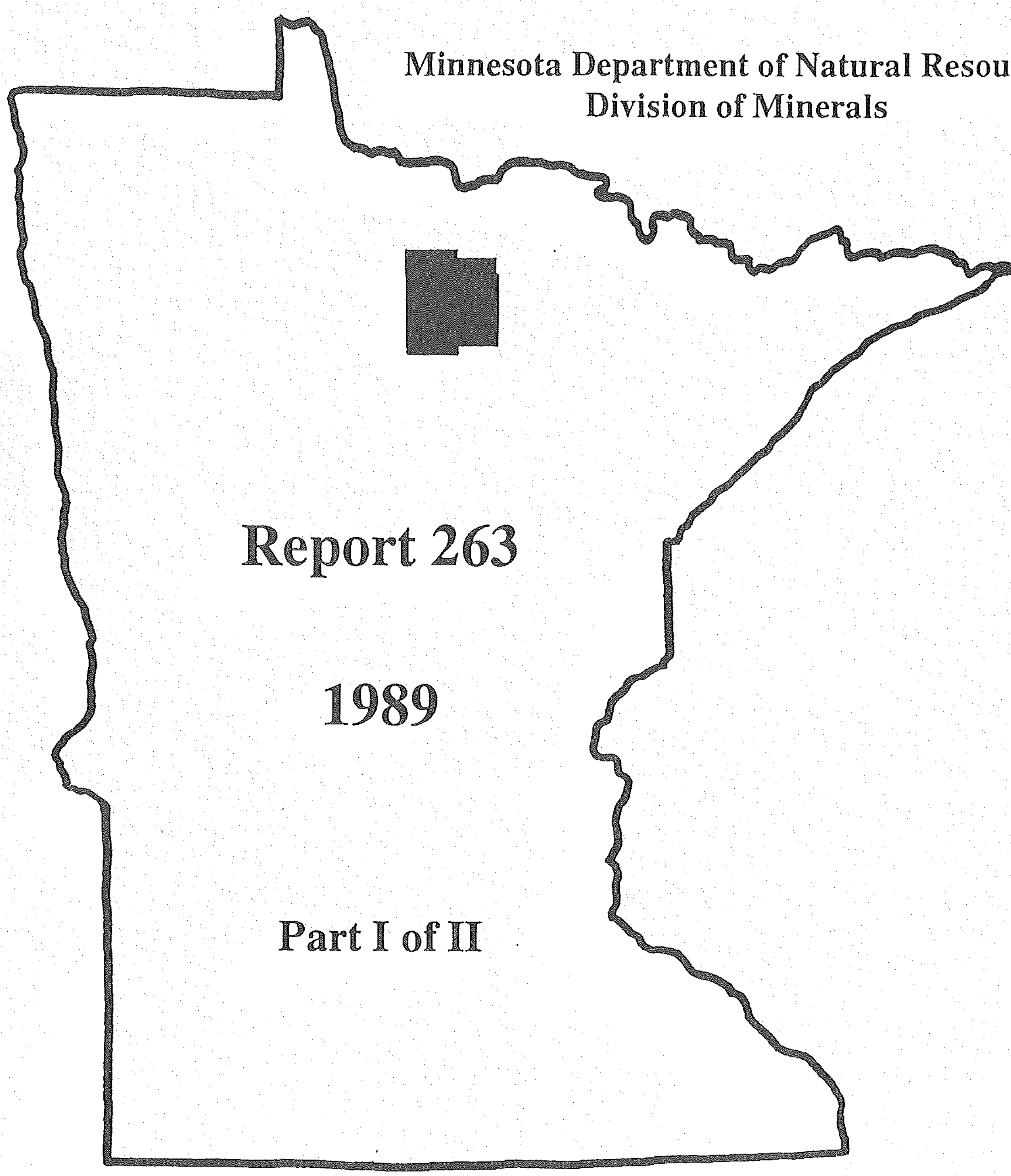
Regional Geochemical Survey of Glacial Drift Drill Samples Over Archean Granite - Greenstone Terrane in the Effie Area, Northern Minnesota

Minnesota Department of Natural Resources
Division of Minerals



Report 263

1989

Part I of II

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

Regional Geochemical Survey of Glacial Drift Drill Samples Over Archean Granite - Greenstone Terrane in the Effie Area, Northern Minnesota

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A Minerals Diversification Project

1989

Report 263
Part I of II

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Abstract

A regional geochemical survey was conducted during 1988-89 by drilling Rotasonic cores of buried glacial drift over roughly 33 townships of Archean (Superior Province) terrane in southern Koochiching and northern Itasca counties between Big Falls and Bigfork. The objectives are directed at mineral potential evaluation and include the identification of glacial drift stratigraphy, favorable stratigraphy and sample media for geochemistry, examination of saprolite and bedrock lithology, and the organization of pertinent data into a computer database.

The underlying Archean bedrock (Quetico and Wawa subprovinces) is poorly understood, being largely unexplored prior to the current Minnesota Geological Survey (MGS) mapping program. Twenty-three Rotasonic drill holes, totalling 4,232 ft., were cored in 34 drilling days in the Effie area. The glacial drift stratigraphy logged by Gary Meyer (MGS) is more complex than to the east or north (Martin, et al., 1988). We have identified the late Wisconsinan Koochiching lobe and Rainy lobe drift, older (pre-late Wisconsinan) drift and saprolite. Lumping the stratigraphy into five general packages--Koochiching drift, Rainy drift, Old Rainy drift, Winnipeg drift, and laterite--there were 14 different stratigraphic columns found in the 23 drill holes. Twelve holes encountered saprolite, ranging in thickness from 1 to 58 feet.

Twenty holes reached bedrock and/or saprolite. The average total depth was 185 feet, ranging from 60 to 296 feet deep. The bedrock data is being integrated into the broader-scale MGS mapping program (Jirsa, 1989A). In a cooperative effort, the Minerals Division (DNR) drilled 9 of the 23 holes at locations the MGS had selected for their current geologic drilling and mapping program in this area.

The glacial drift and saprolite core samples were split and composited within stratigraphic units for processing of heavy mineral concentrates (HMC), -63 micron fraction for Au & Ag, and clay size fraction for base metals. Roughly 190 HMC samples and 190 complementary -63 um samples were analyzed for gold. Limited mineralogy work has been done on the saprolite and nonmag HMC samples. The complexity of the stratigraphy automatically limits our ability to make generalizations about the trace element distributions by subdividing the total sample number into many small subpopulations.

Good cores of older tills and saprolites were obtained for the first time and are available for inspection. Significant information relating to identification of drift types and sample media has been compiled. The average number of gold grains per 10 kg of till samples is much higher here than to the east. Summarizing the HMC results, there are 4 holes with multiple-sample gold grain counts worthy of further evaluation, and 4 other holes with other multielement values greater than or equal to 3 times the median. None of the patterns are interpreted to be adjacent to a bedrock source. The limited dataset does not offer good insights into the geochemical variability expected at the local or property scale. Therefore, the significance of the elevated values in the above 8 drill holes is very difficult to rate.

Rotasonic cores were drilled in three additional townships (T46N-R29W, T46N-R28W, T45N-R27W) in east-central Minnesota overlying Early Proterozoic bedrock. The stratigraphic and geochemical data obtained will be used to plan for possible future mineral evaluation surveys in that region.

