the magnetite with spinel inclusions, the magnetite associated with ilmenite or the coarse-grained magnetite that occurs as broken and rounded grains.

6. 203 grains of ilmenite were analyzed from throughout the samples. In general, ilmenite compositions are very uniform. MgO contents vary from 0 to 5 wt% (average 2.0 wt%) and TiO2 contents vary from 45 to 52 wt% (average 49.1 wt%). Cr contents are generally very low. Ilmenites were recognized as euhedral and anhedral inclusions in Cr-spinel, spinel or chromite in 11 of the samples. 14 grains were analyzed and these contained more Cr, Ti and Mg than ilmenite not found with Cr-spinel. Average electron microprobe analyses of each kind are listed in Table 3. Perhaps it could be speculated that Mg rich ilmenites might be a good indicator for Cr spinels and chromite.

7. Of the 100 magnetite grains analyzed, the vast majority would be considered titanomagnetite. The median TiO2 content is between 6 and 7 wt%. Cr2O3 content varies from 0 to 9 wt% with a median around 2%. There would be a complete continuum between the magnetite and chromite (or chrome spinel) in terms of Cr2O3 content except that samples with Cr2O3 contents in excess of 10% were separated into the chromite/spinel grouping. Within the magnetites themselves there is a slight positive correlation between MgO and Cr2O3 content. Individual and average values are compiled in Table 4. For ease of discussion, the letters in the table for area correspond to township and range as follows

and shown by Figure 3.

| Township | Range | Letter |
|---|---|---|
| 60 | 11 | a |
| 61 | 10 | b |
| 60 | 10 | c |
| 59 | 10 | d |
| 61 | 9 | e |
| 60 | 9 | f |
| 59 | 9 | g |
| 61 | 8 | h |
| 60 | 8 | i |
| 59 | 7 | j |

Average Cr2O3 content (Table 4) of magnetite seems to change with area. In areas a through d, the western part of the sampling area, average Cr2O3 content varies from 2.2 to 4.3 wt%. In areas e through j, average Cr2O3 content varies from 0.4 to 1.68 wt%. This well could be a reflection of the bedrock geology because the rocks in the west are thought to be layered troctolite and gabbro, and the rocks in the east are anorthositic series rocks. As a general statement as the overall Cr content of the heavy mineral concentrate increases, so does the Cr content of the magnetite.

Average TiO2 content of the titanomagnetite varies from 6.68 wt% in areas a through d (average of 61 analyses) to 7.88 wt% in areas e through j (29 analyses). Analyses of magnetite interpreted to be IF have been deleted from the averages, if they are included the above numbers change from 5.99 in a through d to 7.16 in the eastern part of the area.

8. 81 analyses of Cr-rich spinels are presented in Table 5. Samples 21197 and 20483 contain Mg-Fe spinel, sample 21593 contains ulvospinel and samples 20483, 21267, 21446 and 21557 contain Cr rich chromites (greater than 48% Cr2O3). All the other analyses belong to chromite solid solution series and have been called chromite in Table 5. This is different from Table 1 where grains have been labelled chromite, Cr-spinel and spinel. These are the names designated during the point-counting process.

In sample 20456 within the same grains are co-existing chromites one of which is light grey and the other dark. They have textures indicating that the dark grey phase exsolved from the light grey. Cr content of each is similar however the light grey phase is much richer in TiO2, FeO and Fe2O3 and poorer in MgO and Al2O3 compared to the dark grey phase. These appear to be end member phases one of which is an aluminous rich Cr-Mg chromite the other a Titaniferous Cr-Fe chromite. When all analyses are plotted on a Cr/Cr + Al vs Mg/Mg + Fe plot (Figure 1), they fall between the positions designated by the phases in 20456 (Figure 2) indicating that they fall within the solid solution area. This is true for all analyses of chromites from areas a through d with the exception of the spinels noted above. The Cr rich chromites found in areas e,f and h do not show this trend, indicating another source. What is particularly interesting in this trend, is that analyses of spinel and Fe rich chromite from DU-15 also fall on this trend (Sabelin, 1985). It should be noted however that absolute values of Cr and Al differ between samples from glacial drift and DU-15, only their ratios are similar. Analyses of spinel phases from DU-15 are consistently higher in Al and lower in Cr content compared to those from the glacial drift.

In all the chromites and spinels analyzed from areas a through d, there is a strong positive correlation between Al2O3 content and Mg/Mg + Fe ratio. There is also a positive correlation between %Cr2O3 content and Mg/Mg + Fe ratio from 10% to 28% Cr2O3 where the curve flattens out. This is true for all analyses except for the Cr rich chromites noted above.

9. Overall, the composition of the opaque oxides in glacial drift samples mimic the the geochemistry of the area, which in turn seems to be a good indication of bedrock source.

## REFERENCES

Sabelin, T., 1985. Metallurgical evaluation of chromium-bearing drill core samples from the Duluth Complex: Mineral Resource Research Center, University of Minnesota, DNR Report 248, 58 pp.

# Table 1: Point Counts of Partial Heavy Mineral Concentrates

| Sample# | coun | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | Total | Cr | Co | V | TiO2 | Fe2O3 | MgO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20437 | 738 | 94.04 | 0.54 | | 2.57 | 0.54 | 0.14 | 1.08 | | | 0.27 | 0.27 | 0.54 | | | 99.99 | 5935 | 90 | 530 | 2.92 | 14.94 | 5.80 |
| 20443 | 690 | 90.87 | 0.29 | | 2.90 | 1.01 | 1.01 | 1.01 | 1.59 | 0.14 | 1.16 | | | | | 99.98 | 1280 | 137 | 404 | 4.15 | 24.72 | 12.96 |
| 20456 | 668 | 91.17 | 1.50 | 0.30 | 2.40 | 0.60 | 0.60 | 1.65 | 0.30 | 0.15 | 1.35 | | | | | 100.02 | 3550 | 153 | 519 | 3.46 | 23.13 | 23.13 |
| 20462 | 640 | 84.69 | 1.72 | 0.63 | 5.63 | 2.19 | 0.78 | 1.88 | 0.16 | 0.47 | 1.88 | | | | | 100.03 | 5060 | 203 | 988 | 8.05 | 34.76 | 14.62 |
| 20474 | 952 | 93.70 | 1.05 | | 1.26 | 0.95 | 1.16 | 0.74 | 0.11 | 0.42 | 0.63 | | | | | 100.02 | 2070 | 95 | 504 | 4.47 | 19.64 | 7.04 |
| 20483 | 425 | 59.29 | 3.29 | 7.53 | 15.06 | 4.71 | 2.35 | 2.82 | | 3.29 | 0.94 | | 0.71 | | | 99.99 | 6925 | 225 | 1422 | 10.06 | 40.32 | 14.41 |
| 20494 | 687 | 85.32 | 3.08 | 1.03 | 7.34 | | 0.73 | 0.88 | 0.44 | 0.44 | 0.59 | | 0.15 | | | 100.00 | 2491 | 159 | 775 | 7.05 | 29.80 | 12.53 |
| 20515 | 471 | 68.37 | 2.55 | 0.85 | 12.74 | 0.21 | 4.03 | 3.18 | | 6.37 | 1.06 | | | 0.64 | | 100.00 | 724 | 167 | 1501 | 14.81 | 42.65 | 6.00 |
| 20541 | 686 | 87.61 | 2.33 | 0.87 | 2.92 | 0.44 | 1.17 | 2.92 | | 1.02 | 0.73 | | | | | 100.01 | 2280 | 145 | 759 | 8.22 | 27.79 | 9.50 |
| 20546 | 548 | 91.42 | 0.36 | 0.73 | 3.47 | 0.36 | 0.91 | 1.46 | 0.18 | 1.09 | | | | | | 99.98 | 2770 | 100 | 315 | 2.65 | 16.95 | 11.99 |
| 20567 | 696 | 86.49 | 1.15 | 0.97 | 5.89 | 0.14 | 0.86 | 1.58 | 0.43 | 0.86 | 0.72 | | | | 0.90 | 99.99 | 3853 | 155 | 721 | 7.18 | 27.07 | 12.87 |
| 20591 | 745 | 64.16 | 3.36 | 1.21 | 13.56 | 1.61 | 3.89 | 4.70 | 0.40 | 5.50 | 1.61 | | | | | 100.00 | 1465 | 162 | 1266 | 11.78 | 38.35 | 7.41 |
| 20873 | 579 | 93.96 | 1.38 | | 2.07 | 0.52 | 0.86 | 0.69 | | 0.35 | 0.17 | | | | | 100.00 | 245 | 69 | 503 | 4.13 | 17.89 | 4.41 |
| 20887 | 580 | 93.62 | 2.59 | | 2.93 | | | 0.34 | | 0.17 | 0.34 | | | | | 99.99 | 445 | 80 | 554 | 5.09 | 20.27 | 5.10 |
| 20944 | 762 | 87.40 | 3.54 | | 3.02 | 0.52 | 2.10 | 0.92 | | 2.49 | | | | | | 99.99 | 300 | 109 | 803 | 7.72 | 27.46 | 6.08 |
| 21114 | 688 | 95.78 | 0.87 | 0.15 | 2.62 | | 0.15 | 0.44 | | | | | | | | 100.01 | 178 | 60 | 328 | 2.81 | 13.22 | 3.33 |
| 21149 | 559 | 93.20 | 0.89 | 0.36 | 3.40 | | 0.72 | 1.25 | | | 0.18 | | | | | 100.00 | 333 | 86 | 548 | 6.66 | 19.59 | 4.59 |
| 21197 | 889 | 93.03 | 1.69 | 0.34 | 2.02 | 0.45 | 1.01 | 0.22 | 0.45 | 0.11 | 0.67 | | | | | 99.99 | 1110 | 138 | 496 | 4.82 | 23.86 | 13.97 |
| 21207 | 722 | 93.91 | 1.52 | 0.14 | 3.19 | 0.14 | 0.42 | 0.28 | 0.28 | | 0.14 | | | | | 100.02 | 1905 | 164 | 805 | 7.92 | 30.47 | 14.20 |
| 21225 | 576 | 85.42 | 1.74 | 0.52 | 7.64 | | 1.39 | 0.35 | | 2.08 | 0.87 | | | | | 100.01 | 514 | 143 | 720 | 7.88 | 29.29 | 9.04 |
| 21267 | 583 | 78.56 | 3.43 | 0.69 | 8.58 | 0.17 | 1.72 | 0.86 | 0.17 | 3.95 | 1.89 | 0.17 | | | | 100.19 | 849 | 163 | 1171 | 12.44 | 36.24 | 6.89 |
| 21307 | 636 | 95.10 | 0.79 | 0.47 | 1.73 | 0.16 | 0.47 | 0.31 | 0.31 | | 0.47 | | | 0.16 | | 99.97 | 1562 | 146 | 299 | 2.59 | 22.68 | 19.70 |
| 21446 | 655 | 58.17 | 3.97 | 0.61 | 20.15 | 0.92 | 3.36 | 4.58 | 0.46 | 7.33 | 0.46 | | | | | 100.01 | 615 | 196 | 1568 | 16.43 | 45.60 | 6.55 |
| 21552 | 613 | 37.19 | 10.44 | 6.04 | 32.95 | 2.45 | 3.75 | 1.14 | 1.47 | 2.28 | 2.28 | | | | | 99.99 | 2061 | 292 | 1881 | 26.81 | 49.55 | 5.64 |
| 21557 | 690 | 58.84 | 4.20 | 1.33 | 23.04 | 1.42 | 3.77 | 2.90 | 0.72 | 3.04 | 0.43 | | | | 0.29 | 99.98 | 1115 | 231 | 1498 | 18.08 | 46.59 | 7.22 |
| 21593 | 614 | 60.26 | 5.70 | 0.98 | 20.36 | 0.33 | 3.09 | 3.75 | | 4.72 | 0.81 | | | | | 100.00 | 883 | 219 | 1599 | 17.29 | 45.90 | 5.96 |
| 21641 | 1518 | 81.09 | 0.72 | 0.99 | 7.91 | 0.86 | 1.98 | 1.52 | | 2.04 | 2.83 | | | | 0.07 | 100.01 | 1188 | 207 | 1198 | 15.80 | 43.72 | 7.64 |
| 21657 | 723 | 45.37 | 10.65 | 2.07 | 20.06 | 2.07 | 6.09 | 4.84 | | 8.44 | 0.28 | 0.14 | | | | 100.01 | 1001 | 211 | 2197 | 19.30 | 51.74 | 4.26 |
| 21661 | 552 | 53.44 | 5.98 | 1.27 | 19.93 | 0.18 | 3.80 | 5.62 | 0.54 | 7.25 | 0.72 | 0.18 | | 1.09 | | 100.00 | 845 | 206 | 1927 | 19.46 | 49.46 | 5.13 |
| 21689 | 589 | 56.71 | 3.06 | 1.36 | 19.69 | | 4.41 | 4.07 | | 9.34 | 1.19 | | | 0.17 | | 100.00 | 876 | 201 | 1818 | 18.80 | 48.02 | 5.39 |
| 21698 | 732 | 85.52 | 4.51 | 2.19 | 5.87 | 0.14 | 0.55 | 0.68 | | | 0.55 | | | | | 100.01 | 3930 | 215 | 706 | 6.96 | 33.09 | 22.66 |
| 21700 | 520 | 86.70 | 5.38 | 0.19 | 4.81 | 0.19 | 1.73 | 0.58 | | 0.38 | | | | 0.19 | | 100.15 | 3380 | 209 | 518 | 4.94 | 29.88 | 23.96 |
| 21702 | 837 | 95.22 | 1.08 | 0.48 | 2.39 | | 0.12 | 0.36 | 0.12 | 0.24 | | | | | | 100.01 | 1795 | 176 | 246 | 2.22 | 24.46 | 22.88 |
| 21724 | 757 | 89.96 | 3.70 | 0.66 | 3.30 | | 0.26 | 0.26 | | 0.79 | 0.92 | 0.13 | | | | 99.98 | 2715 | 187 | 813 | 8.23 | 32.74 | 17.80 |
| 21728 | 596 | 85.91 | 1.68 | 0.50 | 7.89 | 0.17 | 1.85 | 0.34 | | 0.67 | 1.01 | | | | | 100.02 | 2116 | 192 | 681 | 8.48 | 30.74 | 18.35 |
| 21730 | 547 | 83.91 | 2.74 | 0.73 | 8.41 | 0.18 | 1.65 | | 0.18 | 1.10 | 1.10 | | | | | 100.00 | 2779 | 216 | 790 | 9.36 | 34.63 | 20.11 |
| 21750 | 665 | 92.63 | 1.35 | 0.45 | 3.01 | 0.15 | 0.15 | 0.30 | | | 1.95 | | | | | 99.99 | 2182 | 142 | 478 | 4.84 | 22.61 | 16.92 |
| 21752 | 700 | 94.57 | 1.29 | 0.14 | 2.86 | | 0.14 | 0.71 | 0.29 | | | | | | | 100.00 | 2929 | 163 | 471 | 4.07 | 25.31 | 21.41 |
| 21766 | 604 | 78.15 | 4.80 | 1.49 | 10.10 | | 0.66 | 0.83 | | 1.32 | 0.50 | | 0.99 | | 1.16 | 100.00 | 5241 | 187 | 951 | 9.05 | 31.38 | 15.02 |

1. gangue
2. magnetite
3. magnetite/spinel
4. ilmenite
5. ilmenite/magnetite/spinel together
6. magnetite/hematite
7. oxidized grains including hematite
8. ilmenite/spinel
9. magnetite/ilmenite
10. simplectite of oxide and silicate
11. sulfide
12. composite grains consisting of rounded oxides chromite in a silicate matrix
13. ilmenite/hematite
14. mostly spinel

Table 2: Electron Microprobe Analyses of Opaque Oxides

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
| 20437-01-1 | 1 | Spinel | 2.67 | 26.37 | 0.28 | 23.51 | 12.09 | 0.04 | 10.50 | 28.11 | 103.57 |
| 20437-01-1 | 2 | Spinel | 2.57 | 25.53 | 0.39 | 23.41 | 11.18 | 0.06 | 9.75 | 27.64 | 100.53 |
| 20437-01-1 | 3 | Spinel | 2.63 | 26.01 | 0.13 | 23.62 | 11.74 | 0.12 | 9.96 | 27.20 | 101.41 |
| 20437-01-1 | 4 | Spinel | 2.58 | 25.59 | 0.30 | 22.64 | 10.97 | 0.10 | 10.34 | 27.97 | 100.49 |
| 20437-01-1 | 5 | Spinel | 2.98 | 25.61 | 0.22 | 23.28 | 12.44 | 0.00 | 9.88 | 25.63 | 100.04 |
| 20437-01-1 | 6 | Spinel | 2.82 | 25.45 | 0.29 | 23.65 | 11.32 | 0.20 | 9.81 | 27.31 | 100.85 |
| 20437-01-2A | 1 | Spinel | 1.84 | 26.52 | 0.32 | 24.76 | 11.71 | 0.04 | 8.75 | 27.78 | 101.72 |
| 20437-01-2A | 2 | Spinel | 1.72 | 27.16 | 0.12 | 24.34 | 12.42 | 0.00 | 9.57 | 28.40 | 103.73 |
| 20437-01-3 | 1 | Magnetite | 6.35 | 2.15 | 0.15 | 34.87 | 50.42 | 0.00 | 0.86 | 2.09 | 96.89 |
| 20437-01-3 | 2 | Magnetite | 5.80 | 2.31 | 0.23 | 34.18 | 52.21 | 0.00 | 1.19 | 2.22 | 98.14 |
| 20437-01-4 | 1 | Spinel | 4.04 | 27.27 | 0.49 | 29.00 | 18.67 | 0.00 | 5.41 | 15.05 | 99.93 |
| 20437-01-4 | 2 | Spinel | 4.80 | 26.96 | 0.43 | 30.08 | 18.61 | 0.08 | 5.54 | 15.13 | 101.63 |
| 20437-01-4 | 3 | Spinel | 3.13 | 25.52 | 0.37 | 24.62 | 13.05 | 0.00 | 9.50 | 26.07 | 102.26 |
| 20437-01-4 | 4 | Spinel | 2.89 | 25.05 | 0.29 | 23.96 | 13.49 | 0.00 | 9.88 | 26.63 | 102.19 |
| 20437-01-4 | 5 | Ilmenite | 50.08 | 0.30 | 0.67 | 39.04 | 6.53 | 0.33 | 2.89 | 0.13 | 99.97 |
| 20437-01-4 | 6 | Orthopyroxene | 0.18 | 0.13 | 0.43 | 17.66 | 0.00 | 54.55 | 27.50 | 1.15 | 101.60 |
| 20437-01-4A | 1 | Ilmenite | 51.50 | 0.11 | 0.48 | 41.21 | 3.37 | 0.00 | 2.59 | 0.02 | 99.28 |
| 20437-01-5 | 1 | Spinel | 2.39 | 26.25 | 0.36 | 22.77 | 9.37 | 0.12 | 10.14 | 28.80 | 100.20 |
| 20437-01-5 | 2 | Ilmenite | 56.02 | 0.32 | 0.44 | 35.15 | 1.90 | 0.00 | 8.29 | 0.13 | 102.25 |
| 20437-01-5 | 3 | Spinel | 2.34 | 26.14 | 0.33 | 22.92 | 10.16 | 0.08 | 9.95 | 28.19 | 100.11 |
| 20443 | 1 | Magnetite | 5.84 | 5.05 | 0.36 | 34.67 | 45.89 | 0.06 | 0.80 | 4.21 | 96.88 |
| 20443 | 4 | Ilmenite | 51.20 | 0.01 | 0.49 | 40.68 | 3.35 | 0.00 | 2.73 | 0.08 | 98.54 |
| 20443 | 8 | Ilmenite | 50.68 | 0.30 | 0.40 | 39.27 | 6.87 | 0.00 | 3.31 | 0.20 | 101.03 |
| 20443 | 10 | Ilmenite | 49.20 | 0.14 | 0.49 | 37.40 | 5.81 | 0.00 | 3.57 | 0.16 | 96.77 |
| 20443 | 12 | Ilmenite | 49.60 | 0.02 | 0.71 | 40.00 | 3.82 | 0.18 | 2.16 | 0.08 | 96.57 |
| 20443 | 13 | Magnetite | 4.66 | 4.81 | 0.18 | 33.84 | 48.28 | 0.09 | 0.61 | 3.94 | 96.41 |
| 20443 | 14 | Magnetite | 5.50 | 4.61 | 0.23 | 33.30 | 45.70 | 0.09 | 1.20 | 4.34 | 94.97 |
| 20443 | 15 | Magnetite | 5.59 | 4.54 | 0.34 | 34.25 | 47.62 | 0.11 | 1.24 | 4.24 | 97.93 |
| 20443 | 16 | Magnetite | 5.83 | 4.78 | 0.29 | 34.50 | 46.72 | 0.16 | 1.14 | 4.40 | 97.82 |
| 20443 | 17 | Ilmenite | 48.48 | 0.13 | 0.26 | 37.73 | 7.09 | 0.08 | 3.14 | 0.12 | 97.03 |
| 20456-01-1 | 1 | Ilmenite | 50.76 | 0.17 | 0.39 | 42.20 | 4.79 | 0.05 | 1.71 | 0.09 | 100.16 |
| 20456-01-1 | 2 | Magnetite | 4.45 | 2.63 | 0.34 | 34.65 | 54.60 | 0.04 | 0.21 | 2.28 | 99.20 |
| 20456-01-1 | 3 | Magnetite | 3.88 | 2.75 | 0.18 | 33.91 | 55.46 | 0.00 | 0.51 | 2.46 | 99.15 |
| 20456-01-2 | 1 | Ilmenite | 9.50 | 5.30 | 0.28 | 5.80 | 75.29 | 0.06 | 1.38 | 4.60 | 102.21 |
| 20456-01-2 | 1 | Magnetite | 9.50 | 5.30 | 0.28 | 37.86 | 39.59 | 0.06 | 1.38 | 4.60 | 98.57 |
| 20456-01-3 | 1 | Spinel | 9.20 | 21.42 | 0.36 | 32.82 | 22.89 | 0.09 | 4.65 | 6.42 | 97.85 |
| 20456-01-3 | 2 | Spinel | 10.06 | 19.95 | 0.49 | 33.18 | 20.50 | 0.63 | 4.13 | 6.12 | 95.06 |
| 20456-01-3 | 3 | Spinel | 1.08 | 24.88 | 0.25 | 21.94 | 11.79 | 0.30 | 9.79 | 29.31 | 99.34 |
| 20456-01-3 | 4 | Spinel | 1.29 | 25.11 | 0.18 | 22.84 | 8.42 | 0.15 | 9.88 | 32.16 | 100.03 |