1.0 Executive Summary

This project was initiated to establish a framework for future work in a region that currently has very little active exploration of state mineral lands. It covers a region containing roughly three belts of Archean supracrustal rocks within the Wawa-Shebandowan Subprovince of the Superior Province. The eight broad objectives are described in the Introduction.

The primary contributions of this project include:

1) Identification of the complex glacial drift stratigraphy including the older tills.

2) Characterization of the laterite underlying the glacial drift in this region and the implications it has to overburden geochemistry.

3) Identification of the heavy mineral concentrates (HMC) of till or saprolite as the most useful sample media in most conditions of the region. With such low background values for gold and evidence for incorporation of local bedrock, it is suggested that either Rainy till, Old Rainy till, or Winnipeg till may be used for sampling, depending on which comprises the lowermost 100 feet of the drill hole.

4) The geochemical data has been grouped into subpopulations by drift type and underlying bedrock type and thresholds have been suggested for some Rainy lobe till elements. The median values, suggested to be the best estimate of background, are presented for the older drift units.

5) Twenty new data points of sound bedrock (or recognition of bedrock from saprolite) were added to the concurrent Minnesota Geological Survey (MGS) regional bedrock mapping program.

6) Presentation of the geochemical data on a set of trace element distribution maps. A summary interpretation map highlights the drill holes that deserve further evaluation.

7) Core samples of all these geologic units--glacial drift, saprolite, bedrock--are now available for inspection at the DNR Core Library in Hibbing. The older till units and the saprolite are especially interesting to view, in light of the supplementary geochemical and mineralogical data available for them.

8) The entire data set is available in digital form on flexible diskettes in transportable ASCII file format.

The positive aspects found in this region include the diverse bedrock tectono-stratigraphic terranes (Thurston, et al., 1988) in the three greenstone belts and the higher overall gold grain counts (or averages per sample) compared to adjacent regions. These are balanced by the negative aspects including the presence of thicker glacial drift (185 feet average) and presence of older tills and saprolite. Supergene enrichment should be considered for any gold mineralization model that is applicable in this region.

The primary requirement in future drilling programs should be to distinguish till samples of Labradorean provenance (i.e. Rainy or Old Rainy) from those of Keewatin provenance (Table 9). The most useful sample media is suggested to be heavy minerals with a gold grain count and classification from Labradorean provenance tills. Where the Winnipeg lobe till lies on bedrock, it contains numerous local bedrock clasts. Thus, it may contain dispersal trains and, in those cases, should also be useful as a sample media for gold grains. There are a number of means to backtrack a suspected gold-bearing dispersal train to the bedrock source. Within this region of older tills, it is suggested that detailed mineralogy studies be used to discriminate false anomalies, to backtrack on a detailed scale and to confirm the source (Table 4). The specific mineralogy within (or composition of) heavy minerals, the magnetic fraction, intermediate density minerals, or the -63 um fraction could be used for these purposes, depending on the local bedrock type or landscape conditions.

In regards to gold grain counts, the median values for the Rainy lobe tills, Old Rainy lobe tills (except hole OB-321), and the Winnipeg lobe tills remain sufficiently low (see median values equal to 0, 1, or 2 grains in Table 5) that true dispersal trains near gold-bearing bedrock sources should provide excellent contrast of much higher grain counts.

In regards to gold grain classification, such as abraded vs. delicate, the question of whether supergene processes have changed primary gold grain morphology must be considered here.

One author (D.P.M.) suggests that high gold grain counts in holes OB-321, OB-318, OB-301, and OB-315 should encourage further evaluation in those townships. None of the samples, or drill holes, exhibits geochemical data indicative of the "head" of a dispersal train, i.e., nearby to gold-bearing bedrock source (Fig. 2). Rather, the higher gold grain counts could imply a local source as part of the "tail" of a dispersal train. For example, in hole OB-315, there are 11 gold grains in one Rainy till sample which is 13 feet higher in the stratigraphy than an Old Rainy till sample bearing 11 gold grains.

The sample with the highest gold grain count, 30, is in OB-321, quite high above the bedrock. Although all the other samples in that hole also contain some gold, its source or implications are enigmatic at this time.

The gold grain counts in OB-318 are slightly elevated, and the simple two-layer stratigraphy, the structural geology, and the relatively shallow drift boost the rating for this area.

Finally, in hole OB-301, the usually barren Winnipeg lobe till contain some gold. Again, the location near the Coon Lake syenite pluton and the relatively shallow drift boost the rating for this area. A biogeochemical survey of widely spaced black spruce bark samples may be a rapid, economical means to evaluate an occurrence such as this.

In regards to other metals, holes OB-310, OB-329, OB-306, OB-320, and OB-313 contain multielement values greater than 3 times the median value (see Section 12.1). The most significant seems to be in OB-310, which contains one Rainy lobe till sample with anomalous Cu, As, Bi, Sb, Pb, and Ni in the nonmagnetic HMC. An examination revealed that pyrite is present in the HMC, although no other ore minerals were observed.

The conclusion is that overburden drilling is a feasible means of gold exploration within most townships in this region, and valuable reference data has been assembled within which further exploration can proceed systematically.

2.0 Recommendations

Suggestions for future DNR Minerals work, which should be helpful to exploration geologists wishing to work in this region, include the following:

1. Perform "half distance of transport" estimates by doing pebble counts in the Rainy lobe down-ice from distinctive lithology outcrops. Do this near the Coon Lake Pluton, if possible, to estimate transport half distances (Fig. 2).

2. Do more drilling in selected townships (greater than or equal to 3 more holes per township) in a follow-up survey to obtain gold grain counts and geochemistry to compare the three greenstone belts to each other to try to determine which is more productive. This would better define the geographic and stratigraphic location of favorable drift units for sampling and lead to a practical working strategy for an economical sampling program. Also, the three hypotheses presented in Discussion of Geochemical Results, which are significant to interpretations, would be better constrained.

3. Perform a test survey on biogeochemistry for gold in four townships (T61N-R25W, T61N-R26W, T154N-R25W, T154N-R26W) where the drift is less than or equal to 100 feet thick. Take one sample of black spruce bark per section with the goal of seeking patterns in thick glacial cover that could be tested by glacial drift drilling.

4. Further evaluate laterite secondary gold grain morphology (Fig. 4). This requires extracting gold grains from in-place laterite samples (i.e. core from OB-329) and viewing them with a microscope. Establish whether the ODM grain classification system needs modification for these samples. Examine the +10M screen fraction that is currently excluded from analysis to see if gold-bearing pisolites or other laterite fragments, which could be incorporated into the glacial drift, may occur within that fraction.

5. Relate magnetic fraction composition to bedrock type. The amount of recycling of older sediments, for example, into Rainy lobe tills, needs evaluation. The magnetic fraction, the CO_2 content, quantified nonmag mineralogy (gram weight x point count weight % by mineral species), and microprobe mineral compositions appear to offer the best potential solutions to recycled sediment questions.

6. Develop a working theory for regional and local patterns of gold dispersal here. Try to understand the question "Why are there 3 to 6 times more gold grains per sample in this region?"

7. Attempt to overcome the scheduling and other obstacles to produce a final report that is one entity, rather than broken up into discrete sections by different authors, as this one is.

8. Drill a reverse circulation hole next to an appropriate Rotasonic core bearing complex stratigraphy to provide one example for improving the identification of all till types in cuttings. Or test down-the-hole geophysics to help identify stratigraphy in reverse circulation drill programs.

9. Re-analyze selected samples of -63 um fraction for gold, following wet screening (vs. dry). The dry screening has been contracted to the assay labs, and poor performance and documentation has resulted. Proper evaluation of the effectiveness of screening has not been possible.

10. Build the database to be able to compare thresholds over different bedrock types, especially contrasting Rainy lobe till vs. Old Rainy till. Is it workable, as suggested, to simply call the till Labradorean provenance and use a common threshold value? More statistically valid conclusions are necessary to answer this.

3.0 Acknowledgements

First, we appreciate our management's sponsorship, cooperation, and willingness to let us pursue our own path to complete this large project on schedule. Secondly, the cooperation of the MGS, especially Mark Jirsa's and Terry Boerboom's bedrock descriptions, is greatly appreciated.

Pat Geiselman contributed significantly to the group effort required during fieldwork and his work ethic is to be applauded. Due to the diligence of Rick Ruhanen, this report has benefited greatly from improvements in infrastructure. He has upgraded our computer network and implemented the use of Ventura Publishing System. Jacki Jiran provided valuable assistance with the computer work which permitted us to complete the work on schedule. Coleen Keppel had the enviable task of actually entering the report text and most tables. She also learned the new Ventura Publishing System, with Jacki's assistance, in record time to try it on this report. The result of their efforts is a far more readable document and one that is much improved. Tim Pastika transferred out of this project at about the midterm. David Dahl replaced Tim, and David greatly contributed to the statistical data handling part of the report by quickly grasping the essence of the objectives. Greg Walsh did most of the drafting for the DNR maps and suggested valuable improvements to them. Earl Mailhot also helped draft some maps. Dorothy Erickson helped input the master sample list and lab data into the computer datafiles. Gene Karel processed the drill contract through the state bid system and handled the major state accounting functions. Gene Miller and Karl Kiehn provided legal review of mineral ownership records on more than 100 parcels. All their efforts are appreciated. Even though the dataset was not organized and available for inspection, my brief discussions with Dr. Colin Dunn, Geological Survey of Canada, were very helpful. This report is certainly improved as a result, and we sincerely appreciate his efforts.

4.0 Introduction

The project was designed primarily to seek mining-camp-scale gold and other metal occurrences within three Archean Superior Province greenstone belts covered by 50 to 250 feet of glacial drift in an area totalling approximately 1100 square miles in northern Minnesota (see concept, Appendix 3-2; also Stanley and Smee, 1988). The survey design was based upon a specific set of objectives, budget criteria, anticipated geologic landscape conditions, and limited information about a virtually unexplored area. It was patterned after a survey completed the previous biennium on adjacent townships to the east (see Map 1-1). That project identified an area of high potential for gold near Linden Grove, St. Louis County (Martin, et al., 1988). That survey required four holes per township to identify regional patterns in glacial drift (Figs. 1 and 3), and had a much simpler two-layer stratigraphy with very little saprolite. The Rotasonic drill method, in contrast to air- or mud-rotary, was found to provide drift cores that are essential to set up a regional survey of this type. Heavy mineral concentrates and gold grain counts from the buried Rainy lobe till were more useful than the -63 um fraction sample media. However, with the expected fine-grained laterite gold, and laterite incorporated into the glacial drift, the -63 um fraction had to be reevaluated in the Effie landscape.

The geochemical phase of this project must be considered incomplete at this time, since three additional holes per township must be drilled to fulfill the original goal. Because of the high drilling costs, the work has to be spread over more than one biennium. Following the Minerals Division policy, these state lands will be available for leasing, if requested, in 1989. Thus, our intent is to complete the project with further drilling in future biennia, and this is considered to be an interim report. This intent must be balanced by DNR policy to work around, but not in, sections that have active leasing.

A secondary goal was to drill one Rotasonic core in each of three townships in the Ironton area of east-central Minnesota to evaluate the complex landscape there to plan for future work. The area is underlain by Middle Precambrian rocks with good mineral potential, but there are so many till sheets that the geochemistry is poorly understood. The stratigraphic and geochemical data obtained will be used to plan for possible future mineral evaluation surveys in this region.

4.1 Objectives

The specific objectives include:

1. Create geochemical maps of the buried glacial drift that seek to identify areas of high mineral potential.

2. Identify the buried glacial drift stratigraphy to interpret the general directions of glacial transport and appropriate drift units for sampling.

3. Test which sample media (i.e. heavy mineral concentrates, silt-size fraction, clay size fraction or saprolite itself) would best serve this regional survey.

4. Test the geochemistry of each strata to evaluate its correlation to bedrock on a regional scale.

5. Evaluate the distribution of weathered bedrock, which probably represents a period of Cretaceous laterite weathering and sedimentation as described by Parham (1970) in southern

Minnesota.

6. Improve the bedrock map, which the MGS is currently developing, by providing new bedrock drill core samples.

7. Provide samples of the glacial stratigraphy, laterite stratigraphy, or bedrock to the DNR Core Library for geologists to examine or sample.

8. Present the data in digital form for distribution on flexible diskettes in tranportable ASCII file format.

In summary, the overall goal is to define the general landscape conditions (see Appendix 3-2 for brief description of Fortescue's landscape geochemistry), on a township-by-township basis, within whose framework future exploration programs will have to challenge. The data is presented so that it can be reviewed on a case-by-case basis, and as a regional overview.

4.2 Funding

This project was funded as part of the Minerals Diversification Program for the 1987-89 biennium at the rate of $100,000 each year. It was proposed and supervised by the DNR Minerals Division, with a significant contribution on glacial geology and bedrock geology by the Minnesota Geological Survey (MGS).

4.3 Chronology of Events and Contributors

The DNR Minerals Division is the lead agency and carries responsibility for this report. Individuals with specialized experience within glacial drift stratigraphy, bedrock geology, geophysics, and geochemistry contributed to different parts of the project. The contributions are found as separate report sections on glacial drift stratigraphy and seismics, since these were necessary at intermediate stages within the project schedule. However, the contribution on bedrock geology, by Terrence Boerboom and Mark Jirsa of the MGS, was merged into the Drill Hole Summary Sheets within the body of the report.

The entire project, from fieldwork to report completion, was confined to a 14-month period, April 88 through May 89. The primary components of the project were completed on the following schedule:

1. Drill Site Selection April & May, 88

2. Drilling, 0.9 miles of core May & June, 88

3. Logging & Sampling, 1350 boxes
August thru October, 88

4. HMC Processing & Assays
October thru April, 89

5. Building Computer Datafiles
January thru April, 89

6. Report Writing April and May, 89

Since the analytical laboratory took much longer than scheduled to complete the assays, the authors were forced to severely limit the scheduled data manipulations and some entire avenues of interpretation.

When this project was starting up, the MGS was simultaneously broadening their bedrock mapping work. From the Sherry Lake Quadrangle (Jirsa, 1988), which is roughly ten miles to the east and contains relatively abundant outcrop area, the MGS expanded into a regional mapping project, primarily by interpreting new aeromagnetic data and doing selective shallow drilling. In a cooperative effort, DNR Minerals agreed to drill Rotasonic cores at 9 sites selected by the MGS to support their bedrock mapping. Those 9 sites are reported here as OB-303, -309, -310, -311, -318, -319, -320, -321, and -329. In addition, since Mark Jirsa (MGS) wanted to log the bedrock from those sites for his bedrock mapping, the MGS volunteered to contribute his descriptive logs of the bedrock in all the Rotasonic drill holes, and which were supplemented with Terrence Boerboom's (MGS) thin section petrography. The result is an excellent product from the people with the most current field experience in these greenstone belts.