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20456-01-3 | 5 | Spinel | 1.54 | 27.08 | 0.21 | 22.14 | 10.92 | 0.19 | 10.13 | 28.29 | 100.50 |
| 20456-01-3 | 6 | Spinel | 8.45 | 20.45 | 0.25 | 33.02 | 22.65 | 0.11 | 4.71 | 8.00 | 97.64 |
| 20456-01-3 | 7 | Spinel | 7.45 | 22.08 | 0.42 | 30.79 | 19.56 | 0.21 | 5.36 | 11.57 | 97.44 |
| 20456-01-3 | 8 | Ilmenite | 47.99 | 0.22 | 5.23 | 37.86 | 4.09 | 0.15 | 0.00 | 0.13 | 95.67 |
| 20456-01-3 | 9 | Ilmenite | 47.55 | 0.18 | 5.43 | 37.26 | 4.39 | 0.09 | 0.00 | 0.09 | 94.99 |
| 20456-01-4 | 1 | Ilmenite | 51.39 | 0.27 | 0.62 | 40.27 | 3.04 | 0.13 | 2.98 | 0.08 | 98.78 |
| 20456-01-4 | 2 | Ilmenite | 50.38 | 0.07 | 0.53 | 38.92 | 5.46 | 0.06 | 3.28 | 0.05 | 98.75 |
| 20456-01-4 | 3 | Ilmenite | 49.86 | 0.00 | 0.51 | 36.85 | 5.93 | 0.05 | 4.19 | 0.04 | 97.43 |
| 20456-01-4 | 4 | Ilmenite | 49.17 | 0.10 | 0.33 | 35.68 | 7.51 | 0.26 | 4.60 | 0.11 | 97.76 |
| 20456-01-4 | 6 | Ilmenite | 12.82 | 0.00 | 0.55 | 8.71 | 68.20 | 6.30 | 1.27 | 3.05 | 100.90 |
| 20456-01-4 | 6 | Magnetite(?) | 12.82 | 0.00 | 0.55 | 38.24 | 35.32 | 6.30 | 1.27 | 3.05 | 97.55 |
| 20456-01-5 | 2 | Magnetite | 0.00 | 0.00 | 0.09 | 29.07 | 67.26 | 0.47 | 0.60 | 0.04 | 97.53 |
| 20456-01-5 | 5 | Magnetite(?) | 14.39 | 0.05 | 0.75 | 42.06 | 34.85 | 0.21 | 0.03 | 1.88 | 94.22 |
| 20456-01-5 | 5 | Ilmenite | 14.39 | 0.05 | 0.75 | 12.12 | 68.19 | 0.21 | 0.03 | 1.88 | 97.62 |
| 20456-0-5 | 1 | Magnetite | 0.02 | 0.14 | 0.01 | 29.18 | 67.78 | 0.55 | 0.80 | 0.11 | 98.59 |
| | | | | | | | | | | | |
| 20462 | 1 | Ilmenite | 47.54 | 0.35 | 0.41 | 33.62 | 10.39 | 0.06 | 4.89 | 0.04 | 97.30 |
| 20462 | 2 | Ilmenite | 10.92 | 0.02 | 0.35 | 5.29 | 77.19 | 0.06 | 2.34 | 4.17 | 100.34 |
| 20462 | 2 | Magnetite | 10.92 | 0.02 | 0.35 | 36.91 | 41.98 | 0.06 | 2.34 | 4.17 | 96.75 |
| 20462 | 3 | Spinel | 5.03 | 25.89 | 0.34 | 27.83 | 20.51 | 0.00 | 6.40 | 12.90 | 98.90 |
| 20462 | 5 | Spinel | 5.05 | 25.78 | 0.31 | 28.07 | 20.23 | 0.04 | 6.25 | 13.04 | 98.77 |
| 20462 | 6 | Orthopyroxene | 0.29 | 0.02 | 0.50 | 19.55 | 50.18 | | 27.90 | 0.89 | 99.33 |
| 20462 | 8 | Hematite | 0.65 | 0.06 | 0.00 | 0.00 | 97.43 | 1.35 | 0.32 | 0.61 | 100.42 |
| 20462 | 10 | Hematite | 0.25 | 0.00 | 0.02 | 0.00 | 100.90 | 0.00 | 0.02 | 0.25 | 101.44 |
| 20462 | 11 | Hematite | 0.23 | 0.00 | 0.09 | 0.00 | 99.50 | 0.07 | 0.00 | 0.38 | 100.27 |
| 20462 | 13 | Hematite | 1.13 | 0.04 | 0.14 | 0.00 | 93.35 | 0.00 | 1.30 | 0.82 | 96.78 |
| 20462 | 14 | Spinel | 4.02 | 17.36 | 0.48 | 30.74 | 35.11 | 0.09 | 3.04 | 7.64 | 98.48 |
| 20462 | 15 | Ilmenite | 51.51 | 0.29 | 0.48 | 35.76 | 5.02 | 0.19 | 5.65 | 0.09 | 98.99 |
| 20462 | 16 | Ilmenite | 46.08 | 0.09 | 0.42 | 38.09 | 10.07 | 0.20 | 1.64 | 0.18 | 96.77 |
| 20462 | 17 | Hematite | 0.00 | 0.06 | 0.14 | 0.00 | 98.97 | 0.77 | 0.00 | 0.02 | 99.96 |
| 20462 | 18 | Ilmenite | 50.78 | 0.43 | 0.50 | 37.74 | 5.90 | 0.00 | 4.16 | 0.09 | 99.60 |
| 20462 | 19 | Magnetite | 6.75 | 7.37 | 0.19 | 34.84 | 41.55 | 0.13 | 1.39 | 4.58 | 96.80 |
| 20462 | 20 | Magnetite | 6.07 | 7.55 | 0.23 | 34.65 | 43.94 | 0.08 | 1.25 | 4.11 | 97.88 |
| | | | | | | | | | | | |
| 20474 | 9 | Ilmenite | 50.19 | 0.24 | 0.44 | 37.09 | 5.52 | 0.07 | 4.26 | 0.07 | 97.88 |
| 20474 | 10 | Spinel | 3.79 | 14.13 | 0.32 | 29.78 | 41.65 | 0.16 | 3.89 | 6.87 | 100.59 |
| 20474 | 11 | Ilmenite | 53.54 | 0.27 | 0.58 | 29.41 | 9.57 | 0.06 | 10.18 | 0.10 | 103.71 |
| | | | | | | | | | | | |
| 20483 | 1 | Ilmenite | 48.04 | 0.11 | 0.49 | 35.66 | 11.72 | 0.00 | 3.95 | 0.19 | 100.16 |
| 20483 | 2 | Ilmenite | 48.48 | 0.11 | 0.35 | 37.93 | 9.49 | 0.02 | 2.98 | 0.00 | 99.36 |
| 20483 | 3 | Ilmenite | 47.37 | 0.20 | 0.33 | 37.75 | 9.90 | 0.00 | 2.53 | 0.11 | 98.19 |
| 20483 | 3 | Ilmenite | 48.43 | 0.25 | 0.30 | 38.50 | 9.57 | 0.05 | 2.66 | 0.05 | 99.81 |
| 20483 | 4 | Ilmenite | 48.04 | 0.16 | 0.34 | 36.83 | 10.91 | 0.05 | 3.38 | 0.05 | 99.76 |
| 20483 | 5 | Ilmenite | 48.39 | 0.01 | 0.65 | 42.40 | 6.01 | 0.04 | 0.76 | 0.09 | 98.35 |
| 20483-02 | 2 | Spinel | 4.73 | 24.14 | 0.28 | 28.51 | 18.11 | 0.00 | 6.31 | 17.02 | 99.10 |

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20483-02 | 3 | Ilmenite | 50.70 | 0.21 | 0.29 | 41.80 | 6.12 | 0.04 | 1.96 | 0.12 | 101.24 |
| 20483-02 | 4 | Orthopyroxene | 0.14 | 0.09 | 0.43 | 17.31 | 0.00 | 52.18 | 23.96 | 1.10 | 95.21 |
| 20483-02 | 5 | Spinel | 4.59 | 25.90 | 0.43 | 26.52 | 16.92 | 0.05 | 7.50 | 17.31 | 99.22 |
| 20483-02 | 6 | Spinel | 0.40 | 44.93 | 1.91 | 15.39 | 5.83 | 0.22 | 10.23 | 15.59 | 94.50 |
| 20483-02 | 7 | Chromite | 5.42 | 24.37 | 0.17 | 28.31 | 19.44 | | 6.44 | 14.15 | 98.30 |
| 20483-02 | 8 | Spinel | 5.17 | 1.09 | 0.15 | 28.35 | 40.11 | 0.63 | 7.39 | 19.68 | 102.57 |
| 20483-02 | 9 | Orthopyroxene | 0.30 | 0.07 | 0.41 | 19.88 | 0.00 | 53.54 | 24.67 | 1.00 | 99.87 |
| 20483-02 | 10 | Magnetite | 10.82 | 2.14 | 0.27 | 38.42 | 40.45 | 0.20 | 0.96 | 2.45 | 95.71 |
| 20483-02 | 10 | Ilmenite | 10.82 | 2.14 | 0.27 | 7.74 | 74.71 | 0.20 | 0.96 | 2.45 | 99.29 |
| 20483-02 | 11 | Ilmenite | 10.39 | 2.16 | 0.25 | 7.45 | 76.09 | 0.22 | 0.92 | 2.16 | 99.64 |
| 20483-02 | 11 | Magnetite | 10.39 | 2.16 | 0.25 | 38.15 | 41.91 | 0.22 | 0.92 | 2.16 | 96.16 |
| 20483-02 | 12 | Ilmenite | 52.43 | 0.07 | 0.88 | 31.55 | 7.18 | 0.07 | 8.25 | 0.18 | 100.61 |
| | | | | | | | | | | | |
| 20494 | 1 | Magnetite | 7.59 | 4.03 | 0.16 | 37.66 | 46.44 | 0.00 | 0.77 | 3.95 | 100.60 |
| 20494 | 2 | Ilmenite | 47.63 | 0.13 | 0.44 | 40.49 | 8.90 | 0.04 | 1.06 | 0.15 | 98.84 |
| 20494 | 3 | Chromite | 2.68 | 26.61 | 0.19 | 24.23 | 16.90 | 1.00 | 7.73 | 18.75 | 98.09 |
| 20494 | 4 | Chromite | 4.13 | 25.19 | 0.43 | 28.86 | 19.40 | 0.00 | 5.97 | 16.88 | 100.86 |
| 20494 | 5 | Chromite | 4.44 | 26.14 | 0.47 | 29.54 | 18.21 | 0.11 | 5.81 | 16.82 | 101.54 |
| 20494 | 6 | Chromite | 3.03 | 27.70 | 0.36 | 27.72 | 16.45 | 0.09 | 6.13 | 18.56 | 100.04 |
| 20494 | 8 | Ilmenite | 49.76 | 0.38 | 0.00 | 35.25 | 9.30 | 0.00 | 5.33 | 0.24 | 100.26 |
| 20494 | 9 | Magnetite | 0.00 | 0.16 | 0.01 | 31.32 | 69.51 | 0.26 | 0.00 | 0.06 | 101.32 |
| 20494 | 10 | Ilmenite | 50.06 | 0.25 | 0.36 | 38.52 | 7.02 | 0.14 | 3.44 | 0.09 | 99.88 |
| | | | | | | | | | | | |
| 20515-01-2 | 1 | Magnetite | 4.02 | 3.02 | 0.17 | 33.80 | 55.00 | 0.00 | 0.21 | 1.40 | 97.62 |
| 20515-01-2 | 3 | Magnetite (?) | 22.57 | 0.02 | 0.89 | 50.40 | 20.50 | 0.24 | 0.04 | 2.21 | 96.87 |
| 20515-01-2 | 3 | Ilmenite | 22.57 | 0.02 | 0.89 | 19.30 | 55.10 | 0.24 | 0.04 | 2.21 | 100.37 |
| 20515-01-2 | 4 | Ilmenite | 19.07 | 0.02 | 0.17 | 15.90 | 61.80 | 0.11 | 0.60 | 2.67 | 100.34 |
| 20515-01-2 | 4 | Magnetite | 19.07 | 0.02 | 0.17 | 47.10 | 27.10 | 0.11 | 0.60 | 2.67 | 96.84 |
| 20515-01-2 | 6 | Magnetite | 14.03 | 0.16 | 0.32 | 44.60 | 41.80 | 0.16 | 0.20 | 1.73 | 103.00 |
| 20515-01-2 | 8 | Hematite | 0.01 | 0.04 | 0.00 | 0.00 | 100.30 | 0.46 | 0.05 | 0.06 | 100.92 |
| 20515-01-2 | 10 | Ilmenite | 17.29 | 0.24 | 0.24 | 15.10 | 65.80 | 0.80 | 0.11 | 1.17 | 100.75 |
| 20515-01-2 | 10 | Magnetite | 17.29 | 0.24 | 0.24 | 45.80 | 31.60 | 0.80 | 0.11 | 1.17 | 97.25 |
| 20515-01-3 | 1 | Hematite | 0.14 | 0.00 | 0.00 | 0.00 | 100.20 | 0.51 | 0.18 | 0.02 | 101.05 |
| 20515-01-3 | 2 | Magnetite | 0.27 | 0.00 | 0.07 | 31.44 | 69.28 | 0.34 | 0.05 | 0.00 | 101.45 |
| 20515-01-3 | 3 | Magnetite | 18.65 | 0.00 | 0.41 | 45.50 | 28.90 | 0.06 | 1.54 | 2.86 | 97.92 |
| 20515-01-3 | 3 | Ilmenite | 18.65 | 0.00 | 0.41 | 13.61 | 64.30 | 0.06 | 1.54 | 2.86 | 101.43 |
| 20515-01-3 | 4 | Ilmenite | 49.11 | 0.00 | 0.46 | 39.80 | 7.04 | 0.26 | 2.20 | 0.16 | 99.03 |
| 20515-01-3 | 5 | Magnetite | 10.11 | 0.20 | 0.32 | 39.70 | 45.70 | 0.14 | 0.63 | 3.34 | 100.14 |
| 20515-01-4 | 3 | Magnetite | 0.07 | 0.07 | 0.18 | 31.51 | 70.72 | 0.11 | 0.16 | 0.09 | 102.91 |
| 20515-01-4 | 4 | Ilmenite | 51.79 | 0.09 | 0.56 | 44.80 | 4.16 | 0.00 | 0.65 | 0.00 | 102.05 |
| 20515-01-5 | 1 | Hematite | 0.00 | 0.13 | 0.07 | 0.00 | 99.90 | 0.04 | 0.00 | 0.00 | 100.14 |
| 20515-01-6 | 1 | Orthopyroxene in sim | 0.00 | 0.00 | 0.65 | 25.85 | 0.00 | 51.55 | 21.72 | 0.76 | 100.53 |
| 20515-01-6 | 2 | Magnetite in simplec | 6.42 | 0.00 | 0.30 | 37.00 | 55.71 | 0.38 | 0.51 | 2.32 | 102.64 |
| 20515-01-6 | 3 | Magnetite | 14.82 | 0.13 | 0.24 | 36.60 | 43.00 | 0.06 | 1.25 | 3.31 | 99.41 |
| 20515-02-1 | 6 | Ilmenite | 46.91 | 0.00 | 0.36 | 37.01 | 7.65 | 0.07 | 2.70 | 0.13 | 94.83 |

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20515-02-1 | 7 | Ilmenite | 46.33 | 0.10 | 0.54 | 37.82 | 6.69 | 0.00 | 1.85 | 0.12 | 93.45 |
| 20515-02-1 | 8 | Ilmenite | 45.19 | 0.05 | 0.43 | 34.37 | 10.60 | 0.00 | 3.27 | 0.12 | 94.03 |
| 20515-02-1 | 11 | Ilmenite | 47.36 | 0.00 | 0.71 | 39.78 | 5.75 | 0.07 | 1.17 | 0.10 | 94.94 |
| 20515-02-1 | 12 | Ilmenite | 47.35 | 0.13 | 0.38 | 39.04 | 5.07 | 0.00 | 1.77 | 0.02 | 93.76 |
| 20515-02-1 | 13 | Ilmenite | 47.67 | 0.02 | 0.41 | 39.06 | 3.53 | 0.00 | 1.90 | 0.13 | 92.72 |
| 20515-02-1 | 14 | Ilmenite | 48.36 | 0.11 | 0.41 | 38.40 | 4.66 | 0.11 | 2.62 | 0.11 | 94.78 |
| 20515-02-1 | 15 | Ilmenite | 10.64 | 0.00 | 0.31 | 9.15 | 76.11 | 0.16 | 0.06 | 0.06 | 96.49 |
| 20515-02-1 | 15 | Magnetite | 10.64 | 0.00 | 0.31 | 38.34 | 43.61 | 0.16 | 0.06 | 0.06 | 93.18 |
| 20515-02-1 | 16 | Ilmenite | 48.59 | 0.00 | 0.56 | 40.10 | 5.26 | 0.12 | 1.70 | 0.05 | 96.38 |
| 20515-02-2 | 1 | Ilmenite | 50.78 | 0.11 | 0.54 | 43.42 | 1.22 | 0.00 | 0.95 | 0.04 | 97.06 |
| 20515-02-2 | 2 | Ilmenite | 49.70 | 0.00 | 0.53 | 42.71 | 1.66 | 0.00 | 0.81 | 0.09 | 95.50 |
| 20515-02-2 | 3 | Ilmenite | 47.24 | 0.00 | 0.61 | 41.13 | 4.36 | 0.02 | 0.41 | 0.05 | 93.82 |
| 20515-02-2 | 4 | Ilmenite | 47.59 | 0.00 | 0.42 | 41.23 | 3.70 | 0.17 | 0.64 | 0.00 | 93.75 |
| 20515-02-2 | 5 | Ilmenite | 49.77 | 0.09 | 0.46 | 39.28 | 3.93 | 0.05 | 2.81 | 0.04 | 96.43 |
| 20515-02-2 | 6 | Ilmenite | 49.18 | 0.29 | 0.41 | 38.75 | 4.00 | 0.07 | 2.84 | 0.12 | 95.66 |
| 20541 | | Orthopyroxene sim | 0.34 | 0.08 | 0.33 | 18.23 | 0.00 | 50.93 | 27.40 | 0.68 | 97.99 |
| 20541 | | Magnetite simplectit | 4.17 | 5.96 | 0.11 | 32.68 | 48.36 | 1.46 | 1.06 | 3.76 | 97.56 |
| 20541 | 4 | Magnetite | 5.36 | 7.37 | 0.38 | 33.03 | 42.96 | 0.11 | 1.07 | 4.13 | 94.41 |
| 20541 | 5 | Hematite | 0.02 | 0.00 | 0.00 | 0.00 | 96.62 | 0.70 | 0.20 | 0.07 | 97.61 |
| 20541 | 12 | Spinel | 5.33 | 27.13 | 0.46 | 29.89 | 18.58 | 0.07 | 4.98 | 12.05 | 98.49 |
| 20546 | 3 | Magnetite w sp lam | 2.77 | 7.53 | 0.23 | 31.40 | 49.50 | 0.00 | 1.06 | 3.91 | 96.40 |
| 20546 | 4 | Magnetite w il lam | 17.51 | 0.13 | 0.33 | 48.00 | 36.14 | 0.10 | 0.03 | 0.87 | 103.11 |
| 20546 | 6 | Ilmenite | 49.21 | 0.27 | 0.44 | 38.58 | 6.70 | 0.40 | 2.93 | 0.05 | 98.58 |
| 20546 | 7 | Ilmenite | 49.05 | 0.48 | 0.43 | 38.11 | 6.91 | 0.00 | 3.12 | 0.04 | 98.14 |
| 20546 | 8 | Ilmenite | 52.40 | 0.23 | 0.60 | 40.31 | 2.41 | 0.17 | 3.48 | 0.00 | 99.60 |
| 20546 | 9 | Ilmenite | 49.27 | 0.43 | 0.40 | 36.52 | 8.45 | 0.24 | 4.14 | 0.10 | 99.55 |
| 20546 | 10 | Magnetite with hemat | 0.09 | 0.08 | 0.13 | 30.00 | 66.40 | 0.18 | 0.00 | 0.15 | 97.03 |
| 20546 | 11 | Hematite | 0.10 | 0.09 | 0.00 | 0.00 | 98.04 | 0.18 | 0.00 | 0.18 | 98.59 |
| 20546 | 12 | Ilmenite | 47.60 | 0.01 | 4.00 | 38.60 | 6.36 | 0.00 | 0.09 | 0.13 | 96.79 |
| 20546 | 13 | Ilmenite | 47.70 | 0.18 | 0.53 | 37.30 | 7.85 | 0.15 | 2.83 | 0.10 | 96.64 |
| 20546 | 14 | Spinel | 7.66 | 21.34 | 0.40 | 32.87 | 20.91 | 0.15 | 3.32 | 8.43 | 95.08 |
| 20546 | 16 | Spinel | 4.64 | 20.80 | 0.30 | 32.82 | 31.42 | 0.02 | 2.53 | 7.60 | 100.13 |
| 20546 | 17 | Ilmenite | 49.35 | 0.20 | 0.46 | 35.28 | 7.07 | 0.13 | 4.84 | 0.05 | 97.38 |
| 20567 | 9 | Ilmenite | 54.71 | 0.25 | 0.37 | 34.87 | 3.21 | 0.11 | 7.83 | 0.17 | 101.52 |
| 20567 | 10 | Spinel | 2.55 | 32.30 | 0.30 | 26.68 | 14.54 | 0.14 | 6.61 | 17.57 | 100.69 |
| 20567 | 11 | Ilmenite | 53.14 | 0.30 | 0.54 | 39.63 | 4.77 | 0.02 | 4.27 | 0.13 | 102.80 |
| 20567 | 12 | Ilmenite | 53.02 | 0.23 | 0.55 | 38.81 | 4.83 | 0.08 | 4.66 | 0.10 | 102.28 |
| 20567 | 14 | Spinel | 2.02 | 24.34 | 0.10 | 22.31 | 15.02 | 0.11 | 10.48 | 27.26 | 101.64 |
| 20567 | 15 | Ilmenite | 56.69 | 1.20 | 0.50 | 31.45 | 2.91 | 0.00 | 10.67 | 0.23 | 103.65 |
| 20567 | 17 | Chromite | 8.65 | 21.43 | 0.29 | 32.55 | 25.58 | 0.13 | 5.82 | 8.58 | 103.03 |
| 20567 | 18 | Magnetite | 4.35 | 1.51 | 0.17 | 35.00 | 57.90 | 0.04 | 0.26 | 1.56 | 100.79 |
| 20567-02-4 | 1 | Ilmenite | 46.02 | 0.00 | 0.78 | 40.09 | 12.02 | 0.09 | 0.28 | 0.04 | 99.32 |