At the beginning of the project, Tom Lawler of the DNR Minerals Division set up a test project for reflection seismic depth-to-bedrock estimates at 10 drill sites. He has written a separate section in this report about that work.

Finally, Gary Meyer of the MGS was contracted to perform the logging of the glacial drift cores. Gary completed a similar task on Rotasonic cores, reported in DNR Report 252 (1988), in areas adjacent to the east and a few miles to the north. Thus, he is very familiar with the stratigraphy and the task of stratigraphic correlation into this project area. His work had to be completed soon after the drilling to support the geochemical sampling. His report on glacial drift stratigraphy was completed January 31, 1989, and is, therefore, presented as a separate section within this report. Note that his work was essentially completed before assay results were available, so he did not benefit from them during his efforts to correlate stratigraphy.

5.0 Location and Access

The primary drilling area is around the town of Effie (see Map 1-1) with the northern boundary approximately 38 miles south of International Falls on Highway 71. It covers approximately 33 townships (approx. 1100 sq. miles) in northern Itasca County and southern Koochiching County with the county boundary almost bisecting the area east to west. The area is contiguous with the Orr area to the east (Martin, et al., 1988). The secondary area near Ironton (Map 1-1) was surveyed as a test for consideration as a future project. Ironton is approximately 84 miles (14 townships) south of Effie. This area is approximately 14 miles northeast of Brainerd along Highway 210, covers three townships (approx. 108 sq. miles), and straddles the Aitkin or Crow Wing County boundary with the southeastern corner extending over Mille Lacs Lake.

All holes were drilled with a truck-mounted Rotasonic drill rig and sites were on clearings that serve as log landings, usually 100 ft. from a road (Map 1-2). The summer access trail to the drill site had to accommodate a 2,000 gallon water truck with drill steel as well as the drill rig. As such there were 8 townships that had no trails, and we could not drill. Detailed site location maps are available on request.

6.0 Exploration History and Land Status

There are three greenstone belts that underlie the 33 townships of the Effie area. There has been relatively little previous exploration in this area, probably due to the thick glacial drift cover. There are currently 26 private exploration drill cores from the area that have been received by the DNR Core Library. The drill hole locations are in six different townships and within 14 different sections (see Table 10). Most of the past work was focused on the Archean Deer Lake Gabbro Complex, where there are numerous outcrops and thin glacial drift cover. At least three master's theses (Berkley, 1972; Ripley, 1973; Nicol, 1980) and one MGS Report of Investigations #20 (Berkley and Himmelberg, Part A; Ripley, Part B, 1978) describe the Deer Lake Complex. A similar glacial drift geochemistry survey was recently completed by the DNR Minerals Division (Martin, et al., 1988; Map 1-1). It provides useful comparative data for Rainy lobe till samples obtained by drilling, such as an arithmetic average of 1 gold grain per 17 kg of Rainy lobe till (n = 128 samples).

There is a considerable amount of current work in progress in this area. There are two active state leases within the area outlined by this report (see DNR Lessee's Listing). The U.S. Geological Survey has flown aeromagnetics over this area in conjunction with a CUSMAP project on the International Falls and Roseau 2° sheets (Bracken & Godson, 1988; Horton & Smith, 1987). That data is scheduled for release in mid-1989. The USGS also flew airborne E-M over the Coon Lake syenite pluton in T61N-R25W as part of a small test project (Smith, Labson & Horton, 1989). The MGS is currently completing a bedrock mapping project that covers a larger area than this geochemistry survey. Their project is based on information on 60-plus new drill holes and the new USGS the aeromagnetic survey (Jirsa, 1988; Jirsa, 1989A; Jirsa, 1989B; Jirsa, in prep.). Roughly 40 miles to the northwest, across the border into Ontario, the Ontario Geological Survey is conducting a regional glacial drift geochemistry project in the Wabigoon Subprovince (Bajc, 1988).

Finally, there is a considerable amount of state mineral land currently available for leasing across all three greenstone belts.

7.0 Overview of Geology

The physiography, glacial drift, weathered bedrock and bedrock have been examined in the Effie and Ironton areas (Table 3). The Archean Superior Province granite-greenstone terrane of the Effie area provides some interesting combinations of topography, drainage systems, glacial drift features, vegetation and bedrock features.

Glacial drift stratigraphy is very complex in several of the drill holes in these areas. During the last 1.5 million years, there have been four major glacial epochs, with complementary interglacial times. Within the late Wisconsinan, ice lobes from two ice centers, Keewatin and Labradorean, advanced over this region depositing the Koochiching lobe drift and Rainy lobe drive, respectively. Similar pairs of ice centers are interpreted from the pre-late Wisconsinan till types. Although there were several advances of the pre-late Wisconsinan lobes, they have only been differentiated into the Old Rainy (Labradorean provenance) and the Winnipeg (Keewatin provenance) for this report.

During the Cretaceous, thick weathered mantles formed on the bedrock under tropical climatic conditions (Parham, 1970). The mantles were not completely eroded prior to or by the glaciers, and lie buried beneath glacial drift. In many cases, the weathered material has been incorporated into the glacial drift. The distribution of buried saprolite and older till units is not well defined by available drill cores (Map 1-6).

7.1 Physiography

Surface elevations in the Effie area range from a maximum of 1490 feet to a minimum of 1185 feet. The continental divide is roughly 12 miles south of the area, and the river systems flow to the north. The primary river is the Bigfork River. The northern 1/3 of the area is primarily black spruce forest or peatlands and the southern 2/3 is covered by scattered and mixed conifer and deciduous forests. Clay-rich Koochiching lobe glacial drift is the predominant surficial material. Buried Rainy lobe moraines create uplands that extend across the top of Itasca County, through the survey area. Outcrops are scarce, existing mainly in the southeastern quarter (Map 1-3). The Coon Lake pluton creates an upland in the southeast corner with an elevation of about 1430 feet. The Lake Aggassiz Peatland Natural Landmark occupies roughly 23 square miles in T64N-R25W and T65N-R25W (Map 1-2).

The Ironton area is located 84 miles south of the Effie area (Map 1-1). The maximum elevation in the area is 1406 feet and the minimum is 1210 feet. The continental divide is located 72 miles north of the area; consequently, the rivers flow south into the Mississippi River system. The forests are mainly mixed hardwoods. The Rainy lobe glacial drift is exposed at the surface in the western half of the area and the St. Louis sublobe is exposed in the eastern half. A St. Louis sublobe moraine divides the area and trends approximately 140°. There are several drumlins in the southwest corner. The area is dotted with many lakes and streams, and the southeast corner reaches Mille Lacs Lake. The area also extends over the Cuyuna Iron Range in the northwest corner.

7.2 Glacial Drift Stratigraphy by Gary Meyer (MGS)

7.2.1 Introduction

This portion of the report summarizes and interprets data on subsurface Quaternary deposits in northern Minnesota based chiefly on visual examination of core obtained by a rotasonic drilling program of the Department of Natural Resources (DNR) Minerals Division. Twenty three holes were drilled in the Effie area (Map 1-3) and three holes were drilled in the smaller Ironton area (Map 2-3). Holes were widely spaced at one to a township in order to survey the large area involved. Continuous 3"-diameter core of the entire Quaternary section to Precambrian bedrock was taken in all but four holes in the Effie area, and in two of three holes in the Ironton area. Recovery was generally good. The objective of this time-constrained report is to portray the regional framework of the Quaternary stratigraphy as deduced from the high-quality rotasonic drill core.

Both areas were repeatedly overridden by Pleistocene ice advances of both northeastern (Labradorean) and northwestern (Keewatin) provenance. Glacial sediment deposited prior to the last (late Wisconsinan) major glaciation is found preserved in the subsurface in increasing thickness and complexity west and south of the major Precambrian outcrop area of northeastern Minnesota. This holds true in the Effie area, where thickness and complexity of pre-late Wisconsinan drift generally increases from northeast to southwest.

For the purpose of discussion, in this report pre-late Wisconsinan glacial ice advancing into northwestern Minnesota from the Keewatin ice center is termed the Winnipeg lobe, after Lake Winnipeg and its environs, where much of the glacier's sediment load was derived (Fig. 7-1). Sediment laid down by earlier ice advances of northwest provenance in general lack the characteristically high content of Cretaceous Pierre Shale fragments present in deposits of the late Wisconsinan Des Moines lobe of Minnesota, implying separate ice-flow directions. The term "Winnipeg" lobe replaces that of "Wadena" lobe of earlier workers. This became necessary when it was shown that sandy till of the Wadena drumlin field, thought to be a characteristic deposit of the Wadena lobe, was actually laid down by the northeast-provenance Rainy lobe (Meyer, 1986; Goldstein, 1987). Till characteristic of the Winnipeg lobe is carbonate-rich and has a loamy to clayey texture.

Another new, provisional term coined in this report is that of the Koochiching lobe (Fig. 7-2) after Koochiching County, Minnesota. Previous workers referred to the northwest-provenance ice lobe, which moved into northern Minnesota, as the St. Louis sublobe of the Des Moines lobe. Due to its unique morphology and sediment load, only that portion of its ice which reached south of the Mesabi iron range is referred to as St. Louis sublobe in this report. The remainder of the ice advance is termed the Koochiching lobe.

Ice moving into northern Minnesota from the northeast, based on its several deposits, did not apparently vary greatly in its flow direction throughout the Pleistocene. The term "Rainy" lobe is therefore retained for both late Wisconsinan and older glacial deposits (Fig. 7-1). Ice of northeastern provenance alternated with and apparently preceded that of northwestern provenance in each of the major glaciations across central Minnesota (Meyer, 1986). This is thought to be the case in the Effie and Ironton areas as well (Fig. 7-3). The two older Rainy lobe drifts in the Effie area are thought to correspond to the two identified in the Ironton area, but only the upper Winnipeg lobe drift in the Effie area is thought to be present in the Ironton area. The pre-late Wisconsinan glacial sediment record in Minnesota is far from complete, and much work remains to better elucidate its depositional history.

7.2.2 Previous Work

Winter and others (1973) mapped and described the Quaternary geology of the Mesabi-Vermilion iron range area, primarily on the basis of extensive exposures in the mining district. The northern boundary of their map area lies a few miles southeast of the Effie area. The "basal" till of their report is equivalent to Winnipeg lobe till in this report, and their "bouldery" till is probably equivalent to both late Wisconsinan and older Rainy lobe till, because its lower portion is in places characterized by an oxidation zone and a textural change. The western portion of their surficial "brown silty" till was laid down by the Koochiching lobe, but the eastern portion is Rainy lobe sediment. This last relationship was recognized by Steinmaus (1983) whose study of the geology and geochemistry of the glacial deposits of northeastern Itasca County extended into the southeastern corner of the Effie area.

Eng (1980) mapped the surficial geology of Koochiching County in support of the DNR peat program, relying primarily on interpretation of airphotos. Meyer produced a report for an earlier DNR rotasonic drilling program for the Little Fork area to the north of Effie, and the Orr area to the northeast (Martin and others, 1988). Regional studies that include the Ironton area were produced by Schneider (1961) and recently Mooers (1988). The glacial history of both study areas is treated broadly in Wright (1972), and relationships of the regional glacial geology to the rest of the state are shown on the Quaternary geologic map of Minnesota by Hobbs and Goebel (1982).

7.2.3 Methods

Core was logged in a temporary storage facility of the DNR Minerals Division in Hibbing. Textural analysis and pebble counts were completed for 33 samples, primarily of pre-late Wisconsinan till. No field work was carried out for this report. Locations of water-well, USBM, USGS, MnDOT, MGS and industrial exploration-hole subsurface data on file at the Minnesota Geological Survey are shown on Maps 1-3 and 2-3, as are measurements of glacial striation directions. Most driller's water-well locations were not checked, and may be imprecise or incorrect. Quaternary stratigraphy and bedrock topography between rotasonic drill holes (Maps 2-3 & 1-4, and Plate 4-2) are largely interpreted from unconfirmed well information. The cross sections, therefore, should be viewed as only a generalized representation of the Quaternary stratigraphy, with reliable data points miles apart.

Characteristics noted during logging of the core include texture, Munsell color, reaction to hydrochloric acid, pebble abundance and type, presence of organics, and sedimentary structure. Graphic and descriptive logs of each of the holes drilled are presented in Part II because of their large-scale format. During logging, depths recorded on individual samples were checked against the on-site log provided by the DNR to determine actual thickness of the various units encountered. Recovery was not always good, sediment was occasionally "sluffed" in from above, and cores were sometimes distorted during drilling or following extraction from the core barrel. The true depths of some lithologic contacts may be 1 or 2 feet from their apparent depth, despite efforts to maintain accuracy.

7.2.4 Quaternary Units

The Quaternary section in the northeastern portion of the Effie area is dominated by late Wisconsinan drift, primarily till and lake sediment of the Koochiching lobe. The implication is that the Rainy lobe was highly erosive in this area, largely removing older deposits (and saprolite), and laying down relatively thin deposits in their place. Pre-late Wisconsinan drift in general increases in thickness and complexity to the west and south in the subsurface of the Effie area. A deep, buried bedrock valley (Map 1-4), which bisects the area from northeast to southwest, contains a complex fill, apparently dominated in the lower portion by thick sand and gravel. The deep valley may in reality deepen to the north rather than the southwest as portrayed, but data are insufficient for determination.

The eastern portion of the Quaternary section in the Ironton area is controlled by a major buried bedrock valley (Map 2-3), which is believed to extend in the subsurface from Mille Lacs Lake to the Red River Valley (Olsen and Mossler, 1982). Only three holes were drilled in the area, one of which did not reach bedrock, but in general it appears that the section in the western portion consists primarily of Rainy lobe drift over bedrock, whereas the drift sequence is much more complex in the eastern portion over the bedrock low (see hole OB-402).