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20567-02-4 | 2 | Ilmenite | 45.30 | 0.04 | 0.80 | 39.48 | 12.79 | 0.04 | 0.25 | 0.00 | 98.70 |
| 20567-02-4 | 3 | Ilmenite | 46.80 | 0.04 | 0.83 | 40.62 | 11.88 | 0.09 | 0.35 | 0.07 | 100.68 |
| 20567-02-4 | 4 | Ilmenite | 46.41 | 0.01 | 0.80 | 40.39 | 11.92 | 0.09 | 0.30 | 0.05 | 99.97 |
| 20567-02-5 | 1 | Magnetite | 6.25 | 6.11 | 0.33 | 35.33 | 44.85 | 0.06 | 0.93 | 4.34 | 98.20 |
| 20567-02-5 | 2 | Magnetite | 6.03 | 5.76 | 0.29 | 34.62 | 44.96 | 0.08 | 1.25 | 4.72 | 97.65 |
| 20567-02-6 | 6 | Chromite | 5.30 | 13.07 | 0.34 | 32.83 | 38.87 | 0.10 | 2.62 | 6.64 | 99.77 |
| 20567-02-6 | 6 | Chromite | 5.15 | 13.01 | 0.27 | 32.64 | 39.75 | 0.00 | 2.73 | 6.42 | 99.97 |
| 20567-02-6 | 6 | Chromite | 5.30 | 13.54 | 0.32 | 33.02 | 39.31 | 0.09 | 2.68 | 6.44 | 100.70 |
| 20567-02-8 | | Magnetite | 4.10 | 7.82 | 0.30 | 32.30 | 48.86 | 0.10 | 1.43 | 3.04 | 97.95 |
| 20567-03 | 1 | Ilmenite | 48.03 | 0.03 | 0.46 | 39.44 | 9.65 | 0.10 | 1.84 | 0.09 | 99.64 |
| 20567-03 | 2 | Magnetite | 16.06 | 4.23 | 0.30 | 28.90 | 43.60 | 0.38 | 1.87 | 4.73 | 100.07 |
| 20567-03 | 2 | Ilmenite | 16.06 | 4.23 | 0.30 | 10.80 | 65.36 | 0.38 | 1.87 | 4.73 | 103.73 |
| 20567-03 | 3 | Spinel | 4.39 | 27.61 | 0.34 | 30.65 | 21.67 | 0.08 | 4.08 | 10.77 | 99.59 |
| 20567-03 | 3 | Spinel | 4.39 | 26.84 | 0.43 | 30.83 | 22.75 | 0.15 | 3.88 | 10.48 | 99.75 |
| 20591 | 1 | Ilmenite | 48.88 | 0.03 | 0.53 | 42.94 | 6.68 | 0.13 | 0.27 | 0.00 | 99.46 |
| 20591 | 2 | Magnetite | 7.33 | 0.09 | 0.22 | 36.97 | 50.22 | 0.19 | 0.34 | 2.87 | 98.23 |
| 20591 | 3 | Quartz | 0.11 | 0.00 | 0.00 | 0.68 | 0.00 | 97.91 | 0.00 | 0.49 | 99.19 |
| 20591 | 5 | Magnetite | 4.91 | 2.63 | 0.00 | 34.64 | 55.70 | 0.14 | 0.92 | 1.70 | 100.64 |
| 20591 | 6 | Orthopyroxene | 0.05 | 0.00 | 0.35 | 31.52 | 0.00 | 37.19 | 33.50 | 0.00 | 102.61 |
| 20591 | 7 | Ilmenite | 51.01 | 0.03 | 0.55 | 42.25 | 3.76 | 0.10 | 1.72 | 0.02 | 99.44 |
| 20591 | 8 | Ilmenite | 51.61 | 0.00 | 0.61 | 45.17 | 1.31 | 0.08 | 0.35 | 0.02 | 99.15 |
| 20591 | 12 | Magnetite | 5.21 | 6.19 | 0.17 | 34.47 | 47.95 | 0.07 | 1.13 | 4.02 | 99.21 |
| 20873 | 1 | Ilmenite | 49.96 | 0.00 | 0.37 | 40.99 | 5.64 | 0.00 | 2.00 | 0.12 | 99.08 |
| 20873 | 3 | Ilmenite | 49.71 | 0.48 | 0.43 | 40.84 | 6.14 | 0.20 | 1.92 | 0.04 | 99.76 |
| 20873 | 4 | Magnetite | 6.16 | 0.30 | 0.18 | 36.28 | 52.24 | 0.19 | 0.02 | 2.59 | 97.96 |
| 20873 | 5 | Ilmenite | 50.14 | 0.13 | 0.96 | 43.51 | 4.47 | 0.08 | 0.34 | 0.00 | 99.63 |
| 20873 | 6 | Ilmenite | 49.04 | 0.20 | 0.44 | 41.10 | 6.51 | 0.05 | 1.43 | 0.00 | 98.77 |
| 20873 | 7 | Hematite | 0.07 | 0.00 | 0.09 | 0.00 | 96.73 | 1.00 | 0.09 | 0.13 | 98.11 |
| 20873 | 8 | Hematite | 0.00 | 0.07 | 0.01 | 0.00 | 99.48 | 0.77 | 0.00 | 0.00 | 100.33 |
| 20887 | 2 | Ilmenite | 49.77 | 0.00 | 0.61 | 43.49 | 5.76 | 0.15 | 0.36 | 0.08 | 100.22 |
| 20887 | 3 | Ilmenite | 52.14 | 0.02 | 0.52 | 46.00 | 2.00 | 0.21 | 0.20 | 0.13 | 101.22 |
| 20887 | 4 | Ilmenite | 48.33 | 0.00 | 0.43 | 40.40 | 7.16 | 0.06 | 1.47 | 0.09 | 97.94 |
| 20887 | 6 | Ilmenite | 50.69 | 0.03 | 0.70 | 43.82 | 4.56 | 0.10 | 0.56 | 0.11 | 100.57 |
| 20887 | 7 | Magnetite | 6.90 | 0.35 | 0.25 | 37.31 | 50.35 | 0.11 | 0.14 | 3.74 | 99.15 |
| 20887 | 8 | Ilmenite | 51.16 | 0.11 | 0.53 | 42.92 | 3.48 | 0.05 | 1.43 | 0.05 | 99.73 |
| 20944 | 1 | Orthopyroxene | 0.00 | 0.05 | 0.04 | 38.89 | | 36.77 | 27.23 | 0.00 | 102.98 |
| 20944 | 2 | Ilmenite | 47.29 | 0.00 | 0.48 | 35.87 | 13.00 | 0.02 | 3.46 | 0.14 | 100.26 |
| 20944 | 3 | Magnetite | 13.67 | 0.09 | 0.43 | 42.60 | 39.48 | 0.38 | 0.78 | 2.94 | 100.37 |
| 20944 | 4 | Ilmenite | 36.53 | 0.11 | 1.96 | 29.99 | 31.29 | 1.86 | 0.49 | 0.66 | 102.89 |
| 20944 | 5 | Magnetite | 0.00 | 0.00 | 0.00 | 30.55 | 68.03 | 1.83 | 0.00 | 0.00 | 100.41 |
| 20944 | 6 | Ilmenite | 46.99 | 0.00 | 0.60 | 39.24 | 9.80 | 0.04 | 1.35 | 0.13 | 98.15 |

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20944 | 8 | Ilmenite | 46.84 | 0.00 | 0.39 | 39.10 | 10.21 | 0.08 | 1.47 | 0.09 | 98.18 |
| 20944 | 9 | Ilmenite | 11.53 | 0.12 | 0.00 | 9.12 | 78.03 | 0.24 | 0.70 | 3.43 | 103.17 |
| 20944 | 9 | Magnetite | 11.53 | 0.12 | 0.00 | 40.98 | 42.36 | 0.24 | 0.70 | 3.43 | 99.36 |
| 20944 | 11 | Magnetite/il lam | 5.98 | 0.00 | 0.21 | 34.60 | 52.40 | 0.00 | 0.64 | 2.30 | 96.13 |
| 20944 | 12 | Magnetite/HEM LAM | 10.96 | 0.18 | 0.29 | 39.87 | 43.10 | 0.88 | 0.59 | 2.93 | 98.80 |
| 21114 | 1 | Ilmenite | 50.74 | 0.00 | 0.28 | 44.04 | 4.43 | 0.00 | 0.73 | 0.10 | 100.32 |
| 21114 | 2 | Ilmenite | 49.67 | 0.05 | 0.54 | 43.58 | 3.58 | 0.13 | 0.30 | 0.00 | 97.85 |
| 21114 | 3 | Ilmenite | 48.85 | 0.09 | 0.49 | 43.07 | 5.50 | 0.07 | 0.20 | 0.16 | 98.43 |
| 21114 | 4 | Ilmenite | 49.78 | 0.00 | 0.67 | 43.16 | 4.68 | 0.15 | 0.52 | 0.09 | 99.05 |
| 21114 | 5 | Ilmenite | 49.09 | 0.04 | 0.56 | 40.51 | 6.00 | 0.08 | 1.72 | 0.04 | 98.04 |
| 21149 | 1 | Ilmenite | 48.88 | 0.00 | 1.36 | 42.33 | 7.13 | 0.21 | 0.14 | 0.00 | 100.05 |
| 21149 | 2 | Ilmenite | 47.15 | 0.02 | 0.48 | 40.27 | 7.89 | 0.08 | 0.92 | 0.00 | 96.81 |
| 21149 | 3 | Ilmenite | 47.90 | 0.13 | 0.46 | 39.74 | 8.97 | 0.00 | 1.61 | 0.56 | 99.37 |
| 21149 | 5 | Ilmenite | 48.29 | 0.18 | 0.49 | 38.49 | 8.29 | 0.14 | 2.49 | 0.11 | 98.48 |
| 21149 | 6 | Ilmenite | 49.23 | 0.00 | 0.56 | 43.18 | 6.00 | 0.00 | 0.29 | 0.16 | 99.42 |
| 21149 | 7 | Magnetite | 16.42 | 0.06 | 0.27 | 46.95 | 33.66 | 1.93 | 0.00 | 3.61 | 102.90 |
| 21149 | 8 | Hematite | 0.04 | 0.00 | 0.05 | 0.00 | 98.37 | 1.10 | 0.00 | 0.15 | 99.71 |
| 21197 | 1 | Ilmenite | 49.42 | 0.28 | 0.46 | 38.57 | 7.87 | 0.07 | 3.03 | 0.11 | 99.81 |
| 21197 | 2 | Ilmenite | 48.83 | 0.08 | 0.27 | 38.81 | 6.95 | 0.08 | 2.71 | 0.02 | 97.75 |
| 21197 | 3 | Ilmenite | 47.92 | 0.02 | 0.75 | 39.87 | 8.90 | 0.07 | 1.38 | 0.16 | 99.07 |
| 21197 | 4 | Magnetite | 4.57 | 4.61 | 0.19 | 33.70 | 49.80 | 0.08 | 0.81 | 3.65 | 97.41 |
| 21197 | 5 | Ilmenite | 43.93 | 2.27 | 0.63 | 31.25 | 10.66 | 0.05 | 4.27 | 6.29 | 99.35 |
| 21197 | 6 | Ilmenite | 48.68 | 0.38 | 0.44 | 39.39 | 2.65 | 0.05 | 2.21 | 4.71 | 98.51 |
| 21197 | 7 | Ilmenite | 52.19 | 0.12 | 0.59 | 38.03 | 4.12 | 0.13 | 4.66 | 0.20 | 100.04 |
| 21197 | 8 | Spinel | 0.22 | 4.95 | 0.15 | 17.75 | 4.46 | 0.08 | 15.25 | 57.25 | 100.11 |
| 21197 | 9 | Spinel | 0.20 | 5.20 | 0.08 | 17.52 | 3.97 | 0.17 | 15.11 | 56.67 | 98.92 |
| 21197 | 10 | Magnetite | 7.09 | 0.63 | 0.32 | 36.13 | 49.45 | 0.20 | 0.66 | 3.38 | 97.86 |
| 21197 | 11 | Magnetite | 9.04 | 0.61 | 0.34 | 38.04 | 45.08 | 0.09 | 0.77 | 4.21 | 98.18 |
| 21197 | 11 | Ilmenite | 9.04 | 0.61 | 0.34 | 6.41 | 80.29 | 0.09 | 0.77 | 4.21 | 101.76 |
| 21197 | 12 | Ilmenite | 48.35 | 0.11 | 0.28 | 37.53 | 7.79 | 0.04 | 3.18 | 0.13 | 97.41 |
| 21197 | 13 | Ilmenite | 48.88 | 0.00 | 0.26 | 37.77 | 7.72 | 0.16 | 3.32 | 0.14 | 98.25 |
| 21207 | 2 | Ilmenite | 49.83 | 0.23 | 0.23 | 39.39 | 5.99 | 0.07 | 2.91 | 0.18 | 98.83 |
| 21207 | 5 | Ilmenite | 49.56 | 0.04 | 2.54 | 41.92 | 3.73 | 0.07 | 0.04 | 0.08 | 97.98 |
| 21207 | 6 | Chromite | 5.77 | 17.34 | 0.23 | 33.74 | 30.65 | 0.07 | 2.17 | 7.81 | 97.78 |
| 21207 | 7 | Ilmenite | 47.76 | 0.55 | 0.51 | 38.65 | 7.09 | 0.14 | 2.12 | 0.14 | 96.96 |
| 21207 | 8 | Ilmenite | 49.23 | 0.44 | 0.50 | 39.40 | 7.22 | 0.00 | 2.45 | 0.08 | 99.32 |
| 21207 | 9 | Ilmenite | 49.29 | 0.00 | 0.43 | 40.07 | 6.12 | 0.08 | 2.14 | 0.24 | 98.37 |
| 21207 | 10 | Ilmenite | 52.20 | 0.00 | 0.15 | 45.04 | 1.19 | 0.00 | 0.98 | 0.00 | 99.56 |
| 21207 | 12 | Ilmenite | 49.76 | 0.12 | 0.30 | 40.79 | 5.57 | 0.18 | 2.05 | 0.07 | 98.84 |
| 21207 | 13 | Ilmenite | 50.29 | 0.08 | 0.48 | 37.11 | 7.03 | 0.07 | 4.28 | 0.16 | 99.50 |
| 21207 | 14 | Ilmenite | 46.70 | 0.00 | 0.44 | 38.41 | 10.91 | 0.13 | 1.76 | 0.04 | 98.39 |

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21225 | 1 | Ilmenite | 47.72 | 0.14 | 0.35 | 41.43 | 6.69 | 0.02 | 0.63 | 0.09 | 97.07 |
| 21225 | 2 | Ilmenite | 50.14 | 0.00 | 0.41 | 42.96 | 4.93 | 0.07 | 0.96 | 0.02 | 99.49 |
| 21225 | 3 | Magnetite | 9.95 | 0.13 | 0.32 | 40.61 | 48.87 | 0.19 | 0.41 | 2.50 | 102.98 |
| 21225 | 4 | Magnetite | 3.23 | 2.50 | 0.06 | 34.71 | 58.64 | 0.00 | 0.10 | 2.31 | 101.55 |
| 21225 | 5 | Ilmenite | 47.52 | 0.00 | 0.46 | 39.09 | 11.80 | 0.99 | 1.78 | 0.09 | 101.73 |
| 21225 | 7 | Magnetite | 9.04 | 0.00 | 0.16 | 39.74 | 48.85 | 0.07 | 0.28 | 3.13 | 101.27 |
| 21225 | 8 | Ilmenite | 46.84 | 0.38 | 0.32 | 37.04 | 13.42 | 0.02 | 2.67 | 0.21 | 100.90 |
| 21225 | 9 | Magnetite | 9.01 | 6.63 | 0.25 | 39.26 | 43.33 | 0.13 | 1.35 | 4.44 | 104.40 |
| 21225 | 10 | Magnetite | 8.46 | 6.16 | 0.30 | 37.42 | 42.18 | 0.05 | 1.41 | 4.49 | 100.47 |
| 21267 | 4 | Ilmenite | 48.74 | 0.08 | 0.43 | 42.52 | 7.89 | 0.16 | 0.49 | 0.13 | 100.44 |
| 21267 | 5 | Ilmenite | 50.75 | 0.00 | 0.48 | 42.92 | 6.11 | 0.27 | 1.25 | 0.19 | 101.97 |
| 21267 | 6 | Magnetite | 8.19 | 0.04 | 0.17 | 38.70 | 51.12 | 0.32 | 0.36 | 2.56 | 101.46 |
| 21267 | 7 | Ilmenite | 48.13 | 0.00 | 0.37 | 40.52 | 8.48 | 0.04 | 1.34 | 0.04 | 98.92 |
| 21267 | 8 | Magnetite | 9.06 | 0.10 | 0.15 | 39.40 | 48.69 | 0.16 | 0.50 | 3.18 | 101.24 |
| 21267 | 9 | Ilmenite | 51.77 | 0.43 | 0.26 | 41.87 | 3.48 | 0.05 | 2.48 | 0.10 | 100.44 |
| 21267 | 10 | Ilmenite | 49.79 | 0.14 | 0.69 | 43.88 | 6.72 | 0.07 | 0.11 | 0.12 | 101.52 |
| 21267 | 11 | Ilmenite | 53.58 | 0.00 | 0.25 | 47.90 | 0.79 | 0.08 | 0.01 | 0.18 | 102.79 |
| 21267 | 13 | Ilmenite | 50.53 | 0.04 | 0.34 | 42.58 | 6.69 | 0.00 | 1.41 | 0.23 | 101.82 |
| 21267 | 14 | Ilmenite | 50.45 | 0.00 | 0.36 | 42.43 | 7.20 | 0.00 | 1.44 | 0.04 | 101.92 |
| 21267 | 15 | Orthopyroxene | 0.20 | 0.01 | 0.55 | 26.49 |  | 49.48 | 21.30 | 0.72 | 98.75 |
| 21267 | 16 | Ilmenite | 49.35 | 0.00 | 0.41 | 41.54 | 8.48 | 0.16 | 1.36 | 0.13 | 101.43 |
| 21267 | 17 | Magnetite | 0.00 | 0.07 | 0.13 | 31.13 | 69.45 | 1.17 | 0.02 | 0.11 | 102.08 |
| 21267 | 18 | Ilmenite | 49.64 | 0.00 | 0.56 | 42.70 | 7.35 | 0.00 | 0.75 | 0.12 | 101.12 |
| 21267 | 19 | Magnetite | 11.75 | 0.14 | 0.30 | 42.71 | 45.49 | 0.15 | 0.29 | 2.70 | 103.53 |
| 21267 | 20 | Magnetite | 4.04 | 1.07 | 0.12 | 35.70 | 60.50 | 0.32 | 0.03 | 1.33 | 103.11 |
| 21267 | 21 | Chromite | 0.48 | 48.25 | 0.25 | 16.09 | 8.97 | 0.00 | 11.70 | 13.48 | 99.22 |
| 21307 | 1 | Ilmenite | 46.10 | 0.07 | 2.76 | 38.64 | 7.84 | 0.36 | 0.01 | 0.11 | 95.89 |
| 21307 | 2 | Ilmenite | 48.30 | 0.12 | 3.03 | 40.04 | 7.67 | 0.00 | 0.18 | 0.11 | 99.45 |
| 21307 | 3 | Ilmenite | 49.00 | 0.25 | 0.43 | 38.42 | 7.60 | 0.07 | 2.92 | 0.24 | 98.93 |
| 21307 | 4 | Magnetite | 0.13 | 0.11 | 0.07 | 30.60 | 67.50 | 0.08 | 0.00 | 0.06 | 98.55 |
| 21307 | 5 | Hematite | 0.00 | 0.02 | 0.07 | 0.00 | 98.41 | 0.08 | 0.04 | 0.09 | 98.71 |
| 21307 | 6 | Hematite | 0.00 | 0.16 | 0.08 | 0.00 | 97.28 | 0.12 | 0.02 | 0.18 | 97.84 |
| 21307 | 7 | Ilmenite | 46.80 | 0.05 | 0.31 | 38.36 | 7.90 | 0.31 | 1.91 | 0.10 | 95.74 |
| 21307 | 8 | Ilmenite | 48.57 | 0.09 | 0.43 | 39.62 | 8.55 | 0.00 | 2.03 | 0.04 | 99.33 |
| 21307 | 11 | Ilmenite | 48.68 | 0.14 | 0.48 | 38.10 | 9.06 | 0.19 | 2.91 | 0.07 | 99.63 |
| 21307 | 12 | Ilmenite | 48.61 | 0.31 | 0.25 | 39.77 | 5.93 | 0.04 | 2.07 | 0.09 | 97.07 |
| 21307 | 13 | Ilmenite | 49.73 | 0.03 | 0.33 | 38.97 | 5.91 | 0.00 | 3.04 | 0.13 | 98.14 |
| 21307 | 15 | Ilmenite | 47.00 | 0.03 | 0.42 | 37.95 | 10.79 | 0.07 | 2.18 | 0.14 | 98.58 |
| 21307 | 16 | Ilmenite | 47.54 | 0.08 | 0.45 | 39.30 | 8.42 | 0.13 | 1.68 | 0.16 | 97.76 |
| 21446 | 1 | Ilmenite | 48.28 | 0.00 | 0.97 | 42.24 | 6.77 | 2.35 | 0.11 | 0.08 | 100.80 |
| 21446 | 2 | Hematite | 0.00 | 0.14 | 0.04 |  | 97.06 | 0.98 | 0.10 | 0.06 | 98.38 |