7.2.4.1 Winnipeg Lobe

Tills from at least four separate advances of the Winnipeg lobe (Fig. 7-3) are thought to be present in the study areas. The upper two Winnipeg lobe tills in the Ironton area are separated by a few inches of lake sediment and a paleosol. The other Winnipeg tills are interbedded with Rainy lobe tills. Winnipeg lobe tills are characterized by common to abundant Paleozoic carbonate clasts, and rare to common clasts of Cretaceous (older than Pierre Shale) limestone and shale. Texture ranges from loam to silt loam to clay loam. Color is typically dark gray to very dark gray, but can range from gray to greenish gray due to incorporation of local sediment. Although characterized by far-travelled rock types, local bedrock and saprolite is clearly incorporated in Winnipeg lobe till where it occurs in the basal part of the Quaternary section. Winnipeg till, as with all pre-late Wisconsinan till in the subsurface, is compact and indurated. From the holes where bedded sediment associated with the Winnipeg lobe was encountered (OB-320 and 331), it would appear that its ice was commonly fronted by a glacial lake during advance and retreat within the Effie area, as were later late Wisconsinan ice lobes. Gravelly sand above interglacial sediment in OB-321 may represent a proglacial outwash from the equivalent Winnipeg lobe advance in the Ironton area (3 or 4 on Fig. 7-3). Wood from the sand yielded a radiocarbon date of greater than 40,600 years BP.

7.2.4.2 Old Rainy Lobe

The Rainy lobe advanced at least twice into both the Effie and Ironton areas prior to its latest advance in the late Wisconsinan (Fig. 7-3). Rainy lobe drift is characterized by an abundant assemblage of Precambrian rock-clasts--Archean clasts in deposits north and west of the Mesabi iron range, but chiefly Proterozoic clasts south of the range as in the Ironton area. Rainy lobe till in the Effie area is gray to greenish gray in color, whereas in the Ironton area it tends to have a more brownish (7.5YR) cast. Rainy lobe sediment in the two study areas varies from noncalcareous to calcareous, depending on how much underlying Winnipeg lobe sediment was incorporated into Rainy lobe ice. Carbonate content therefore tends to increase down-ice from northeast to southwest.

Old Rainy till varies texturally from loam to sandy loam, with common to abundant gravel and boulders. Silt content typically is much higher relative to clay, as compared to Winnipeg or Koochiching lobe till. The high clay content of northwest-provenance till is attributed to disintegration of Cretaceous shale, whereas the high silt content in Rainy till is rock flour from glacial abrasion of crystalline rocks. Pre-late Wisconsinan Rainy till tends to have more matrix silt and clay than does till of the late Wisconsinan Rainy lobe. Old Rainy till is even more compact than late Wisconsinan subglacial Rainy till, and in places the two are distinguished by a leached and oxidized zone at the top of the older till. Bedded sediment of all size ranges is commonly associated with till of the older Rainy lobes.

7.2.4.3 Superior Lobe

Superior lobe drift was identified in only one hole (OB-402) in the Ironton area. It underlies St. Louis sublobe drift, and local glacial history, as currently understood, would place it stratigraphically below late Wisconsinan Rainy lobe drift. The Superior drift was also probably deposited during the last glaciation, although it is deeply oxidized in OB-402. Superior drift is characterized by a distinct reddish-brown (5YR) color when oxidized, and it contains a unique suite of Keweenawan rock fragments. Superior lobe till is similar in texture to Rainy lobe till, although on average Superior till is probably less rocky. Thick deposits of coarse fluvial sediment commonly occur within the Superior lobe drift section.

Brown to reddish-brown, noncalcareous clay laminae were noted toward the top of late Wisconsinan Rainy lobe lake sediment in the northern part of the Effie area (OB-310, 312, 318, 322). This clay was introduced into the large proglacial lake fronting the Rainy lobe during its standstill at the Vermilion moraine, just prior to the advance of the Koochiching lobe into the lake basin (Martin and others, 1988, p. 20). The clay originated either from a large glacial lake dammed by the Superior lobe south of the Mesabi range, or from meltwater coming from ice at the Highland moraine to the east (Hobbs and Goebel, 1982). Reddish-brown inclusions in Koochiching lobe subglacial till in OB-306 were probably plucked up from this lake deposit to the northwest.

7.2.4.4 Rainy Lobe

Rainy lobe drift of late Wisconsinan age was encountered in all but five holes in the Effie area, and two of three in the Ironton area. Late Wisconsinan Rainy till of both areas is typically only slightly calcareous, but can exhibit higher acidic reactions depending on content of incorporated older calcareous drift. Texture of subglacial till is primarily sandy loam to loamy sand, with a high content of gravel to boulders. Texture of supraglacial till is more variable and can be more matrix dominated.

The dominant geomorphic feature left by the Rainy lobe in the Effie area is a recessional moraine, herein named the Effie moraine, which trends generally from northwest to east across the study area (Map 1-3). West of Effie it is covered by Koochiching lobe drift; east of Effie it is more distinct and parallels the somewhat younger Vermilion moraine (Hobbs and Goebel, 1982). Several ridges that trend at an angle southeast from the moraine are thought to be Rainy lobe eskers deposited by meltwater flowing toward the gap between the Mesabi range and the Itasca moraine at Grand Rapids. One such esker was penetrated by hole OB-320, where an esker apparently of the Koochiching lobe is nearly juxtaposed for over a mile (Map 1-3). An alternative explanation is that the more subdued eskers are earlier, more deeply buried Koochiching lobe eskers that consist primarily of reworked Rainy lobe sediment.

Interestingly, although bedded sediment is common above and within subglacial Rainy till, very little was encountered below it in the Effie area. This implies that relatively little meltwater was coming from the advancing Rainy lobe, and that furthermore, the meltwater was able to drain to the west. Following retreat of the Rainy lobe, thick deltaic sand and gravel topped by lake silt and clay were laid down over Rainy till in most of the Effie area.

Evidence for a local readvance of Rainy lobe ice over the lacustrine sediment was encountered in holes OB-323 and 329, and especially in OB-322 in the northwestern portion of the Effie area. Till associated with this readvance has a more loamy texture than typical and varies from slightly calcareous to calcareous. Carbonate pebbles are relatively common in places, and possibly indicate a shift in ice flow direction. This till is overlain by lake sediment that correlates with Rainy lobe lake sediment to the northeast, and therefore ice of the readvance was gone from the area for some time before the arrival of Koochiching lobe ice.

Bedded sediment associated with Rainy lobe till in the Ironton area is primarily outwash sand and gravel, as Rainy lobe meltwater was able to drain southward. A thick outwash sequence is present above till in OB-401 and below till in OB-403.

7.2.4.5 Koochiching Lobe

Koochiching lobe sediment dominates the Quaternary sequence in the northeastern part of the Effie area, and is thicker than 200 feet in holes OB-310 and 312. It generally thins to the southwest over thicker, older glacial sediment, with an apparent exception in the area around OB-313 and 319 in the south. Evidence for at least two distinct phases of the Koochiching lobe are present across most of the Effie area, where two Koochiching till units are typically separated by lacustrine sediment. In contrast to the Little Fork and Orr areas to the north and northeast (Martin and others, 1988), however, here the second phase, based on thickness of sediment, appears to have been longer lived than the first phase. Both phases were fronted by a large glacial lake during both advance and retreat across most of the Effie area.

Koochiching lobe till of both phases exhibits great textural variability, from clay to sandy loam, but in general the lower till is a loam to sandy loam, whereas the upper till is a clay to clay loam. The basal portion, and in places the bulk of the lower till (OB-306, 319), commonly is a calcareous sandy loam generally lacking in Cretaceous shale clasts. The lack of these indicator clasts is thought to be the result of dilution by the obviously extensive incorporation of underlying Rainy drift. Careful examination is necessary to distinguish the two tills, especially in the southern part of the Effie area where carbonate is not an uncommon component of Rainy till.

Koochiching lobe till is distinguished from other tills of the Effie area by its common to abundant shale content. It is more clayey and carbonate-rich than Rainy lobe till, and less dense than both it and tills of the Winnipeg lobe. Due to its depositional environment at the margin of a large glacial lake, Koochiching till is in places difficult to distinguish from massive, dropstone-rich lacustrine sediment. The till is commonly extremely clayey due to incorporation of overridden lake clay. Sand and pebbles tend to be grouped in lake clay, and are generally not as common as in even the most clayey of tills. Lake clay is softer, exhibits sedimentary structure, and has a sheen on freshly broken surfaces.

Extensive deposits of ice-contact sand and gravel in the form of both kames and eskers are present in the southwestern and southernmost parts of the Effie area. Much of the meltwater from the entire Koochiching lobe was apparently channeled through this area toward outlets to the southeast.

7.2.4.6 St. Louis Sublobe

St. Louis sublobe drift in the Ironton area consists primarily of reworked Superior lobe lake sediment and Rainy lobe till, because it was deposited at the margin of the sublobe. St. Louis sublobe till therefore varies from clayey to sandy in texture, and from noncalcareous to calcareous. St. Louis sublobe sediment is reddish brown due to incorporation of Superior lobe lake clay. It was distinguished from Superior lobe sediment in OB-402 by an unoxidized-oxidized contact. Rainy lobe drift is not as reddish and generally is more sandy than St. Louis sublobe drift.

7.2.5 Prospecting Applications

Till at or near the base of the Quaternary sequence is the best sampling medium for prospecting purposes. Late Wisconsinan Rainy lobe till occupies this position in the northeastern part of the Effie area (Map 1-3)). A recent study from a similar drilling program to the north and east (Martin and others, 1988) has shown that this till is useful for prospecting. Elsewhere in the Effie area, however, late Wisconsinan Rainy till does not typically occur as the basal till, and the several tills occurring above bedrock require a greater density of subsurface data to work out local drift stratigraphy and ice-flow directions.

A good understanding of the regional bedrock topography is also critical to an exploration program. In general, subglacial transport carries entrained debris toward topographic lows, and transport distances through valleys or bedrock lows are longer than across intervening bedrock highs (Clark, 1987). The apparently more variable bedrock topography in the southern and eastern parts of the Effie area should have limited transport distances of basal till in these areas (Map 1-4).

The Effie moraine (Map 1-3), buried by a mantle of Koochiching lobe sediment across most of the Effie area, provides the best source for estimating local ice-flow directions of the late Wisconsinan Rainy lobe. In the vicinity of the Effie moraine, the ice is expected to have flowed perpendicular to the moraine's trend. A glacial striation measurement north of the moraine (Map 1-3) is perpendicular, as are measurements southeast of the town of Effie. The latter striations, however, could have been formed by Koochiching lobe ice which also moved in a southeastward direction in this area, as indicated by the general lobe morphology. Two additional measurements north of the Effie moraine in the eastern part of the study area indicate a more east-southeast flow direction for the Koochiching lobe there. A drumlin field about 15 miles (24 km) to the south of the Effie area (Hobbs and Goebel, 1982) also indicates a shift in flow direction from east to southeast across the study area for the Koochiching lobe.

Atypical flow directions for the Rainy lobe in the Effie area, which are reflected in the trend of the Effie moraine, were caused by a bedrock high in the Deer Lake area (Olsen and Mossler, 1982) that obstructed the southwestward flow of the ice. Flowpaths of earlier advances of the Rainy lobe can be expected to have been similarly altered by the Deer Lake bedrock high, but may not correspond locally to those indicated by the late Wisconsinan Effie moraine.

Winnipeg lobe flowpaths in the Effie area can be assumed to have been more toward the south than that of the Koochiching lobe on the basis of presumed source areas, although flowpaths were probably fairly similar in the southern portion of the study area. In areas of complex glacial stratigraphy coupled with variable bedrock topography, such as the southern Effie area, all subglacially deposited till units must be regarded as suitable for sampling.

The Ironton area can also be divided between an area of simple glacial stratigraphy to the west, and more complex stratigraphy to the east, although with less confidence because of the few rotasonic holes. Only relatively thin older deposits are believed to be present below late Wisconsinan Rainy lobe drift in the west, whereas drift of diverse provenance is present in the subsurface to the east. The Brainerd drumlin field immediately to the southwest of the Ironton area (Hobbs and Goebel, 1982) provides an excellent indicator of ice-flow direction for the Rainy lobe. Apparently Rainy lobe ice moved in a southwestward direction across the western part of the Ironton area, and in a more southward direction across the eastern part; older Rainy lobe ice can be assumed to have moved in similar directions. In contrast, the Superior lobe probably flowed toward the northwest across the Ironton area. Winnipeg lobe ice flow was in general to the southeast.

7.3 Lateritic Weathering of Bedrock

Thick kaolinitic weathering of bedrock is developed over an area of some 150,000 km^2 in Minnesota, North Dakota, and South Dakota (Smith, 1987). Parham (1970) provides the most complete description of this from his work in southern Minnesota. The relief of the landscape at the end of the Cretaceous, if analogous to granite-greenstone part of the Amazon Craton where alternate periods of laterization and arid climates have occurred, could have been: a) low savannah terrane with deeply incised creeks into bedrock formed over the granites and greywackes of the granite-greenstone terrane (Brinck, 1955); b) plateaus and ridges covered with ferrite-bearing brown to red-brown clays or lateritic hard cap formed over the volcanics and sediments; c) the upper courses of the creeks are incised into bedrock as do locally the broad river valleys (E. H. Dahlberg, pers. comm.).

Weathered mantles in this region of the state lie buried under the glacial drift (Maps 1-5 and 1-6). When this weathering profile was complete, there could have been four zones: the pisolitic layer or lateritic duracrust, reworked saprolite, kaolinitic saprolite, and saprolite overlying fresh bedrock (Smith, 1987; Parham, 1970) (see Fig. 7B). The complete Cretaceous history here, such as possible overlying sediments, is unclear at this time. In the Effie area, our cores consist of reworked saprolite, kaolinitic saprolite and saprolite (see Fig. 7A). We interpret that the upper zones have been removed by glaciation. In some holes, the weathered bedrock has been completely eroded.

A complete weathering profile was cored in Becker County, DDH 1-2, by M. A. Hanna Company in 1951. To get a more detailed account of the mineralogy and geochemistry, this weathered bedrock was sampled at three-foot intervals for mineralogy and "whole rock" assay. Five samples were taken for mineralogy (Table 11) and three were taken for assay (Appendix 2-6).