| SAMPLE | NAME POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21446 | 3 | Magnetite | 6.05 | 0.11 | 0.82 | 35.94 | 57.18 | 0.21 | 0.01 | 0.26 | 100.58 |
| 21446 | 5 | Ilmenite | 48.64 | 0.00 | 0.45 | 40.89 | 7.28 | 0.00 | 1.34 | 0.16 | 98.76 |
| 21446 | 8 | Hematite | 12.05 | 0.30 | 0.15 | | 87.05 | 0.08 | 0.10 | 0.09 | 99.82 |
| 21446 | 9 | Ilmenite | 49.03 | 0.00 | 0.32 | 42.11 | 5.72 | 0.05 | 0.93 | 0.00 | 98.16 |
| 21446 | 10 | Chromite | 0.53 | 51.69 | 0.27 | 14.70 | 7.83 | 0.17 | 11.86 | 10.23 | 97.28 |
| 21446 | 11 | Chromite | 0.40 | 51.33 | 0.26 | 16.00 | 6.92 | 0.46 | 11.55 | 12.44 | 99.36 |
| 21446 | 12 | Ilmenite | 49.19 | 0.01 | 0.70 | 42.38 | 6.35 | 0.00 | 0.64 | 0.10 | 99.37 |
| 21446 | 13 | Magnetite | 12.98 | 0.11 | 0.17 | 41.48 | 38.83 | 0.00 | 0.97 | 3.61 | 98.15 |
| 21446 | 13 | Ilmenite | 12.98 | 0.11 | 0.17 | 9.77 | 74.14 | 0.00 | 0.97 | 3.61 | 101.75 |
| 21552 | 2 | Ilmenite | 48.19 | 0.29 | 0.41 | 40.05 | 7.60 | 0.14 | 1.61 | 0.07 | 98.36 |
| 21552 | 3 | Ilmenite | 50.17 | 0.37 | 0.34 | 42.51 | 6.47 | 0.10 | 1.27 | 0.09 | 101.32 |
| 21552 | 6 | Magnetite | 4.10 | 8.70 | 0.19 | 33.74 | 46.40 | 0.07 | 0.70 | 4.05 | 97.95 |
| 21552 | 7 | Ilmenite | 51.92 | 0.13 | 0.34 | 41.26 | 5.17 | 0.05 | 2.85 | 0.04 | 101.76 |
| 21552 | 8 | Magnetite | 8.52 | 1.05 | 0.32 | 37.24 | 48.23 | 0.08 | 0.73 | 1.97 | 98.14 |
| 21552 | 9 | Magnetite | 8.46 | 0.30 | 0.36 | 36.82 | 48.16 | 0.02 | 0.66 | 1.96 | 96.74 |
| 21552 | 10 | Magnetite | 5.02 | 0.20 | 0.13 | 34.47 | 54.18 | 0.00 | 0.71 | 3.43 | 98.14 |
| 21552 | 11 | Ilmenite | 49.06 | 0.11 | 0.21 | 40.44 | 8.09 | 0.00 | 1.94 | 0.10 | 99.95 |
| 21552 | 12 | Magnetite | 0.38 | 0.30 | 0.12 | 31.52 | 67.52 | 0.14 | 0.00 | 0.70 | 100.68 |
| 21557 | 1 | Chromite | 0.50 | 48.43 | 0.36 | 21.34 | 6.41 | 0.14 | 8.30 | 13.95 | 99.43 |
| 21557 | 2 | Ilmenite | 50.80 | 0.27 | 0.43 | 41.96 | 3.23 | 0.09 | 1.84 | 0.00 | 98.62 |
| 21557 | 3 | Ilmenite | 50.39 | 0.09 | 0.29 | 44.55 | 4.16 | 0.04 | 0.26 | 0.14 | 99.92 |
| 21557 | 4 | Ilmenite | 48.45 | 0.00 | 0.50 | 41.92 | 6.19 | 0.13 | 0.64 | 0.13 | 97.96 |
| 21557 | 5 | Ilmenite | 49.91 | 0.00 | 0.58 | 43.62 | 4.13 | 0.02 | 0.38 | 0.04 | 98.68 |
| 21557 | 6 | Ilmenite | 51.14 | 0.11 | 0.69 | 43.88 | 4.18 | 0.00 | 0.79 | 0.07 | 100.86 |
| 21557 | 7 | Magnetite | 15.88 | 0.00 | 0.96 | 43.43 | 33.37 | 0.58 | 0.27 | 1.90 | 96.39 |
| 21557 | 7 | Ilmenite | 15.88 | 0.00 | 0.96 | 12.83 | 67.44 | 0.58 | 0.27 | 1.90 | 99.86 |
| 21557 | 9 | Magnetite | 10.54 | 0.18 | 0.34 | 38.40 | 42.45 | 1.95 | 0.21 | 1.44 | 95.51 |
| 21557 | 9 | Ilmenite | 10.54 | 0.18 | 0.34 | 8.76 | 75.45 | 1.95 | 0.21 | 1.44 | 98.87 |
| 21557 | 10 | Ilmenite | 51.14 | 0.15 | 0.35 | 44.10 | 2.22 | 0.60 | 0.86 | 0.16 | 99.58 |
| 21557 | 11 | Magnetite | 2.44 | 0.08 | 0.05 | 31.62 | 60.46 | 0.00 | 1.05 | 2.79 | 98.49 |
| 21593 | 2 | Ilmenite | 49.40 | 0.03 | 0.70 | 43.34 | 6.52 | 0.13 | 0.21 | 0.00 | 100.33 |
| 21593 | 3 | Magnetite | 15.38 | 0.45 | 0.30 | 44.65 | 35.01 | 0.00 | 0.39 | 2.92 | 99.10 |
| 21593 | 4 | Ilmenite | 47.12 | 0.12 | 0.52 | 41.35 | 9.12 | 1.36 | 0.28 | 0.14 | 100.01 |
| 21593 | 7 | Magnetite | 14.54 | 0.04 | 0.39 | 43.55 | 38.90 | 0.00 | 0.51 | 1.73 | 99.66 |
| 21593 | 8 | Ilmenite | 50.29 | 0.00 | 0.71 | 43.99 | 4.57 | 0.00 | 0.29 | 0.19 | 100.04 |
| 21593 | 10 | Ilmenite | 47.73 | 0.11 | 0.49 | 41.44 | 9.23 | 0.00 | 0.55 | 0.00 | 99.55 |
| 21593 | 11 | Magnetite | 0.65 | 0.03 | 0.06 | 32.20 | 67.84 | 0.15 | 0.00 | 0.87 | 101.80 |
| 21593 | 12 | Ulvospinel | 30.60 | 0.03 | 0.06 | 44.00 | 14.50 | | 9.62 | 0.33 | 99.14 |
| 21593 | 13 | Orthopyroxene | 0.84 | 0.00 | 0.66 | 17.90 | | 52.90 | 24.80 | 0.58 | 97.68 |
| 21593 | 14 | Ilmenite | 49.27 | 0.04 | 0.58 | 42.86 | 7.43 | 0.20 | 0.48 | 0.10 | 100.96 |
| 21593 | 15 | Magnetite | 14.17 | 0.13 | 0.16 | 42.98 | 39.47 | 0.06 | 0.11 | 0.11 | 97.19 |
| 21593 | 15 | Ilmenite | 14.17 | 0.13 | 0.16 | 12.30 | 73.54 | 0.06 | 0.11 | 0.11 | 100.58 |

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21593 | 16 | Magnetite | 7.44 | 0.34 | 0.22 | 38.58 | 51.71 | 0.11 | 0.30 | 3.66 | 102.36 |
| 21593 | 17 | Ilmenite | 49.70 | 0.07 | 1.04 | 43.24 | 5.44 | 0.00 | 0.22 | 0.22 | 99.93 |
| 21641 | 2 | Ilmenite | 47.26 | 0.17 | 0.95 | 40.73 | 7.98 | 2.09 | 0.45 | 0.00 | 99.63 |
| 21641 | 4 | Ilmenite | 48.10 | 0.10 | 0.54 | 38.37 | 9.73 | 0.00 | 2.43 | 0.09 | 99.36 |
| 21641 | 9 | Magnetite | 6.87 | 0.38 | 0.34 | 35.50 | 48.80 | 0.10 | 0.58 | 3.45 | 96.02 |
| 21641 | 14 | Ilmenite | 48.38 | 0.15 | 0.29 | 38.88 | 8.09 | 0.00 | 2.43 | 0.16 | 98.38 |
| 21641 | 15 | Ilmenite | 49.93 | 0.03 | 0.51 | 43.12 | 3.78 | 2.30 | 0.71 | 0.08 | 100.46 |
| 21641 | 16 | Magnetite | 8.52 | 0.12 | 0.05 | 38.50 | 47.69 | 0.00 | 0.46 | 3.66 | 99.00 |
| 21641 | 17 | Ilmenite | 48.23 | 0.25 | 0.66 | 42.30 | 4.87 | 0.26 | 0.24 | 0.11 | 96.92 |
| 21641 | 19 | Ilmenite | 49.62 | 0.00 | 0.48 | 43.40 | 1.44 | 0.00 | 0.41 | 0.07 | 95.42 |
| 21657 | 9 | Ilmenite | 47.10 | 0.09 | 0.36 | 39.30 | 7.67 | 0.00 | 1.50 | 0.00 | 96.02 |
| 21657 | 1 | Magnetite | 0.57 | 0.97 | 0.05 | 31.58 | 54.08 | 0.00 | 0.91 | 10.63 | 98.79 |
| 21657 | 2 | Magnetite | 4.52 | 0.65 | 0.00 | 34.24 | 53.72 | 0.25 | 0.45 | 3.52 | 97.35 |
| 21657 | 3 | Ilmenite | 50.75 | 0.00 | 0.13 | 39.64 | 3.46 | 0.06 | 3.29 | 0.16 | 97.49 |
| 21657 | 4 | Hematite | 4.56 | 0.04 | 0.08 |  | 93.47 | 1.11 | 0.00 | 0.88 | 100.14 |
| 21657 | 6 | Chromite | 3.50 | 13.15 | 0.32 | 32.16 | 40.38 | 0.28 | 1.28 | 5.84 | 96.91 |
| 21657 | 8 | Chromite | 3.56 | 13.48 | 0.25 | 32.46 | 40.48 | 2.44 | 1.32 | 5.84 | 99.83 |
| 21657 | 10 | Ilmenite | 46.60 | 0.22 | 0.53 | 38.70 | 9.40 | 0.00 | 1.52 | 0.09 | 97.06 |
| 21689 | 1 | Magnetite | 2.06 | 1.02 | 0.05 | 31.80 | 57.71 | 0.04 | 0.57 | 3.95 | 97.20 |
| 21689 | 2 | Magnetite | 16.16 | 0.09 | 0.21 | 45.58 | 35.48 | 0.06 | 0.36 | 1.99 | 99.93 |
| 21689 | 4 | Ilmenite | 48.27 | 0.02 | 0.70 | 42.52 | 4.89 | 0.00 | 0.10 | 0.09 | 96.59 |
| 21689 | 5 | Ilmenite | 48.25 | 0.14 | 0.66 | 42.31 | 6.85 | 0.09 | 0.23 | 0.00 | 98.53 |
| 21689 | 6 | Ilmenite | 48.63 | 0.00 | 0.76 | 42.73 | 3.87 | 0.10 | 0.13 | 0.05 | 96.27 |
| 21698 | 1 | Ilmenite | 49.95 | 0.00 | 0.66 | 43.96 | 5.46 | 0.06 | 0.16 | 0.02 | 100.27 |
| 21698 | 2 | Ilmenite | 49.66 | 0.31 | 0.45 | 38.76 | 7.37 | 0.00 | 3.05 | 0.00 | 99.60 |
| 21698 | 3 | Chromite | 6.65 | 21.72 | 0.30 | 32.10 | 25.99 | 0.00 | 4.88 | 10.23 | 101.87 |
| 21698 | 4 | Ilmenite | 50.60 | 0.18 | 0.43 | 40.00 | 6.74 | 0.09 | 2.84 | 0.18 | 101.06 |
| 21698 | 5 | Cr-Spinel | 1.22 | 29.12 | 0.16 | 22.88 | 11.32 | 0.00 | 9.51 | 26.90 | 101.11 |
| 21698 | 6 | Ilmenite | 55.11 | 0.73 | 0.43 | 36.77 | 1.63 | 0.17 | 6.93 | 0.13 | 101.90 |
| 21698 | 7 | Magnetite | 3.29 | 7.42 | 0.17 | 32.87 | 51.38 | 0.11 | 0.93 | 3.13 | 99.30 |
| 21698 | 8 | Ilmenite | 48.71 | 0.18 | 0.41 | 37.47 | 9.66 | 0.04 | 3.32 | 0.20 | 99.99 |
| 21698 | 9 | Magnetite | 4.36 | 8.00 | 0.33 | 34.07 | 48.33 | 0.02 | 0.72 | 3.36 | 99.19 |
| 21698 | 10 | Ilmenite | 51.20 | 0.00 | 0.38 | 40.93 | 5.70 | 0.00 | 2.65 | 0.14 | 101.00 |
| 21698 | 11 | Ilmenite | 51.25 | 0.00 | 2.11 | 43.72 | 2.80 | 0.07 | 0.13 | 0.00 | 100.08 |
| 21698 | 12 | Magnetite | 3.86 | 6.83 | 0.28 | 33.03 | 51.02 | 0.00 | 1.37 | 3.79 | 100.18 |
| 21698 | 13 | Olivine | 0.13 | 0.07 | 0.26 | 25.10 | 0.00 | 37.74 | 39.41 | 0.00 | 102.71 |
| 21700 | 1 | Ilmenite | 48.91 | 0.00 | 0.54 | 38.21 | 7.19 | 0.00 | 2.93 | 0.05 | 97.83 |
| 21700 | 2 | Magnetite | 5.76 | 0.52 | 0.20 | 34.90 | 52.50 | 0.16 | 0.32 | 2.13 | 96.49 |
| 21700 | 3 | Magnetite | 5.07 | 0.59 | 0.05 | 33.90 | 52.30 | 0.00 | 0.30 | 2.38 | 94.59 |
| 21700 | 5 | Ilmenite | 50.83 | 0.08 | 0.20 | 41.35 | 5.12 | 0.13 | 2.33 | 0.16 | 100.20 |

| SAMPLE | NAME POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21700 | 6 | Chromite | 2.80 | 14.85 | 0.34 | 31.40 | 43.18 | 0.11 | 1.47 | 4.15 | 98.30 |
| 21700 | 7 | Chromite | 3.10 | 14.51 | 0.20 | 32.81 | 44.19 | 0.14 | 1.27 | 4.26 | 100.48 |
| 21700 | 8 | Ilmenite | 53.73 | 0.66 | 0.48 | 41.14 | 2.02 | 0.20 | 3.75 | 0.16 | 102.14 |
| 21700 | 9 | Ilmenite | 49.77 | 0.00 | 0.36 | 40.24 | 4.36 | 0.04 | 2.33 | 0.10 | 97.20 |
| 21700 | 10 | Magnetite | 4.87 | 6.53 | 0.25 | 34.11 | 45.88 | 0.00 | 0.64 | 4.34 | 96.62 |
| 21700 | 12 | Magnetite | 4.18 | 6.89 | 0.18 | 33.34 | 47.14 | 0.08 | 0.86 | 4.42 | 97.09 |
| 21700 | 13 | Ilmenite | 50.64 | 0.32 | 0.35 | 39.14 | 5.89 | 0.00 | 3.39 | 0.12 | 99.85 |
| 21700 | 14 | Chromite | 2.79 | 14.19 | 0.14 | 31.54 | 43.68 | 0.11 | 1.44 | 4.13 | 98.02 |
| 21700 | 15 | Magnetite | 4.48 | 7.03 | 0.27 | 33.67 | 46.02 | 0.00 | 0.80 | 4.71 | 96.98 |
| 21700 | 16 | Ilmenite | 52.52 | 0.12 | 0.57 | 41.00 | 3.76 | 0.19 | 3.17 | 0.21 | 101.54 |
| 21700 | 17 | Ilmenite | 50.51 | 0.04 | 0.34 | 44.59 | 6.51 | 0.07 | 0.27 | 0.11 | 102.44 |
| 21702 | 1 | Chromite | 6.54 | 15.69 | 0.35 | 33.72 | 33.74 | 0.05 | 2.49 | 5.94 | 98.52 |
| 21702 | 2 | Chromite | 6.09 | 12.25 | 0.28 | 34.38 | 39.64 | 0.07 | 2.01 | 5.26 | 99.98 |
| 21702 | 4 | Ilmenite | 52.05 | 0.18 | 0.79 | 38.41 | 4.01 | 0.21 | 4.26 | 0.14 | 100.05 |
| 21702 | 5 | Magnetite | 3.71 | 0.88 | 0.03 | 31.47 | 52.80 | 0.00 | 3.01 | 8.62 | 100.52 |
| 21702 | 6 | Magnetite | 4.98 | 0.92 | 0.19 | 33.14 | 53.99 | 0.00 | 1.49 | 3.34 | 98.05 |
| 21702 | 7 | Chromite | 4.48 | 15.79 | 0.32 | 33.46 | 38.88 | 0.00 | 1.84 | 5.80 | 100.57 |
| 21702 | 8 | Chromite | 5.41 | 16.90 | 0.13 | 34.13 | 35.21 | 0.04 | 2.12 | 6.41 | 100.35 |
| 21702 | 9 | Chromite | 6.34 | 15.50 | 0.33 | 34.37 | 34.03 | 0.03 | 2.17 | 6.48 | 99.25 |
| 21702 | 10 | Ilmenite | 49.92 | 0.20 | 0.35 | 39.21 | 7.99 | 0.09 | 2.99 | 0.04 | 100.79 |
| 21702 | 11 | Chromite | 4.32 | 12.04 | 0.36 | 32.18 | 43.15 | 0.00 | 2.26 | 5.31 | 99.62 |
| 21702 | 12 | Chromite | 4.16 | 11.64 | 0.33 | 31.93 | 43.90 | 0.00 | 2.34 | 5.31 | 99.61 |
| 21702 | 13 | Chromite | 3.69 | 18.34 | 0.37 | 32.49 | 35.93 | 0.07 | 1.75 | 6.46 | 99.10 |
| 21702 | 14 | Ilmenite | 45.83 | 0.15 | 0.44 | 37.25 | 13.04 | 0.06 | 1.97 | 0.09 | 98.83 |
| 21724 | 1 | Ilmenite | 48.82 | 0.00 | 1.02 | 42.47 | 6.76 | 0.05 | 0.22 | 0.02 | 99.36 |
| 21724 | 2 | Magnetite | 7.36 | 0.15 | 0.24 | 35.69 | 53.30 | 0.21 | 1.91 | 2.97 | 101.83 |
| 21724 | 3 | Orthopyroxene | 0.04 | 0.00 | 0.43 | 27.95 |  | 34.13 | 35.98 | 0.02 | 98.55 |
| 21724 | 4 | Ilmenite | 46.95 | 0.05 | 0.53 | 38.05 | 10.02 | 0.00 | 2.04 | 0.05 | 97.69 |
| 21724 | 6 | Ilmenite | 46.98 | 0.00 | 0.48 | 37.73 | 10.07 | 0.00 | 2.27 | 0.08 | 97.61 |
| 21724 | 7 | Hematite | 6.34 | 0.63 | 0.00 |  | 88.54 | 0.52 | 0.02 | 1.05 | 97.10 |
| 21724 | 8 | Hematite | 1.41 | 0.52 | 0.00 |  | 95.90 | 0.04 | 0.16 | 0.82 | 98.85 |
| 21724 | 9 | Magnetite | 5.46 | 4.18 | 0.23 | 35.22 | 51.57 | 0.08 | 0.54 | 2.07 | 99.35 |
| 21724 | 11 | Ilmenite | 47.63 | 0.14 | 0.36 | 38.22 | 9.66 | 0.04 | 2.38 | 0.07 | 98.50 |
| 21724 | 12 | Ilmenite | 47.99 | 0.22 | 0.42 | 36.97 | 10.47 | 0.07 | 3.23 | 0.04 | 99.41 |
| 21728 | 1 | Ilmenite | 48.74 | 0.18 | 0.31 | 37.44 | 9.44 | 0.00 | 3.41 | 0.08 | 99.60 |
| 21728 | 2 | Ilmenite | 47.05 | 0.20 | 0.44 | 38.46 | 10.08 | 0.34 | 1.91 | 0.00 | 98.48 |
| 21728 | 3 | Magnetite | 7.86 | 4.51 | 0.21 | 37.51 | 44.97 | 0.15 | 1.01 | 4.34 | 100.56 |
| 21728 | 4 | Ilmenite | 46.43 | 0.17 | 0.41 | 32.25 | 13.22 | 0.18 | 5.10 | 0.14 | 97.90 |
| 21728 | 5 | Ilmenite | 49.12 | 0.18 | 0.38 | 34.35 | 11.88 | 0.00 | 5.29 | 0.12 | 101.32 |
| 21728 | 6 | Ilmenite | 47.79 | 0.52 | 0.37 | 36.48 | 10.49 | 0.00 | 3.43 | 0.23 | 99.31 |
| 21728 | 7 | Magnetite | 6.02 | 0.56 | 0.20 | 34.80 | 51.31 | 0.11 | 0.51 | 2.52 | 96.03 |
| 21728 | 8 | Magnetite | 1.77 | 0.19 | 0.00 | 32.94 | 65.05 | 0.21 | 0.18 | 1.10 | 101.44 |

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21730 | 1 | Magnetite | 5.49 | 0.65 | 0.12 | 34.37 | 52.84 | 0.08 | 0.83 | 2.93 | 97.31 |
| 21730 | 2 | Chromite | 5.13 | 13.38 | 0.11 | 34.19 | 36.27 | 0.04 | 1.25 | 6.66 | 97.03 |
| 21730 | 3 | Chromite | 5.57 | 14.25 | 0.34 | 34.62 | 35.78 | 0.18 | 1.42 | 6.63 | 98.79 |
| 21730 | 4 | Magnetite | 9.95 | 1.84 | 0.34 | 38.84 | 44.54 | 0.00 | 0.93 | 2.94 | 99.38 |
| 21730 | 5 | Ilmenite | 49.25 | 0.05 | 0.34 | 43.66 | 5.46 | 0.00 | 0.16 | 0.02 | 98.94 |
| 21730 | 6 | Ilmenite | 51.21 | 0.00 | 0.48 | 40.29 | 6.71 | 0.05 | 2.96 | 0.05 | 101.75 |
| 21730 | 7 | Ilmenite | 50.66 | 0.13 | 0.39 | 40.19 | 6.13 | 0.11 | 2.79 | 0.12 | 100.52 |
| 21730 | 8 | Magnetite | 4.72 | 4.66 | 0.12 | 34.02 | 51.68 | 0.00 | 0.89 | 2.60 | 98.69 |
| 21730 | 9 | Ilmenite | 51.51 | 0.26 | 0.37 | 40.01 | 4.59 | 0.00 | 3.33 | 0.08 | 100.15 |
| 21730 | 10 | Ilmenite | 51.02 | 0.04 | 0.52 | 43.07 | 3.19 | 0.00 | 1.28 | 0.08 | 99.20 |
| 21730 | 11 | Magnetite | 3.43 | 1.09 | 0.36 | 33.53 | 58.31 | 1.02 | 0.03 | 1.53 | 99.30 |
| 21730 | 12 | Ilmenite | 49.81 | 0.09 | 0.56 | 42.85 | 5.95 | 0.06 | 0.77 | 0.00 | 100.09 |
| 21750 | 1 | Magnetite | 6.87 | 4.50 | 0.17 | 35.32 | 45.43 | 0.04 | 1.04 | 3.50 | 96.87 |
| 21750 | 2 | Magnetite | 6.39 | 4.55 | 0.38 | 35.36 | 49.43 | 0.09 | 1.39 | 3.66 | 101.25 |
| 21750 | 3 | Ilmenite | 47.18 | 0.00 | 0.40 | 35.82 | 10.84 | 0.00 | 3.48 | 0.24 | 97.96 |
| 21750 | 4 | Ilmenite | 48.22 | 0.09 | 0.38 | 37.43 | 8.66 | 0.16 | 3.11 | 0.08 | 98.13 |
| 21750 | 5 | Ilmenite | 48.77 | 0.12 | 0.41 | 37.49 | 7.07 | 0.07 | 3.34 | 0.16 | 97.43 |
| 21750 | 6 | Ilmenite | 50.21 | 0.14 | 0.34 | 40.99 | 7.33 | 0.04 | 2.14 | 0.14 | 101.33 |
| 21750 | 7 | Ilmenite | 49.18 | 0.12 | 0.34 | 37.43 | 8.22 | 0.07 | 3.62 | 0.13 | 99.11 |
| 21750 | 8 | Ilmenite | 51.55 | 0.12 | 0.50 | 42.64 | 5.94 | 0.04 | 1.80 | 0.13 | 102.72 |
| 21750 | 9 | Ilmenite | 50.81 | 0.04 | 0.50 | 41.47 | 6.89 | 0.10 | 2.08 | 0.09 | 101.98 |
| 21750 | 10 | Ilmenite | 50.52 | 0.21 | 0.21 | 41.69 | 7.41 | 0.09 | 1.98 | 0.13 | 102.24 |
| 21750 | 11 | Ilmenite | 50.38 | 0.02 | 0.28 | 41.44 | 6.78 | 0.04 | 2.01 | 0.11 | 101.06 |
| 21750 | 12 | Ilmenite | 49.82 | 0.09 | 0.29 | 40.71 | 8.33 | 0.05 | 2.13 | 0.18 | 101.60 |
| 21750 | 13 | Ilmenite | 51.71 | 0.06 | 0.45 | 39.71 | 6.99 | 0.02 | 3.55 | 0.14 | 102.63 |
| 21750 | 14 | Ilmenite | 50.80 | 0.00 | 0.41 | 41.86 | 5.60 | 0.13 | 1.91 | 0.08 | 100.79 |
| 21750 | 15 | Ilmenite | 51.00 | 0.20 | 0.56 | 38.86 | 5.48 | 0.10 | 3.61 | 0.09 | 99.90 |
| 21750 | 16 | Ilmenite | 51.50 | 0.13 | 0.46 | 39.87 | 5.53 | 0.00 | 3.35 | 0.05 | 100.89 |
| 21752 | 3 | Ilmenite | 50.51 | 0.02 | 0.39 | 42.55 | 5.51 | 0.10 | 1.39 | 0.16 | 100.63 |
| 21752 | 4 | Ilmenite | 49.14 | 0.33 | 0.38 | 36.85 | 10.49 | 0.19 | 3.90 | 0.02 | 101.30 |
| 21752 | 6 | Magnetite | 6.88 | 0.84 | 0.12 | 37.26 | 52.12 | 0.09 | 0.79 | 3.71 | 101.81 |
| 21752 | 7 | Chromite | 5.29 | 13.80 | 0.33 | 34.34 | 37.95 | 0.02 | 1.51 | 6.09 | 99.33 |
| 21752 | 8 | Chromite | 4.83 | 13.91 | 0.23 | 34.34 | 39.13 | 0.02 | 1.39 | 5.98 | 99.83 |
| 21752 | 9 | Chromite | 5.01 | 14.37 | 0.27 | 34.48 | 38.87 | 0.02 | 1.60 | 6.17 | 100.79 |
| 21752 | 10 | Ilmenite | 49.80 | 0.11 | 0.39 | 40.34 | 7.54 | 0.05 | 2.27 | 0.05 | 100.55 |
| 21752 | 11 | Magnetite | 2.24 | 2.80 | 0.11 | 33.48 | 61.34 | 0.11 | 0.20 | 1.49 | 101.77 |
| 21752 | 12 | Magnetite | 5.99 | 1.65 | 0.17 | 35.76 | 52.44 | 0.13 | 0.78 | 3.15 | 100.07 |
| 21752 | 13 | Ilmenite | 48.97 | 0.17 | 0.26 | 38.67 | 8.60 | 0.00 | 2.86 | 0.04 | 99.57 |
| 21752 | 14 | Ilmenite | 49.92 | 0.05 | 0.50 | 40.30 | 8.47 | 0.00 | 2.29 | 0.24 | 101.77 |
| 21752 | 15 | Ilmenite | 51.55 | 0.27 | 0.32 | 40.33 | 5.82 | 0.36 | 3.20 | 0.23 | 102.08 |
| 21752 | 16 | Ilmenite | 49.57 | 0.00 | 0.36 | 42.68 | 7.18 | 0.16 | 0.86 | 0.04 | 100.85 |
| 21752 | 17 | Ilmenite | 49.58 | 0.00 | 0.38 | 41.45 | 8.44 | 0.11 | 1.54 | 0.14 | 101.64 |

| SAMPLE NAME | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21766 | 1 | Chromite | 2.38 | 26.31 | 0.16 | 26.94 | 11.92 | 0.23 | 7.22 | 25.41 | 100.57 |
| 21766 | 2 | Chromite | 4.32 | 14.59 | 0.45 | 29.81 | 38.54 | 0.10 | 3.00 | 5.17 | 95.98 |
| 21766 | 3 | Chromite | 15.17 | 22.55 | 0.36 | 37.16 | 0.00 | 0.04 | 6.25 | 16.06 | 97.59 |
| 21766 | 4 | Chromite | 3.77 | 20.81 | 0.25 | 30.06 | 31.40 | 0.16 | 3.60 | 8.54 | 98.59 |
| 21766 | 5 | Ilmenite | 51.02 | 0.62 | 0.41 | 34.95 | 2.96 | 0.08 | 5.90 | 0.00 | 95.94 |
| 21766 | 8 | Chromite | 1.46 | 25.23 | 0.30 | 27.04 | 20.22 | 0.07 | 5.44 | 19.03 | 98.79 |
| 21766 | 9 | Chromite | 1.14 | 29.37 | 0.40 | 26.38 | 15.63 | 0.04 | 6.06 | 20.77 | 99.79 |
| 21766 | 10 | Chromite | 2.95 | 27.66 | 0.13 | 24.46 | 13.29 | 0.15 | 8.09 | 20.81 | 97.54 |
| 21766 | 11 | Chromite | 3.49 | 23.87 | 0.25 | 22.13 | 9.27 | 0.00 | 11.04 | 28.86 | 98.91 |
| 21766 | 12 | Ilmenite | 48.12 | 0.21 | 0.38 | 37.75 | 4.14 | 0.27 | 2.88 | 0.05 | 93.80 |

Table 3: Average Chemical Analysis of Ilmenite

| | 1 | 2 |
|---|---|---|
| $TiO_2$ | 49.14 | 53.30 |
| $Cr_2O_3$ | 0.11 | 0.40 |
| MnO | 0.58 | 0.49 |
| FeO | 40.16 | 36.83 |
| $Fe_2O_3$ | 6.80 | 4.05 |
| $SiO_2$ | 0.12 | 0.09 |
| MgO | 1.93 | 5.95 |
| $Al_2O_3$ | 0.12 | 0.12 |
| TOTAL | 98.97 | 101.2 |

1 without spinel
2 inclusions in spinel

1 is an average of 191 analyses
2 is an average of 12 analyses

TABLE 4: Analyses of Magnetite

| SAMPLE NAME | AREA | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20494 | a | 1 | Magnetite | 7.59 | 4.03 | 0.16 | 37.66 | 46.44 | 0.00 | 0.77 | 3.95 | 100.60 |
| 20462 | a | 19 | Magnetite | 6.75 | 7.37 | 0.19 | 34.84 | 41.55 | 0.13 | 1.39 | 4.58 | 96.80 |
| 20456-01-1 | a | 2 | Magnetite | 4.45 | 2.63 | 0.34 | 34.65 | 54.60 | 0.04 | 0.21 | 2.28 | 99.20 |
| 20456-0-5 | a | 1 | Magnetite | 0.02 | 0.14 | 0.01 | 29.18 | 67.78 | 0.55 | 0.80 | 0.11 | 98.59 |
| 20443 | a | 14 | Magnetite | 5.50 | 4.61 | 0.23 | 33.30 | 45.70 | 0.09 | 1.20 | 4.34 | 94.97 |
| 20546 | a | 3 | Magnetite w sp lam | 2.77 | 7.53 | 0.23 | 31.40 | 49.50 | 0.00 | 1.06 | 3.91 | 96.40 |
| 20456-01-4 | a | 6 | Magnetite(?) | 12.82 | 0.00 | 0.55 | 38.24 | 35.32 | 6.30 | 1.27 | 3.05 | 97.55 |
| 20541 | a | | Magnetite simplectit | 4.17 | 5.96 | 0.11 | 32.68 | 48.36 | 1.46 | 1.06 | 3.76 | 97.56 |
| 20443 | a | 13 | Magnetite | 4.66 | 4.81 | 0.18 | 33.84 | 48.28 | 0.09 | 0.61 | 3.94 | 96.41 |
| 20541 | a | 4 | Magnetite | 5.36 | 7.37 | 0.38 | 33.03 | 42.96 | 0.11 | 1.07 | 4.13 | 94.41 |
| 20443 | a | 15 | Magnetite | 5.59 | 4.54 | 0.34 | 34.25 | 47.62 | 0.11 | 1.24 | 4.24 | 97.93 |
| 20456-01-5 | a | 2 | Magnetite | 0.00 | 0.00 | 0.09 | 29.07 | 67.26 | 0.47 | 0.60 | 0.04 | 97.53 |
| 20546 | a | 10 | Magnetite with hemat | 0.09 | 0.08 | 0.13 | 30.00 | 66.40 | 0.18 | 0.00 | 0.15 | 97.03 |
| 20462 | a | 20 | Magnetite | 6.07 | 7.55 | 0.23 | 34.65 | 43.94 | 0.08 | 1.25 | 4.11 | 97.88 |
| 20443 | a | 16 | Magnetite | 5.83 | 4.78 | 0.29 | 34.50 | 46.72 | 0.16 | 1.14 | 4.40 | 97.82 |
| 20494 | a | 9 | Magnetite | 0.00 | 0.16 | 0.01 | 31.32 | 69.51 | 0.26 | 0.00 | 0.06 | 101.32 |
| 20546 | a | 4 | Magnetite w il lam | 17.51 | 0.13 | 0.33 | 48.00 | 36.14 | 0.10 | 0.03 | 0.87 | 103.11 |
| 20443 | a | 1 | Magnetite | 5.84 | 5.05 | 0.36 | 34.67 | 45.89 | 0.06 | 0.80 | 4.21 | 96.88 |
| 20456-01-1 | a | 3 | Magnetite | 3.88 | 2.75 | 0.18 | 33.91 | 55.46 | 0.00 | 0.51 | 2.46 | 99.15 |
| 20456-01-5 | a | 5 | Magnetite(?) | 14.39 | 0.05 | 0.75 | 42.06 | 34.85 | 0.21 | 0.03 | 1.88 | 94.22 |
| average | | | | 5.66 | 3.48 | 0.25 | 34.56 | 49.71 | 0.52 | 0.75 | 2.82 | 97.77 |
| 21197 | b | 10 | Magnetite | 7.09 | 0.63 | 0.32 | 36.13 | 49.45 | 0.20 | 0.66 | 3.38 | 97.86 |
| 20437-01-3 | b | 2 | Magnetite | 5.80 | 2.31 | 0.23 | 34.18 | 52.21 | 0.00 | 1.19 | 2.22 | 98.14 |
| 21307 | b | 4 | Magnetite | 0.13 | 0.11 | 0.07 | 30.60 | 67.50 | 0.08 | 0.00 | 0.06 | 98.55 |
| 21752 | b | 11 | Magnetite | 2.24 | 2.80 | 0.11 | 33.48 | 61.34 | 0.11 | 0.20 | 1.49 | 101.77 |
| 20437-01-3 | b | 1 | Magnetite | 6.35 | 2.15 | 0.15 | 34.87 | 50.42 | 0.00 | 0.86 | 2.09 | 96.89 |
| 21730 | b | 4 | Magnetite | 9.95 | 1.84 | 0.34 | 38.84 | 44.54 | 0.00 | 0.93 | 2.94 | 99.38 |
| 21752 | b | 12 | Magnetite | 5.99 | 1.65 | 0.17 | 35.76 | 52.44 | 0.13 | 0.78 | 3.15 | 100.07 |
| 21750 | b | 2 | Magnetite | 6.39 | 4.55 | 0.38 | 35.36 | 49.43 | 0.09 | 1.39 | 3.66 | 101.25 |
| 21752 | b | 6 | Magnetite | 6.88 | 0.84 | 0.12 | 37.26 | 52.12 | 0.09 | 0.79 | 3.71 | 101.81 |
| 21197 | b | 11 | Magnetite | 9.04 | 0.61 | 0.34 | 38.04 | 45.08 | 0.09 | 0.77 | 4.21 | 98.18 |
| 21730 | b | 1 | Magnetite | 5.49 | 0.65 | 0.12 | 34.37 | 52.84 | 0.08 | 0.83 | 2.93 | 97.31 |
| 21730 | b | 8 | Magnetite | 4.72 | 4.66 | 0.12 | 34.02 | 51.68 | 0.00 | 0.89 | 2.60 | 98.69 |
| 21197 | b | 4 | Magnetite | 4.57 | 4.61 | 0.19 | 33.70 | 49.80 | 0.08 | 0.81 | 3.65 | 97.41 |
| 21750 | b | 1 | Magnetite | 6.87 | 4.50 | 0.17 | 35.32 | 45.43 | 0.04 | 1.04 | 3.50 | 96.87 |
| 21730 | b | 11 | Magnetite | 3.43 | 1.09 | 0.36 | 33.53 | 58.31 | 1.02 | 0.03 | 1.53 | 99.30 |
| | | | Average | 5.66 | 2.20 | 0.21 | 35.03 | 52.17 | 0.13 | 0.74 | 2.74 | 98.90 |
| 21702 | c | 5 | Magnetite | 3.71 | 0.88 | 0.03 | 31.47 | 52.80 | 0.00 | 3.01 | 8.62 | 100.52 |
| 20515-01-2 | c | 6 | Magnetite | 14.03 | 0.16 | 0.32 | 44.60 | 41.80 | 0.16 | 0.20 | 1.73 | 103.00 |

| SAMPLE NAME | AREA | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20515-01-2 | c | 3 | Magnetite (?) | 22.57 | 0.02 | 0.89 | 50.40 | 20.50 | 0.24 | 0.04 | 2.21 | 96.87 |
| 21700 | c | 10 | Magnetite | 4.87 | 6.53 | 0.25 | 34.11 | 45.88 | 0.00 | 0.64 | 4.34 | 96.62 |
| 21700 | c | 15 | Magnetite | 4.48 | 7.03 | 0.27 | 33.67 | 46.02 | 0.00 | 0.80 | 4.71 | 96.98 |
| 20515-01-4 | c | 3 | Magnetite | 0.07 | 0.07 | 0.18 | 31.51 | 70.72 | 0.11 | 0.16 | 0.09 | 102.91 |
| 21700 | c | 12 | Magnetite | 4.18 | 6.89 | 0.18 | 33.34 | 47.14 | 0.08 | 0.86 | 4.42 | 97.09 |
| 21641 | c | 16 | Magnetite | 8.52 | 0.12 | 0.05 | 38.50 | 47.69 | 0.00 | 0.46 | 3.66 | 99.00 |
| 21698 | c | 9 | Magnetite | 4.36 | 8.00 | 0.33 | 34.07 | 48.33 | 0.02 | 0.72 | 3.36 | 99.19 |
| 20515-01-6 | c | 3 | Magnetite | 14.82 | 0.13 | 0.24 | 36.60 | 43.00 | 0.06 | 1.25 | 3.31 | 99.41 |
| 21698 | c | 12 | Magnetite | 3.86 | 6.83 | 0.28 | 33.03 | 51.02 | 0.00 | 1.37 | 3.79 | 100.18 |
| 21728 | c | 3 | Magnetite | 7.86 | 4.51 | 0.21 | 37.51 | 44.97 | 0.15 | 1.01 | 4.34 | 100.56 |
| 21641 | c | 9 | Magnetite | 6.87 | 0.38 | 0.34 | 35.50 | 48.80 | 0.10 | 0.58 | 3.45 | 96.02 |
| 20515-01-6 | c | 2 | Magnetite in simplec | 6.42 | 0.00 | 0.30 | 37.00 | 55.71 | 0.38 | 0.51 | 2.32 | 102.64 |
| 21724 | c | 9 | Magnetite | 5.46 | 4.18 | 0.23 | 35.22 | 51.57 | 0.08 | 0.54 | 2.07 | 99.35 |
| 20515-02-1 | c | 15 | Magnetite | 10.64 | 0.00 | 0.31 | 38.34 | 43.61 | 0.16 | 0.06 | 0.06 | 93.18 |
| 21724 | c | 2 | Magnetite | 7.36 | 0.15 | 0.24 | 35.69 | 53.30 | 0.21 | 1.91 | 2.97 | 101.83 |
| 21700 | c | 2 | Magnetite | 5.76 | 0.52 | 0.20 | 34.90 | 52.50 | 0.16 | 0.32 | 2.13 | 96.49 |
| 21728 | c | 8 | Magnetite | 1.77 | 0.19 | 0.00 | 32.94 | 65.05 | 0.21 | 0.18 | 1.10 | 101.44 |
| 21700 | c | 3 | Magnetite | 5.07 | 0.59 | 0.05 | 33.90 | 52.30 | 0.00 | 0.30 | 2.38 | 94.59 |
| 21698 | c | 7 | Magnetite | 3.29 | 7.42 | 0.17 | 32.87 | 51.38 | 0.11 | 0.93 | 3.13 | 99.30 |
| 20515-01-3 | c | 2 | Magnetite | 0.27 | 0.00 | 0.07 | 31.44 | 69.28 | 0.34 | 0.05 | 0.00 | 101.45 |
| 21728 | c | 7 | Magnetite | 6.02 | 0.56 | 0.20 | 34.80 | 51.31 | 0.11 | 0.51 | 2.52 | 96.03 |
| 21702 | c | 6 | Magnetite | 4.98 | 0.92 | 0.19 | 33.14 | 53.99 | 0.00 | 1.49 | 3.34 | 98.05 |
| 20515-01-2 | c | 1 | Magnetite | 4.02 | 3.02 | 0.17 | 33.80 | 55.00 | 0.00 | 0.21 | 1.40 | 97.62 |
| 20515-01-3 | c | 5 | Magnetite | 10.11 | 0.20 | 0.32 | 39.70 | 45.70 | 0.14 | 0.63 | 3.34 | 100.14 |
| | | | average | 6.59 | 2.28 | 0.23 | 35.69 | 50.36 | 0.11 | 0.72 | 2.88 | 98.86 |
| 20591 | d | 12 | Magnetite | 5.21 | 6.19 | 0.17 | 34.47 | 47.95 | 0.07 | 1.13 | 4.02 | 99.21 |
| 20567-02-5 | d | 2 | Magnetite | 6.03 | 5.76 | 0.23 | 34.62 | 44.96 | 0.08 | 1.25 | 4.72 | 97.65 |
| 20567-02-8 | d | | Magnetite | 4.10 | 7.82 | 0.30 | 32.30 | 48.86 | 0.10 | 1.43 | 3.04 | 97.95 |
| 20567 | d | 18 | Magnetite | 4.35 | 1.51 | 0.17 | 35.00 | 57.90 | 0.04 | 0.26 | 1.56 | 100.79 |
| 20567-02-5 | d | 1 | Magnetite | 6.25 | 6.11 | 0.33 | 35.33 | 44.85 | 0.06 | 0.93 | 4.34 | 98.20 |
| 20591 | d | 2 | Magnetite | 7.33 | 0.09 | 0.22 | 36.97 | 50.22 | 0.19 | 0.34 | 2.87 | 98.23 |
| 20591 | d | 5 | Magnetite | 4.91 | 2.63 | 0.00 | 34.64 | 55.70 | 0.14 | 0.92 | 1.70 | 100.64 |
| | | | average | 5.45 | 4.30 | 0.20 | 34.76 | 50.06 | 0.10 | 0.89 | 3.18 | 98.95 |
| 21267 | e | 6 | Magnetite | 8.19 | 0.04 | 0.17 | 38.70 | 51.12 | 0.32 | 0.36 | 2.56 | 101.46 |
| 21267 | e | 17 | Magnetite | 0.00 | 0.07 | 0.13 | 31.13 | 69.45 | 1.17 | 0.02 | 0.11 | 102.08 |
| 21225 | e | 4 | Magnetite | 3.23 | 2.50 | 0.06 | 34.71 | 58.64 | 0.00 | 0.10 | 2.31 | 101.55 |
| 21267 | e | 19 | Magnetite | 11.75 | 0.14 | 0.30 | 42.71 | 45.49 | 0.15 | 0.29 | 2.70 | 103.53 |
| 21225 | e | 9 | Magnetite | 9.01 | 6.63 | 0.25 | 39.26 | 43.33 | 0.13 | 1.35 | 4.44 | 104.40 |
| 21267 | e | 20 | Magnetite | 4.04 | 1.07 | 0.12 | 35.70 | 60.50 | 0.32 | 0.03 | 1.33 | 103.11 |

| SAMPLE | NAME | AREA | POINT | NAME AND NOTES | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21225 | | e | 3 | Magnetite | 9.95 | 0.13 | 0.32 | 40.61 | 48.87 | 0.19 | 0.41 | 2.50 | 102.98 |
| 21225 | | e | 7 | Magnetite | 9.04 | 0.00 | 0.16 | 39.74 | 48.85 | 0.07 | 0.28 | 3.13 | 101.27 |
| 21225 | | e | 10 | Magnetite | 8.46 | 6.16 | 0.30 | 37.42 | 42.18 | 0.05 | 1.41 | 4.49 | 100.47 |
| 21267 | | e | 8 | Magnetite | 9.06 | 0.10 | 0.15 | 39.40 | 48.69 | 0.16 | 0.50 | 3.18 | 101.24 |
| | | | | average | 7.27 | 1.68 | 0.20 | 37.94 | 51.71 | 0.26 | 0.48 | 2.68 | 102.21 |
| 21593 | | f | 16 | Magnetite | 7.44 | 0.34 | 0.22 | 38.58 | 51.71 | 0.11 | 0.30 | 3.66 | 102.36 |
| 21657 | | f | 2 | Magnetite | 4.52 | 0.65 | 0.00 | 34.24 | 53.72 | 0.25 | 0.45 | 3.52 | 97.35 |
| 21446 | | f | 3 | Magnetite | 6.05 | 0.11 | 0.82 | 35.94 | 57.18 | 0.21 | 0.01 | 0.26 | 100.58 |
| 21689 | | f | 2 | Magnetite | 16.16 | 0.09 | 0.21 | 45.58 | 35.48 | 0.06 | 0.36 | 1.99 | 99.93 |
| 21593 | | f | 11 | Magnetite | 0.65 | 0.03 | 0.06 | 32.20 | 67.84 | 0.15 | 0.00 | 0.87 | 101.80 |
| 21593 | | f | 3 | Magnetite | 15.38 | 0.45 | 0.30 | 44.65 | 35.01 | 0.00 | 0.39 | 2.92 | 99.10 |
| 21689 | | f | 1 | Magnetite | 2.06 | 1.02 | 0.05 | 31.80 | 57.71 | 0.04 | 0.57 | 3.95 | 97.20 |
| 21593 | | f | 7 | Magnetite | 14.54 | 0.04 | 0.39 | 43.55 | 38.90 | 0.00 | 0.51 | 1.73 | 99.66 |
| 21657 | | f | 1 | Magnetite | 0.57 | 0.97 | 0.05 | 31.58 | 54.08 | 0.00 | 0.91 | 10.63 | 98.79 |
| | | | | average | 7.49 | 0.41 | 0.23 | 37.57 | 50.18 | 0.09 | 0.39 | 3.28 | 99.64 |
| 20887 | | g | 7 | Magnetite | 6.90 | 0.35 | 0.25 | 37.31 | 50.35 | 0.11 | 0.14 | 3.74 | 99.15 |
| 20873 | | g | 4 | Magnetite | 6.16 | 0.30 | 0.18 | 36.28 | 52.24 | 0.19 | 0.02 | 2.59 | 97.96 |
| 21552 | | h | 8 | Magnetite | 8.52 | 1.05 | 0.32 | 37.24 | 48.23 | 0.08 | 0.73 | 1.97 | 98.14 |
| 21552 | | h | 12 | Magnetite | 0.38 | 0.30 | 0.12 | 31.52 | 67.52 | 0.14 | 0.00 | 0.70 | 100.68 |
| 21557 | | h | 11 | Magnetite | 2.44 | 0.08 | 0.05 | 31.62 | 60.46 | 0.00 | 1.05 | 2.79 | 98.49 |
| 21552 | | h | 9 | Magnetite | 8.46 | 0.30 | 0.36 | 36.82 | 48.16 | 0.02 | 0.66 | 1.96 | 96.74 |
| 21552 | | h | 6 | Magnetite | 4.10 | 8.70 | 0.19 | 33.74 | 46.40 | 0.07 | 0.70 | 4.05 | 97.95 |
| 21552 | | h | 10 | Magnetite | 5.02 | 0.20 | 0.13 | 34.47 | 54.18 | 0.00 | 0.71 | 3.43 | 98.14 |
| 21149 | | i | 7 | Magnetite | 16.42 | 0.06 | 0.27 | 46.95 | 33.66 | 1.93 | 0.00 | 3.61 | 102.90 |
| 20944 | | j | 3 | Magnetite | 13.67 | 0.09 | 0.43 | 42.60 | 39.48 | 0.38 | 0.78 | 2.94 | 100.37 |
| 20944 | | j | 12 | Magnetite/HEM LAM | 10.96 | 0.18 | 0.29 | 39.87 | 43.10 | 0.88 | 0.59 | 2.93 | 98.80 |
| 20944 | | j | 11 | Magnetite/il lam | 5.98 | 0.00 | 0.21 | 34.60 | 52.40 | 0.00 | 0.64 | 2.30 | 96.13 |
| 20944 | | j | 5 | Magnetite | 0.00 | 0.00 | 0.00 | 30.55 | 68.03 | 1.83 | 0.00 | 0.00 | 100.41 |
| | | | | Average | 6.84 | 0.94 | 0.21 | 36.36 | 51.16 | 0.46 | 0.49 | 2.44 | 98.89 |

TABLE 5: Analyses of Chromite and Spinel

| SAMPLE NAME | AREA | POINT | NAME | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20456-01-3 | a | 7 | Chromite | 7.45 | 22.08 | 0.42 | 30.79 | 19.56 | 0.21 | 5.36 | 11.57 | 97.44 |
| 20456-01-3 | a | 5 | Chromite | 1.54 | 27.08 | 0.21 | 22.14 | 10.92 | 0.19 | 10.13 | 28.29 | 100.50 |
| 20456-01-3 | a | 1 | Chromite | 9.20 | 21.42 | 0.36 | 32.82 | 22.89 | 0.09 | 4.65 | 6.42 | 97.85 |
| 20456-01-3 | a | 2 | Chromite | 10.06 | 19.95 | 0.49 | 33.18 | 20.50 | 0.63 | 4.13 | 6.12 | 95.06 |
| 20456-01-3 | a | 3 | Chromite | 1.08 | 24.88 | 0.25 | 21.94 | 11.79 | 0.30 | 9.79 | 29.31 | 99.34 |
| 20456-01-3 | a | 4 | Chromite | 1.29 | 25.11 | 0.18 | 22.84 | 8.42 | 0.15 | 9.88 | 32.16 | 100.03 |
| 20456-01-3 | a | 6 | Chromite | 8.45 | 20.45 | 0.25 | 33.02 | 22.65 | 0.11 | 4.71 | 8.00 | 97.64 |
| 20462 | a | 5 | Chromite | 5.05 | 25.78 | 0.31 | 28.07 | 20.23 | 0.04 | 6.25 | 13.04 | 98.77 |
| 20462 | a | 3 | Chromite | 5.03 | 25.89 | 0.34 | 27.83 | 20.51 | 0.00 | 6.40 | 12.90 | 98.90 |
| 20462 | a | 14 | Chromite | 4.02 | 17.36 | 0.48 | 30.74 | 35.11 | 0.09 | 3.04 | 7.64 | 98.48 |
| 20474 | a | 10 | Chromite | 3.79 | 14.13 | 0.32 | 29.78 | 41.65 | 0.16 | 3.89 | 6.87 | 100.59 |
| 20483-02 | a | 2 | Chromite | 4.73 | 24.14 | 0.28 | 28.51 | 18.11 | 0.00 | 6.31 | 17.02 | 99.10 |
| 20483-02 | a | 5 | Chromite | 4.59 | 25.90 | 0.43 | 26.52 | 16.92 | 0.05 | 7.50 | 17.31 | 99.22 |
| 20483-02 | a | 6 | Chromite | 0.40 | 44.93 | 1.91 | 15.39 | 5.83 | 0.22 | 10.23 | 15.59 | 94.50 |
| 20483-02 | a | 7 | Chromite | 5.42 | 24.37 | 0.17 | 28.31 | 19.44 |  | 6.44 | 14.15 | 98.30 |
| 20483-02 | a | 8 | Spinel | 5.17 | 1.09 | 0.15 | 28.35 | 40.11 | 0.63 | 7.39 | 19.68 | 102.57 |
| 20494 | a | 4 | Chromite | 4.13 | 25.19 | 0.43 | 28.86 | 19.40 | 0.00 | 5.97 | 16.88 | 100.86 |
| 20494 | a | 5 | Chromite | 4.44 | 26.14 | 0.47 | 29.54 | 18.21 | 0.11 | 5.81 | 16.82 | 101.54 |
| 20494 | a | 3 | Chromite | 2.68 | 26.61 | 0.19 | 24.23 | 16.90 | 1.00 | 7.73 | 18.75 | 98.09 |
| 20494 | a | 6 | Chromite | 3.03 | 27.70 | 0.36 | 27.72 | 16.45 | 0.09 | 6.13 | 18.56 | 100.04 |
| 20541 | a | 12 | Chromite | 5.33 | 27.13 | 0.46 | 29.89 | 18.58 | 0.07 | 4.98 | 12.05 | 98.49 |
| 20546 | a | 16 | Chromite | 4.64 | 20.80 | 0.30 | 32.82 | 31.42 | 0.02 | 2.53 | 7.60 | 100.13 |
| 20546 | a | 14 | Chromite | 7.66 | 21.34 | 0.40 | 32.87 | 20.91 | 0.15 | 3.32 | 8.43 | 95.08 |
| 20437-01-1 | b | 3 | Chromite | 2.63 | 26.01 | 0.13 | 23.62 | 11.74 | 0.12 | 9.96 | 27.20 | 101.41 |
| 20437-01-1 | b | 2 | Chromite | 2.57 | 25.53 | 0.39 | 23.41 | 11.18 | 0.06 | 9.75 | 27.64 | 100.53 |
| 20437-01-1 | b | 1 | Chromite | 2.67 | 26.37 | 0.28 | 23.51 | 12.09 | 0.04 | 10.50 | 28.11 | 103.57 |
| 20437-01-1 | b | 6 | Chromite | 2.82 | 25.45 | 0.29 | 23.65 | 11.32 | 0.20 | 9.81 | 27.31 | 100.85 |
| 20437-01-1 | b | 5 | Chromite | 2.98 | 25.61 | 0.22 | 23.28 | 12.44 | 0.00 | 9.88 | 25.63 | 100.04 |
| 20437-01-1 | b | 4 | Chromite | 2.58 | 25.59 | 0.30 | 22.64 | 10.97 | 0.10 | 10.34 | 27.97 | 100.49 |
| 20437-01-2A | b | 1 | Chromite | 1.84 | 26.52 | 0.32 | 24.76 | 11.71 | 0.04 | 8.75 | 27.78 | 101.72 |
| 20437-01-2A | b | 2 | Chromite | 1.72 | 27.16 | 0.12 | 24.34 | 12.42 | 0.00 | 9.57 | 28.40 | 103.73 |
| 20437-01-4 | b | 3 | Chromite | 3.13 | 25.52 | 0.37 | 24.62 | 13.05 | 0.00 | 9.50 | 26.07 | 102.26 |
| 20437-01-4 | b | 1 | Chromite | 4.04 | 27.27 | 0.49 | 29.00 | 18.67 | 0.00 | 5.41 | 15.05 | 99.93 |
| 20437-01-4 | b | 4 | Chromite | 2.89 | 25.05 | 0.29 | 23.96 | 13.49 | 0.00 | 9.88 | 26.63 | 102.19 |
| 20437-01-4 | b | 2 | Chromite | 4.80 | 26.96 | 0.43 | 30.08 | 18.61 | 0.08 | 5.54 | 15.13 | 101.63 |
| 20437-01-5 | b | 1 | Chromite | 2.39 | 26.25 | 0.36 | 22.77 | 9.37 | 0.12 | 10.14 | 28.80 | 100.20 |
| 20437-01-5 | b | 3 | Chromite | 2.34 | 26.14 | 0.33 | 22.92 | 10.16 | 0.08 | 9.95 | 28.19 | 100.11 |
| 21197 | b | 9 | Spinel | 0.20 | 5.20 | 0.08 | 17.52 | 3.97 | 0.17 | 15.11 | 56.67 | 98.92 |
| 21197 | b | 8 | Spinel | 0.22 | 4.95 | 0.15 | 17.75 | 4.46 | 0.08 | 15.25 | 57.25 | 100.11 |
| 21207 | b | 6 | Chromite | 5.77 | 17.34 | 0.23 | 33.74 | 30.65 | 0.07 | 2.17 | 7.81 | 97.78 |
| 21730 | b | 3 | Chromite | 5.57 | 14.25 | 0.34 | 34.62 | 35.78 | 0.18 | 1.42 | 6.63 | 98.79 |
| 21730 | b | 2 | Chromite | 5.13 | 13.38 | 0.11 | 34.19 | 36.27 | 0.04 | 1.25 | 6.66 | 97.03 |
| 21752 | b | 8 | Chromite | 4.83 | 13.91 | 0.23 | 34.34 | 39.13 | 0.02 | 1.39 | 5.98 | 99.83 |
| 21752 | b | 9 | Chromite | 5.01 | 14.37 | 0.27 | 34.48 | 38.87 | 0.02 | 1.60 | 6.17 | 100.79 |

| SAMPLE NAME | AREA | POINT | NAME | TiO2 | Cr2O3 | MnO | FeO | Fe2O3 | SiO2 | MgO | Al2O3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21752 | b | 7 | Chromite | 5.29 | 13.80 | 0.33 | 34.34 | 37.95 | 0.02 | 1.51 | 6.09 | 99.33 |
| 21766 | b | 9 | Chromite | 1.14 | 29.37 | 0.40 | 26.38 | 15.63 | 0.04 | 6.06 | 20.77 | 99.79 |
| 21766 | b | 11 | Chromite | 3.49 | 23.87 | 0.25 | 22.13 | 9.27 | 0.00 | 11.04 | 28.86 | 98.91 |
| 21766 | b | 4 | Chromite | 3.77 | 20.81 | 0.25 | 30.06 | 31.40 | 0.16 | 3.60 | 8.54 | 98.59 |
| 21766 | b | 10 | Chromite | 2.95 | 27.66 | 0.13 | 24.46 | 13.29 | 0.15 | 8.09 | 20.81 | 97.54 |
| 21766 | b | 3 | Chromite | 15.17 | 22.55 | 0.36 | 37.16 | 0.00 | 0.04 | 6.25 | 16.06 | 97.59 |
| 21766 | b | 8 | Chromite | 1.46 | 25.23 | 0.30 | 27.04 | 20.22 | 0.07 | 5.44 | 19.03 | 98.79 |
| 21766 | b | 1 | Chromite | 2.38 | 26.31 | 0.16 | 26.94 | 11.92 | 0.23 | 7.22 | 25.41 | 100.57 |
| 21766 | b | 2 | Chromite | 4.32 | 14.59 | 0.45 | 29.81 | 38.54 | 0.10 | 3.00 | 5.17 | 95.98 |
| 21698 | c | 3 | Chromite | 6.65 | 21.72 | 0.30 | 32.10 | 25.99 | 0.00 | 4.88 | 10.23 | 101.87 |
| 21698 | c | 5 | Chromite | 1.22 | 29.12 | 0.16 | 22.88 | 11.32 | 0.00 | 9.51 | 26.90 | 101.11 |
| 21700 | c | 7 | Chromite | 3.10 | 14.51 | 0.20 | 32.81 | 44.19 | 0.14 | 1.27 | 4.26 | 100.48 |
| 21700 | c | 14 | Chromite | 2.79 | 14.19 | 0.14 | 31.54 | 43.68 | 0.11 | 1.44 | 4.13 | 98.02 |
| 21700 | c | 6 | Chromite | 2.80 | 14.85 | 0.34 | 31.40 | 43.18 | 0.11 | 1.47 | 4.15 | 98.30 |
| 21702 | c | 8 | Chromite | 5.41 | 16.90 | 0.13 | 34.13 | 35.21 | 0.04 | 2.12 | 6.41 | 100.35 |
| 21702 | c | 13 | Chromite | 3.69 | 18.34 | 0.37 | 32.49 | 35.93 | 0.07 | 1.75 | 6.46 | 99.10 |
| 21702 | c | 2 | Chromite | 6.09 | 12.25 | 0.28 | 34.38 | 39.64 | 0.07 | 2.01 | 5.26 | 99.98 |
| 21702 | c | 7 | Chromite | 4.48 | 15.79 | 0.32 | 33.46 | 38.88 | 0.00 | 1.84 | 5.80 | 100.57 |
| 21702 | c | 1 | Chromite | 6.54 | 15.69 | 0.35 | 33.72 | 33.74 | 0.05 | 2.49 | 5.94 | 98.52 |
| 21702 | c | 11 | Chromite | 4.32 | 12.04 | 0.36 | 32.18 | 43.15 | 0.00 | 2.26 | 5.31 | 99.62 |
| 21702 | c | 9 | Chromite | 6.34 | 15.50 | 0.33 | 34.37 | 34.03 | 0.03 | 2.17 | 6.48 | 99.25 |
| 21702 | c | 12 | Chromite | 4.16 | 11.64 | 0.33 | 31.93 | 43.90 | 0.00 | 2.34 | 5.31 | 99.61 |
| 20567 | d | 17 | Chromite | 8.65 | 21.43 | 0.29 | 32.55 | 25.58 | 0.13 | 5.82 | 8.58 | 103.03 |
| 20567 | d | 10 | Chromite | 2.55 | 32.30 | 0.30 | 26.68 | 14.54 | 0.14 | 6.61 | 17.57 | 100.69 |
| 20567 | d | 14 | Chromite | 2.02 | 24.34 | 0.10 | 22.31 | 15.02 | 0.11 | 10.48 | 27.26 | 101.64 |
| 20567-02-6 | d | 6 | Chromite | 5.30 | 13.54 | 0.32 | 33.02 | 39.31 | 0.09 | 2.68 | 6.44 | 100.70 |
| 20567-02-6 | d | 6 | Chromite | 5.15 | 13.01 | 0.27 | 32.64 | 39.75 | 0.00 | 2.73 | 6.42 | 99.97 |
| 20567-02-6 | d | 6 | Chromite | 5.30 | 13.07 | 0.34 | 32.83 | 38.87 | 0.10 | 2.62 | 6.64 | 99.77 |
| 20567-03 | d | 3 | Chromite | 4.39 | 27.61 | 0.34 | 30.65 | 21.67 | 0.08 | 4.08 | 10.77 | 99.59 |
| 20567-03 | d | 3 | Chromite | 4.39 | 26.84 | 0.43 | 30.83 | 22.75 | 0.15 | 3.88 | 10.48 | 99.75 |
| 21267 | e | 21 | Chromite | 0.48 | 48.25 | 0.25 | 16.09 | 8.97 | 0.00 | 11.70 | 13.48 | 99.22 |
| 21446 | f | 10 | Chromite | 0.53 | 51.69 | 0.27 | 14.70 | 7.83 | 0.17 | 11.86 | 10.23 | 97.28 |
| 21446 | f | 11 | Chromite | 0.40 | 51.33 | 0.26 | 16.00 | 6.92 | 0.46 | 11.55 | 12.44 | 99.36 |
| 21593 | f | 12 | Ulvospin | 30.60 | 0.03 | 0.06 | 44.00 | 14.50 |  | 9.62 | 0.33 | 99.14 |
| 21657 | f | 6 | Chromite | 3.50 | 13.15 | 0.32 | 32.16 | 40.38 | 0.28 | 1.28 | 5.84 | 96.91 |
| 21657 | f | 8 | Chromite | 3.56 | 13.48 | 0.25 | 32.46 | 40.48 | 2.44 | 1.32 | 5.84 | 99.83 |
| 21557 | h | 1 | Chromite | 0.50 | 48.43 | 0.36 | 21.34 | 6.41 | 0.14 | 8.30 | 13.95 | 99.43 |

Figure 1: Chromites and Spinels

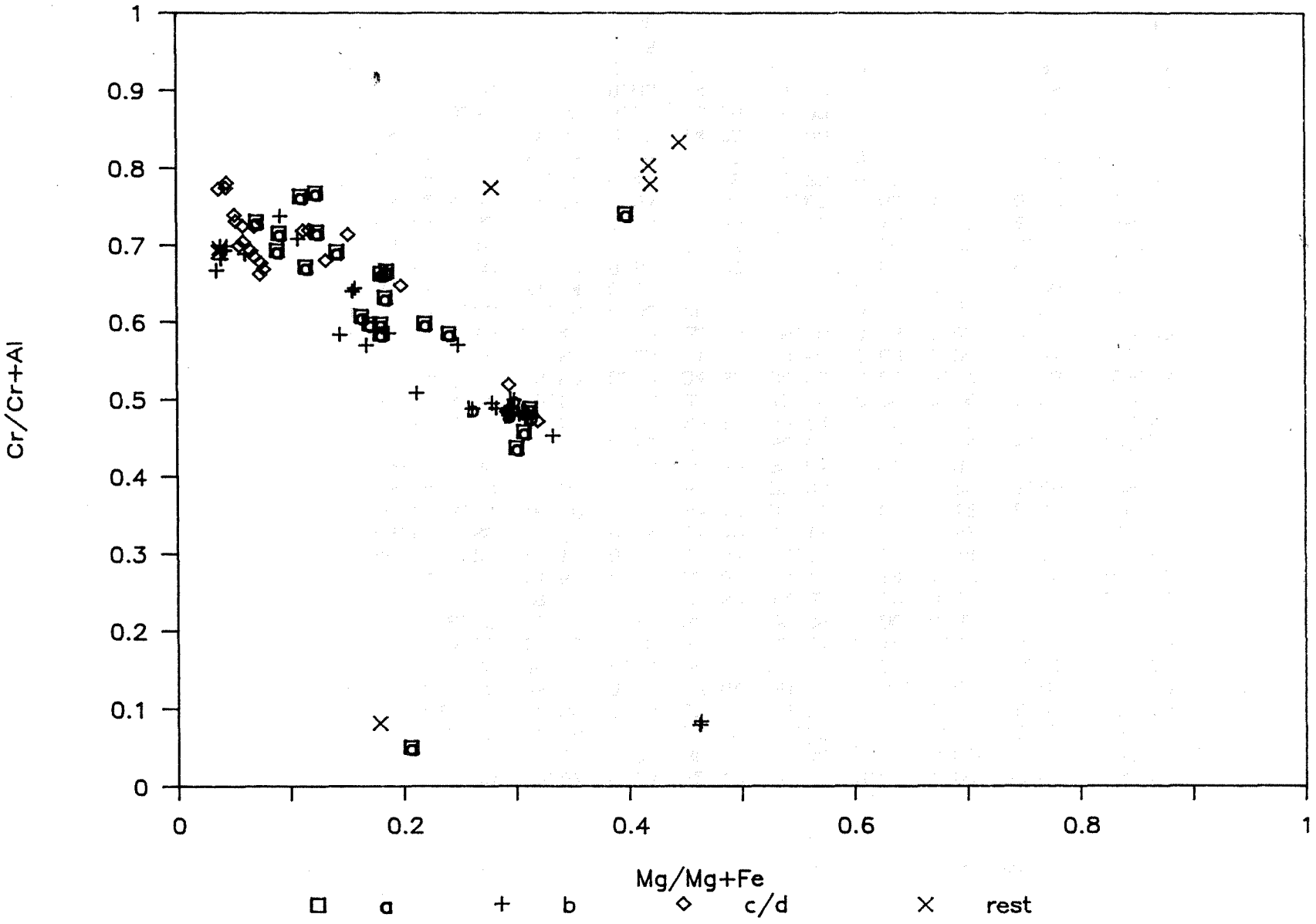
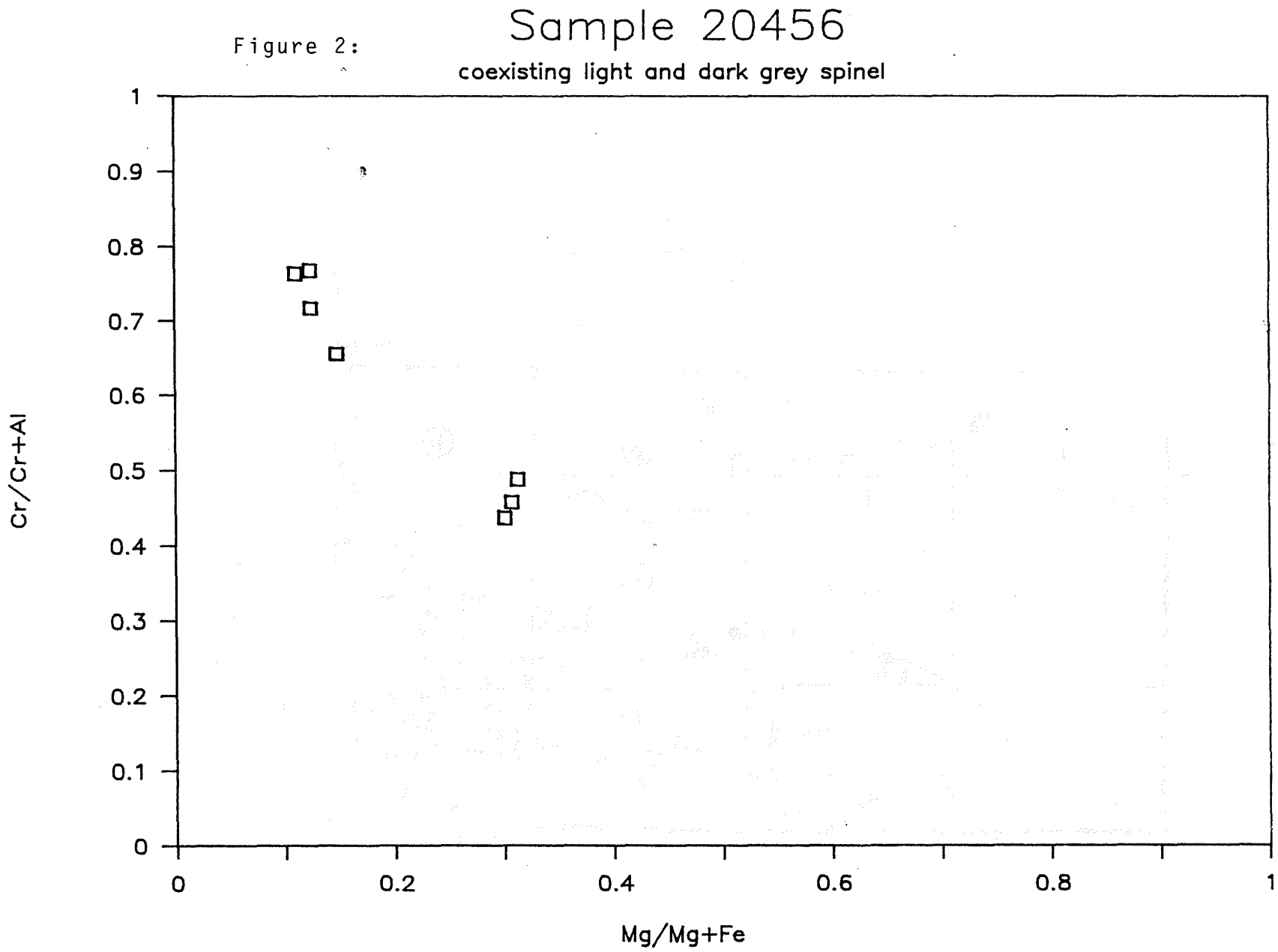


Figure 2:


Sample 20456
coexisting light and dark grey spinel
Cr/Cr+Al
Mg/Mg+Fe
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1

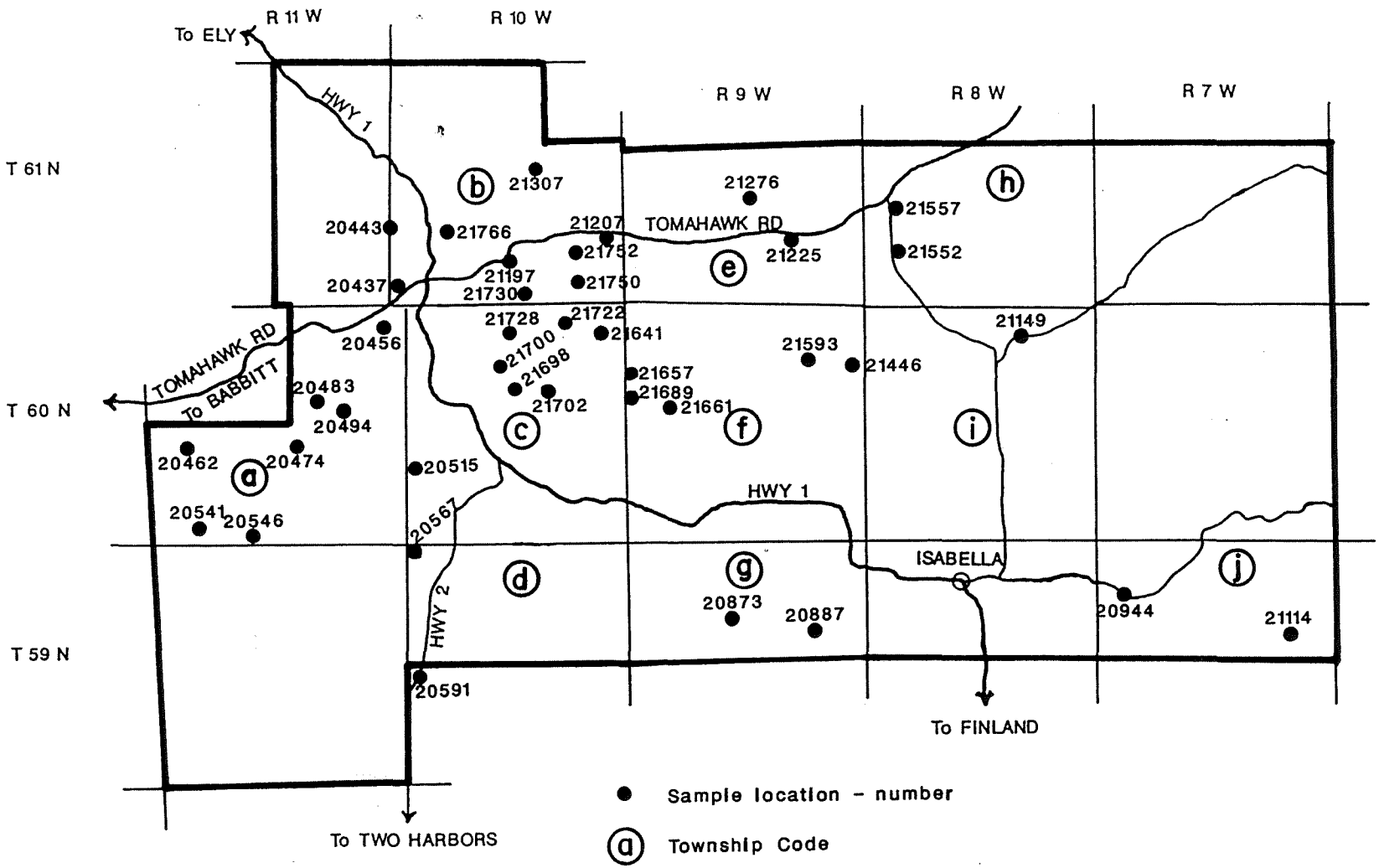



*figure 3*

**SAMPLE LOCATION MAP**

## Discussion of Results

This project has not only satisfied the objectives of the investigation, but has generated a database that will create and support both scientific examination and resource exploration efforts for the future. Colin Dunn, Director of the Geochemical Section, Geological Survey of Canada, has reviewed the collection and processing methods, the analytical data and the preliminary interpretations and is of the opinion, as are the authors, that this database represents an important collection of scientifically reliable and correct geochemical data.

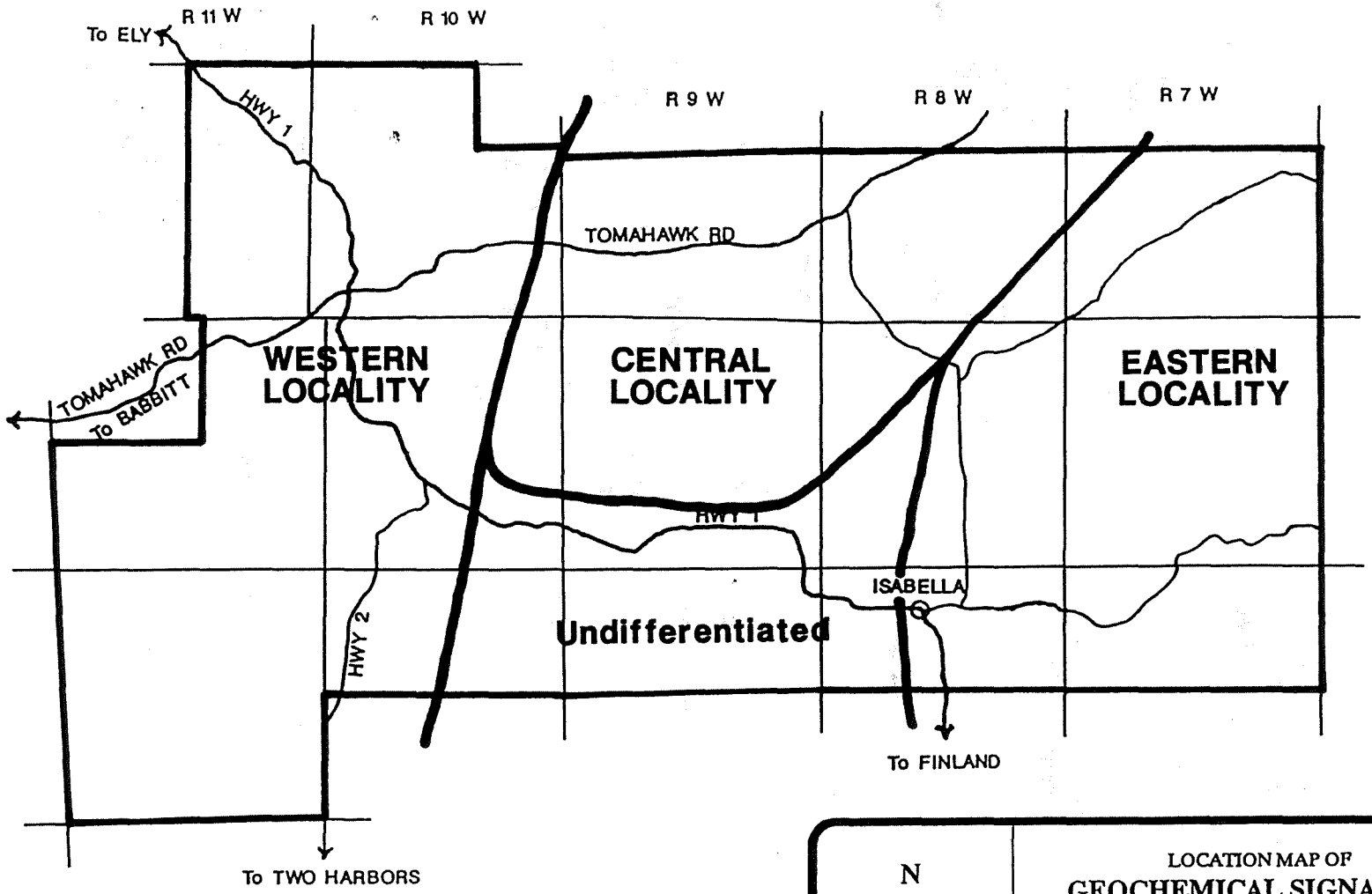
The following remarks are directed to specific discussions on: 1) selected geochemical anomalies within the study area; 2) elemental magnitudes within the sample medias; 3) selection of a media or medias that will work within this Lake County study area; and 4) how the sample processing and analytical methods may be modified to enhance the geochemical results and interpretations.

This geochemical investigation has identified three distinct anomalous localities across the study area, as shown in Figure 22. As contained in the following discussion, these localities all have their own unique character and geochemical signatures.

1. Western Locality: This location occupies the western one-third of the project area. As illustrated by Figure 7 and Plate 2, bedrock for this region is predominantly troctolite, gabbro and olivine-bearing ferro-gabbro, with a fringe of anorthositic gabbro along the eastern boundary. This eastern geochemical boundary is also remarkably coincident with the aeromagnetic and gravity anomalies displayed by Figures 10 and 11. Definition of this area is clearly illustrated by the geochemical contour maps, numbers 1, 5, 10, 12, 16, 21, 23 and 24. Heavy mineral concentrate analyses were initially thought to be the best indicators, but chrome, cobalt and nickel in the clay/silts and humus outline this locality equally well.

Interpretation of previous research by the Division of Minerals (Vadis, 1981 and 1982) suggested that anomalous concentrations within this western locality were a product of glacial transport from the basal contact of the Duluth Complex to the north-northwest. Current research, as indicated in the following discussion, suggests that this anomaly has a much more local explanation. Hobbs (1988) has identified glacial movement from the northeast, not the northwest. An absence of significant nickel between this anomaly and the basal contact to the north-northwest supports this concept. Morton (1989), as quoted on pages 53 to 56, has identified a close correlation between the mineralogy of the partial heavy mineral concentrates she examined with the geochemistry and apparent underlying bedrock at the geochemical sample sites.

Of the anomalous elements within this western locality, chrome, platinum and palladium are economically the most important. Chrome levels greater than 2,150 ppm (95th percentile) occur in the partial heavy mineral concentrates, and this element is considered an indicator for platinum and palladium (Sabelin, 1985 and McDonald, 1988). Although the concentration ratios for the samples were generally less than 10 to 1, 12 partial heavy mineral concentrates contain platinum levels of 10 ppb or greater and 11 of these had palladium values of 33 ppb or greater. A strong correlation between platinum and palladium is not apparent, as only one concentrate analysis produced coincident values for these two elements. Morton has classified chrome spinels associated with platinum from the Duval #15 drill hole using a Cr/Cr + Al versus Mg/Mg + Fe plot. A plot of chromites and chrome spinels from the partial heavy mineral concentrates of this study is very similar, suggesting the same mag-

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LOCATION MAP OF
GEOCHEMICAL SIGNATURE AREAS

PROJECT 262
LAKE COUNTY, MINNESOTA
Scale: 1/4 inch = 1 mile

*figure 22*

matic origin as the rocks in Duval #15.

Nickel and cobalt anomalies occur most commonly over the olivine gabbro core and peripheral troctolite of the Bald Eagle Intrusion (Green, 1966). This intrustion is situated in T.61N., R.10W. and is a subdivision of the western locality. Calculated thresholds of 448.1 ppm and 542.8 ppm for nickel are reported in the partial heavy mineral concentrates and silt and clay fractions, respectively, as shown in Tables 1 and 2. Cobalt thresholds occur at 199.9 ppm and 81.6 ppm, within these media. Nickel and cobalt values above the 95th percentile, when plotted on the sample location map, conform to the outline of this intrusion. These values also suggest that there may be a south-southeast extension for the intrusive. Cobalt, magnesium oxide, and lead displayed in Figure 18, also delineate the Bald Eagle Intrusion as indicated by the marked increase in cobalt, a slight increase in magnesium oxide, and lead values which mimic the cobalt content. Vegetation and humus samples were only collected from the southern edge of the Bald Eagle Intrusion. Although there is a hint of cobalt and nickel within these media, the results are far from conclusive.

The effectiveness of the different sample media within this locality is demonstrated by the geochemical maps, numbers 1, 5, 10, 12, 16, 21 and 24, and the sample number versus assay value graphs (MIP's) of Figures 17 through 20. The presence of chrome, platinum and palladium is most apparent in the partial heavy mineral concentrates. Similar, but less definitive patterns, are evident in the humus and silt and clay medias. Vegetation does not appear to be an effective media for detecting chrome, platinum or palladium within this locality, perhaps due to the tight crystal lattice of chromite and its resistance to weathering which reduces the element mobility and availability to plant systems. Cobalt values are strong and highly variable within the heavy mineral media and subdued, but more easily interpreted, in the silt and clay fractions. Nickel values are very similar in both the heavy mineral and silt and clay fractions. Lead values within the heavy mineral media are subdued with only occasional spikes. Conversely, the silt and clay media produce lead values that occur in distinct and regular patterns.

The project has shown that changes in sample preparation methods and statistical applications can enhance further evaluation and interpretation in this locality. Morton (personal communication) has stated that the chromite is restricted almost entirely to the magnetic fraction. Rather than drying, sieving, splitting, tabling and centrifuging, a simple process of wet sieving followed immediately by wet magnetic separation can be used. Analysis for total chrome content is then appropriate, to be followed by an examination of polished sections and microprobe analyses of the chrome concentrates. Statistical manipulation of the results, in this anomalous locality, should further highlight mineralized locations and element assemblages. Manipulation of results for specific elements, as illustrated by cobalt and nickel over the Bald Eagle Intrusion, may also indicate discrete geochemical anomalies in this western area which could be interpreted as previously unrecognized intrusive bodies or magmatic phases of Duluth Complex rocks.

2. Central Locality: This area is most obviously defined by its clustering of heavy mineral anomalous values for cobalt, vanadium, titanium oxide, zinc and iron oxide, and their expressions by prominent but discontinuous geochemical contours as on maps numbered 2, 3, 4, 7 and 9. As shown by Figure 7 and Plate 2, bedrock underlying this area is predominantly anorthositic gabbro. Of the five media sampled, the heavy minerals and humus values for arsenic, antimony and bromine (Maps 26, 27 and 29) are useful in characterizing this locality. Titanium oxide values

peak at 28%, and results in the 20% to 28% range are common. Cobalt values vary between 200 and 300 ppm. Vanadium peaks at 2200 ppm, and assays above 1500 ppm are common. There is a distinct similarity of expression between cobalt, titanium oxide and vanadium values as demonstrated by Figure 17. The boundary between the anorthositic gabbro and the Bald Eagle Intrusion to the west is sharply delineated on many of the geochemical maps, and is especially marked by a change in element assemblages from one of cobalt, titanium oxide and vanadium to one of cobalt, nickel and chrome. Although the glacial geology of this particular region is very complex, the geochemistry of the heavy mineral concentrates appears to conform to the underlying anorthositic gabbro distribution.

3. Eastern Locality: Unlike the western and central localities, this area is characterized by numerous individualistic occurrences of platinum and palladium in the heavy minerals (Map 1) and lead contours (Map 6). Definition is poor in clay/silt and humus except possibly for zinc (Maps 18 and 25). The best expressions are in all species of vegetation, for chrome and palladium on Maps 31, 37, 43, 49 and 55. The bedrock lithology for this locality, as currently mapped and shown by Figure 7 and Plate 2, includes several rock types. There are rocks of the Duluth Complex including: 1) undifferentiated gabbro, 2) red granophyric granite and adamellite and 3) troctolite or anorthositic troctolite. Also present are Middle Proterozoic, predominantly Keweenawan, mafic extrusive volcanic flows and some poorly understood mafic metavolcanics that may be inclusions or roof pendants in the Duluth Complex. Glacial deposits, representing both the Rainy and Superior lobe glacial advances, are present in this locality as displayed in Figure 8 and Plate 3.

This eastern area appears similar to the western locality because of its assemblage of chrome, platinum and palladium; however, the anomalous chrome values in the east are derived from drastically different media. For example, the preferred medium for chrome in the western locality is the partial heavy mineral concentrates; but in the eastern locality, the chrome values are found in the vegetation and humus samples, as illustrated by geochemical maps 22, 31, 37, 43 and 49. Sites 21633, 22140, 21125 and 20951 demonstrate that chrome is anomalous in humus and in two of the three vegetation species.

There are several theories to explain why these media are able to detect chrome within the eastern locality. These include: 1) a finer grained bedrock, 2) a change in mineralogy from oxide-rich chrome in the western locality to arsenide-rich chrome in the eastern locality, 3) a different magmatic source (Morton, 1989), 4) dust contamination from nearby gravel roads, and 5) a higher background threshold for chrome in the underlying bedrock. Of these possibilities, only dust contamination has been discarded. Colin Dunn (personal communication) has suggested that dust contamination will raise the silicon dioxide content of the vegetation sample and cause a dilution of the trace element content.

Platinum was reflected in all media types of the eastern area except the vegetation species, with a slight preference for the partial heavy mineral concentrates and the silt and clay samples. Very prominent are the numerous heavy mineral occurrences of palladium, indicated on geochemical map number 1. Other anomalous expressions of nickel, zinc, bromine barium, arsenic, antimony and molybdenum are shown by the geochemical maps, numbers 35, 39-41, 45, 52-54 and 57-62.

This eastern locality contains numerous chrome, platinum, palladium and other elemental anomalies, the origins of which are poorly understood. Morton's work on the

chrome spinels and chromite from the western locality helped explain the geochemistry of that area. A similar petrographic/ microprobe study may be useful to interpret the geochemistry for this eastern area as well. The focus, however, can not be on chrome in the partial heavy mineral concentrates because the elemental anomalies do not occur in this media. Instead, a general mineralogical point count of these concentrates may permit an interpretation of the underlying bedrock, including information on mineral composition, chemistry and grain size. Statistical manipulation of geochemical data unique to just the eastern locality is also in order. Vegetation sampling, the preferred media for chrome in this locality, should be extended to the north-northeast beyond the present limit of vegetation sample coverage.

## Satisfying the Objectives

This geochemical project has provided information that makes it possible to give some qualified answers to a number of questions that arise from a regional survey of this type. Earlier in this report, under the heading of "Objectives," a series of questions were formulated for which, it was hoped, this project would provide some answers. The following pages restate and suggest some possible answers to those questions.

*1) WERE SAMPLING AND PROCESSING PROCEDURES APPROPRIATE AND EFFECTIVE? COULD THEY BY IMPROVED? WERE THESE METHODS APPROPRIATE?*

The answer has to be yes for both parts of the question. As a preliminary, regional reconnaissance program the challenge was to obtain a statistically valid sampling of a 400 square mile area. Glacial overburden, soil and humus samples were obtained from 1,162 sample locations in a time and cost effective manner, and the same was true for a later collection of 715 vegetation species at approximately 327 of the same sample sites. The drying and/or processing of the sampled mediums, whether for analyses or storage for future reference, preserved the integrity of all the samples whether stored or shipped for assay.

Drying of samples was the bottleneck in the processing procedures; a direct reflection of the vast number of samples collected and limited drying facilities capacity. There was, however, no alternative for the necessity of drying humus and vegetation samples prior to shipping and analysis in order to prevent sample decay. Dry sieving of the glacial overburden was rapid, effective and appropriate in order to reduce the size and shipping cost for the fractions being analyzed and for producing dry reject material that could be stored for future studies. The equipment was also available to accomplish the dry separation procedures.

As the project advanced, and analytical results were received, it did become evident that an exclusively wet separation for the glacial overburden would be a feasible alternative directed at obtaining a representative heavy mineral concentrate. Although not possible to predict beforehand, wet processing with magnetic concentration now appears to be a preferred method for investigation of the chrome, platinum and palladium occurring in the western anomalous locality described earlier.

A Wilfley Table was utilized to obtain a partial heavy mineral concentrate from the -35 mesh fraction of glacial overburden, and some concentration variations occurred due to the limitations of the tabling system and the materials processed. A heavy liquid separation is preferred in some quarters to overcome these variations. The results of this study have shown that use of the Wilfley Table was adequate for producing a concentrate that would

reflect anomalous areas for the strategic minerals being sought. (Dunn, personal communication.)

*2) WAS THE ANALYTICAL PACKAGE EMPLOYED ADEQUATE FOR THE INVESTIGATION?*

In retrospect, it would have been ideal to assay all eight media for an identical list of elements; however, a blanket analytical contract was signed for all assay work prior to the development of the multimedia geochemical sampling program, and a commercially available standard list of elements for all media was not obtained.

As a general statement, when embarking on a regional geochemical survey, statistical evaluation of the lowest commercially available detection limits should be sought to permit the best results. It was found that chrome, an indicator element for platinum, could be statistically manipulated since all assay values were above the analytical detection limits, thereby permitting a statistical evaluation of the entire sample population. Background values for platinum in the partial heavy mineral concentrates were calculated to be less than 5 ppb; consequently detection limit for platinum of less than the available 10 ppb is necessary to permit complete statistical interpretation of the data for this element.

In a regional survey, where preexisting geochemical data is lacking, a broad analytical package is appropriate. The analytical database from this investigation is intended to serve not only exploration companies, but also academically oriented research projects which often require a broader spectrum of information. This study suggests that a minimal analytical package consisting of chrome, platinum, palladium, cobalt, nickel, magnesium oxide, titanium oxide and vanadium would be adequate for future resource evaluation work in this geological setting. The apparent mutual relationship between cobalt, titanium oxide and vanadium values suggests that an assay for one of these elements could be sufficient during initial reconnaissance.

*3) CAN BEDROCK SOURCE AREAS BE IDENTIFIED AND MINERAL CONCENTRATIONS CHARACTERIZED ON THE BASIS OF A GEOCHEMICAL SIGNATURE?*

Three geochemical localities, which directly reflect the underlying bedrock lithologies, have been delineated within the study area. These include: 1) the western locality, underlain by troctolites and ferro-gabbros and typified by a chrome, nickel, cobalt, platinum and palladium signatures detected in the partial heavy mineral concentrates and silt and clay fraction; 2) the central locality, underlain by anorthositic gabbro and easily recognized by elevated cobalt, titanium oxide and vanadium values in the partial heavy mineral concentrates; and 3) the eastern locality, underlain by a variety of gabbroic and mafic volcanic rocks and recognized by elevated chrome values in humus and vegetation, and by elevated platinum and palladium values in the partial heavy mineral concentrates.

The data from this project was initially treated on a regional basis. Now that three distinct geochemical signatures have been identified, it is possible to evaluate the data within each of those localities to further refine and understand the significance of their signatures.

*4) DID GLACIAL PROCESSES AND HISTORY INFLUENCE THE GEOCHEMICAL RESULTS?*

A direct correlation of the glacial drift geochemistry with the underlying bedrock indicates that glacial transport is not a major

concern in the project area. If need be, local ice and meltwater flow directions can be inferred from the glacial history and detailed surficial map by Hobbs (1988).

The cumulative results of this investigation suggest that glacial transport, over long distances, has not been a factor in the geochemical interpretation of the project area. Variable drift thickness, composition and depositional history have not been detrimental to a straightforward interpretation of the data, which conforms remarkably with the bedrock geology. The glacial history as quoted from Hobbs (1988) earlier in this report and the influence of glacial processes (grinding, shattering, heavy mineral concentration by meltwater, ablation, etc.) must be considered, however, when conducting followup surveys on site-specific anomalies.

*5) WHAT GEOCHEMICAL ANOMALIES EXIST IN THE AREA?*

Three distinct localities have been delineated, each displaying unique geochemical signatures. Within the three localities, the single and multiple element geochemical maps 1 through 62 make it possible to identify these anomalous areas. Further statistical manipulation of the data for each of the three localities individually will outline site specific anomalies just as the geochemical maps of this report have done on the broader scale.

*6) DO THE SURVEY METHODOLOGIES AND INTERPRETIVE TECHNIQUES CHARACTERIZE THE GEOCHEMICAL ANOMALIES THAT ARE PRESENT?*

The principal focus of this investigation was to identify and test methods for locating certain strategic minerals including chrome, platinum, palladium, cobalt, titanium, vanadium and cobalt. Assay data from the several sample media were statistically manipulated, anomalous thresholds calculated and geochemical maps compiled with contours at 80, 85, 90 and 95 percentiles. Three major geochemical regions or localities, each characterized by a distinct elemental signature, were identified. Additional statistical manipulation of data within each locality may be used to further refine specific strategic mineral anomalies.

*7) WHAT IS, OR IS THERE, A PREFERRED SAMPLE MEDIA OR SIZE FRACTION OF MATERIAL FOR USE IN A GEOCHEMICAL RECONNAISSANCE SURVEY OF THE TYPE CONDUCTED?*

Initially, it was hoped that one medium would prove to be the ideal sampling media, however, this has not proven to be the case. The investigation has shown how various elements react within several different media and that sample media selection is dependent upon the elements of interest and their probable host rock associations. For example, chrome and related elements occur in an oxide mineral assemblage within the western locality and may be detected most readily within the magnetic fraction of the partial heavy mineral concentrates. Conversely, in the eastern locality, the preferred media for detection of these elements is humus and vegetation; perhaps suggesting a differing (sulfide?) mineral assemblage or host rock lithologies. In consideration of contrasts such as these, the multimedia approach using a broad list of elements must be utilized in the initial reconnaissance stage. Once major element assemblages and media preferences have been identified, informed decisions focusing on use of the most appropriate media can be made.

*8) WHAT ARE THE COMPARABLE ELEMENT ANALYSIS VALUES WHEN TRANSLATING FROM ONE SAMPLE MEDIA TO ANOTHER?*

The database contains sufficient information to allow for the comparison of multiple elements in eight sample media at hundreds of locations. Maximum, minimum, average assay values and standard deviations for selected elements as detected by these media are presented in Tables 1 through 8. A simplistic view of this data indicates that partial heavy mineral concentrates produce analyses with the highest numerical values and the most easily recongnized anomalies. Assay values decrease in magnitude through the silt and clay fraction and humus samples. The values are at their lowest in the vegetation samples, to such a degree that anomalous results can be ignored on casual inspection and may only be identified by statistical processing of the assay values.

*9) IS IT APPROPRIATE TO APPLY THE CONCEPTUAL APPROACH AND METHODOLOGY OF THIS PILOT STUDY TO OTHER MINNESOTA LOCATIONS WITH DIFFERING BEDROCK GEOLOGY AND GLACIAL HISTORY?*

The multimedia approach is successful in locating regions of apparentally anomalous mineral potential. Even though the glacial history of this area is very complex, geochemical signatures of the unexposed bedrock seem to have been detected through a rapid and cost-effective surface sampling program. Programs such as this should be effective in areas where the glacial drift is less than 50 feet thick, and useful even in areas with up to 125 feet of cover, so long as the results are interpreted with reasonable caution. Care must be used in the matching of the analytical package with the sample media types.

The strength of this program is based on simple logic. A maximum number of sites, a multimedia sampling approach, a carefully selected analytical package, and the application of an appropriate statistical evaluation will produce useful and reliable baseline information which can justify a mineral resources evaluation program. The obvious interpretations will emerge through rigorous examination of data by relatively simple methodologies (Sinclair, 1986).

# COSTS

The direct costs for sample collecting, preparation, shipping, and assaying for this project were the following:

1. Sampling

Expenditures incurred over 78 calendar days or 195 man-days, in or to obtain 1,162 samples each of glacial overburden, A and B soils and humus; and 715 vegetation samples from 327 sites.

| | OB/Soils/Humus | Vegetation | Total |
|---|---|---|---|
| Salaries | $15,760 | $ 4,205 | $19,965 |
| Food & Lodging | 4,158 | 1,142 | 5,300 |
| Transportation | 3,573 | 587 | 4,160 |
| Field Supplies | 1,455 | 250 | 1,705 |
| Auger Operation | 970 | - | 970 |
| TOTALS | $25,916 | $ 6,184 | $32,100 |

2. Preparation

| | | | |
|---|---|---|---|
| Salaries | $12,898 | $ 1,621 | $14,519 |
| Equipment | 237 | - | 237 |
| TOTALS | $13,135 | $ 1,621 | $14,756 |

3. Shipping

| | | | |
|---|---|---|---|
| Freight* & Container | $ 290 | $ 52 | $ 342 |

4. Assaying

| | | | |
|---|---|---|---|
| 567 Heavy Mineral Conc. | $16,800 | - | $16,800 |
| 566 Clay/Silts | 26,864 | - | 26,864 |
| 312 Humus | 8,297 | - | 8,297 |
| 715 Vegetation | - | $19,105 | 19,105 |
| TOTALS | $51,961 | $19,105 | $71,066 |
| GRAND TOTALS | $91,302 | $26,962 | $118,264 |

* Represent only pre-paid UPS shipments. Normal motor freight charges were built into the analytical contract prices.

The foregoing costs represent 60% of the total project budget. A breakdown of these figures shows that the sampling costs were:

| | Per Site | Per Media/Species |
|---|---|---|
| OB/Soils/Humus | $22.30 | $ 7.43 |
| Vegetation | 18.91 | 6.30 |

Sample preparation included sieving and heavy mineral concentrating of glacial overburden and stripping of needles from vegetation twigs at these comparative costs:

| | Per Site | Per Media/Species |
|---|---|---|
| Glacial OB | $23.16 | $11.58 |
| Vegetation | 4.96 (327 sites) | 2.27(715 species) |

Assay costs show that the cheapest analyses were for the 31 elements reported for the heavy mineral concentrates. The same 31 elements were reported for clay/silts, but platinum determinations required extra and costly procedures. Humus and vegetation assays for 21 elements were likewise expensive due to the additional cost for detecting platinum.

It may be argued, with several stipulations, that either heavy minerals or vegetation is the most economical geochemical media to use. Clay is to be avoided as its results are least effective, and most costly to obtain.

# SUMMARY

Bringing this project to a successful conclusion has required considerable hard work and dedication by the people involved. A substantial database has been developed and an equally large volume of geochemical sample material have been collected and preserved, from which even more information can be derived should the need arise.

In the preceding pages, an effort has been made to identify and interpret the geochemical and mineral resource implications of the derived information. The results are not perfect, but they represent the best that is available with the data at hand. There are, undoubtedly, other interpretations that can and will be made by the readers of this document, depending upon their individual biases and expertise. With this recognition, the following conclusions and recommendations are offered.

## Conclusions

1. Anomalous geochemical values of strategic minerals, including platinum, chrome, cobalt, titanium and vanadium, are present in the glacial deposits, humus and selected vegetation species over the interior of the Duluth Complex in Lake County, Minnesota.
2. The detected elements appear to reflect the bedrock units or lithologies.
3. Overburden thickness (maximum of 125-150 feet in the study area) does not appear to significantly distort the bedrock geochemical expression.
4. Complex glacial deposits and depositional history need not deter a surface geochemical sampling program.
5. Transport distances for glacial materials in the study area are apparentally short, less than 1-2 miles.
6. Bedrock geology east of Isabella may require additional interpretation.
7. A multi-media, multi-element geochemical survey is likely to be most successful in a regional reconnaissance program where pre-existing data is scattered, absent or unavailable.
8. Heavy mineral concentrate samples may more closely define bedrock, and the anomalies may be nearer to the source or target.
9. Computer - assisted interpretations of geochemical results are indispensable, especially for humus and vegetation samples.
10. The lowest available detection limits ought to be used for platinum geochemistry.
11. The techniques of this investigation, if used prudently, should be applicable elsewhere in Minnesota, especially for gold.
12. On balance, heavy mineral concentrates are the most reliable geochemical medium on the regional scale because samples are universally available. Vegetation could be equally effective; however, the preferred species are not distributed uniformly thoughout the survey area.

## Recommendations

1. Conduct computer-supported interpretations of the "additional element" analyses included in the database (Part II), but not utilized in the report.
2. Assay the remaining sampled media. The

Division of Minerals has glacial material from 50% of the sample locations, and humus from 73% of the sample locations, available for analyses.

3. Identify, separate and manipulate sub-set data for followup target selections.
4. Rock chip geochemistry.
5. Pebble studies for bedrock characterization and information on direction and/or distance of glacial transport.
6. Site-specific petrographic-microprobe studies of mineral pathfinders.
7. Geochemical traverses from the basal contact into the interior of the Complex.
8. Focus resource evaluations on target areas in the western locality and the eastern locality.

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**Project 262**
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**for**
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# Geochemical Maps
# Heavy Mineral Concentrates

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