The sample taken from the pisolitic layer or lateritic duracrust from DDH 1-2 contained moderate amounts of gibbsite, goethite and hematite and a relatively high amount of siderite. The reworked saprolite contained relatively high amounts of hematite and siderite and moderate amounts of kaolinite. The kaolinitic saprolite contained relatively moderate amounts of kaolinite, goethite and hematite. A very high relative amount of talc was found in the sample taken just above the saprolite zone. The saprolite zone contained a high amount of talc and almost nothing else (see Table 11). One 100-gram sample from three-foot intervals of each of the lateritic duracrust, kaolinitic saprolite and the saprolite in hole 1-2 were assayed. Although there were only three samples taken from this weathering profile, there seems to be some trends in the geochemistry. V, F, Li, and Zr seem to increase in concentration up the weathering profile, and Cr, Co, Ni, Cu, Ba, Zn, K_2O, Na_2O, Rb, Sr, Y, and La seem to increase down the weathering profile. In contrast, Davy & El-Ansary (1986) report Ba, Co, Ni, Rb, Sr, Y, Zn, K_2O, and Na_2O are often depleted in the lower portions of the weathering profiles in Western Australia (Fig. 7B).

Similar mineralogical and geochemical samples were taken from weathered bedrock from the Effie Rotasonic cores using detailed one-foot sample intervals. The pisolitic layer or lateritic duracrust does not exist in our cores. It is usually indurated and rich in goethite and hematite (Rao, 1985 and Smith, 1987). In Western Australia, As, Au, Cr, Cu, Mo, Nb, Sn, Th, V, and W are known to be concentrated in this layer. Ba, Co, La, Mn, Ni, Rb, Sr, Ta, Y, Zn, CaO, K_2O, MgO, and Na_2O are often depleted in the lower portions of the weathering profile in Western Australia (Davy & El-Ansary, 1986).

Three holes in the Effie area contained zones of reworked saprolite that were sampled. These zones range in thickness from 1 to 7 feet and seem to be similar in mineralogy to the weathered material below them (see descriptive logs, Appendix 4-1). The reworked saprolite zone is differentiated from the other zones by the sand, pebbles and pebble line at the bottom of the zone (see Fig. 7).

There are two holes in the Effie area containing kaolinitic saprolite. OB-327 contains 15 feet and OB-329 contains 5 feet of the kaolinitic saprolite. These zones contain high amounts of kaolinite (Davy & El-Ansary, 1986). In the Effie area, the kaolinitic saprolite contains moderate to high amounts of kaolinite (up to 50%), along with quartz and goethite (see Table 11).

The mineralogy in the saprolite zone is usually characterized by relatively high amounts of quartz, kaolinite, muscovite and sometimes chlorite (Davy & El-Ansary, 1986). In the Effie area, quartz, kaolinite, muscovite and chlorite are accompanied by calcite and talc as abundant minerals in the saprolite zones (see Table 11). These zones range in thickness from a couple of feet to over 50 feet (see Map 1-6 and Appendix 4-1). In hole OB-329, goethite and hematite are the most abundant minerals in the saprolite zone.

Moreover, siderite is present in small amounts in most zones of our Effie weathered bedrock. Yet we did not find it described in the literature.

7.4 Bedrock Geology

The region can be broadly subdivided into two divisions of the Archean Superior province (see Maps 1-1B and 1-7). In the north is the Quetico subprovince and to the south is the Wawa-Shebandowan subprovince, with the Vermilion Fault zone approximately marking the boundary(?) between the two (Jirsa, 1989A). There are no significant mineral occurrences reported in the DNR General Exploration Files for this region.

The Quetico subprovince within this region is primarily composed of metasedimentary rocks of low magnetic susceptibility, affiliated with the Vermilion Granitic Complex (op. cit.).

The Wawa-Shebandowan subprovince broadly consists here of three large granitic zones surrounded by three belts of supracrustal rocks. Since the area has very few outcrops, the bedrock geology has been interpreted largely by Jirsa from his work in the Sherry Lake Quadrangle (Jirsa, 1988), new aeromagnetics (Bracken and Godson, 1988), and the MGS shallow drilling program. The bedrock map is in a stage of relatively rapid evolution.

The belts of supracrustal rocks differ from each other in dominant lithologies. In the north, near the Vermilion Fault zone, volcaniclastic rocks predominate and iron formations occur. In the southeast, ultramafic to intermediate volcanic rocks predominate. Also in the extreme southeast is the Coon Lake Pluton which is of syenitic composition and has a magnetic rim zone. This intrusive body may occupy a mega-structural dilational zone (Jirsa, 1989B). One author (D.P.M.) views the surroundings of this intrusive body, within the context of Colvine's (1989) gold mineralization model, as a potential conduit for deep-seated vertical fluid migration. The Ontario Geological Survey staff (Thurston, et al., 1988) recently has theorized a metallogenic model for gold mineralization in greenstone belts that characterizes each belt on lithostratigraphy and structure into four possible cases. These appear to be a useful guide to work toward as we learn more of the bedrock in this region.

Jirsa (1989B) has summarized the inferred tectonic and plutonic history of a 10 quadrangle area, which includes the southeastern portion of this report region, by describing four main elements listed chronologically below:

"1. D_1 deformation involved predominantly north-south compression with local perturbations related to diapiric rise of plutons. One such area is adjacent to the Wasson Lake pluton which was emplaced into border rocks causing folding and migmatization prior to the second deformation.

2. D_2 is a northwest-oriented transpressional deformation. The same style of deformation 60 km to the east in the Vermilion District (Hudleston and others, 1988) implies that D_2 was a regional transpressional event, affecting a large area of the Archean crust.

3. Northeast-trending, dominantly sinistral faulting and syn- to post-tectonic emplacement of variably magnetic, syenitic to monzonitic intrusions (Bello Lake, Coon Lake and Linden plutons).

4. Ubiquitous, northwest-trending, mostly dextral faulting. Many of these faults appear to be splays or to be otherwise related to the Vermilion fault zone. The latest and most brittle of these faults are more north-northwest-trending and many are now occupied by Proterozoic diabasic dikes."

In conclusion, to view the bedrock from a glacier's vantage, there are vast expanses of granitic rocks interwoven by narrow zones of greenstone belts.

The preglacial weathering of the bedrock is discussed in a later section.

8.0 Geophysics

8.1 Magnetic Susceptibility Readings

Magnetic susceptibility readings were taken on glacial drift, saprolite and bedrock core from the Effie and Ironton areas. Readings were taken every 2 feet with a K-2 magnetic susceptibility meter by Elliot Geophysical Co., Inc. Readings ranged from 0 cm/gm/sec to 18 x 10^{-3} cm/gm/sec (see Appendices 1-1B through 1-26B for a graphic log of the magnetic susceptibility for each drill hole).

An average magnetic susceptibility value was calculated for each of the four till types, saprolite and bedrock in the Effie area. The Koochiching and Winnipeg lobe tills had relatively lower magnetic susceptibility readings that averaged .09 x 10^{-3} cm/gm/sec. The Rainy and Old Rainy tills in the Effie area had higher readings that averaged approximately .13 x 10^{-3} cm/gm/sec. Saprolite had very low magnetic susceptibility readings that averaged .04 x 10^{-3} cm/gm/sec. The bedrock had low and moderate readings that average .06 x 10^{-3} cm/gm/sec. Rock fragments, cobbles and boulders often gave higher magnetic susceptibility readings than the rest of the core.

Most glacial units in the three holes drilled in the Ironton area had much higher readings that are likely due to the iron formation in the area.

Although there are some general trends of the magnetic susceptibility of each unit, the values were too similar to be able to differentiate the glacial units on the basis of magnetic susceptibility alone. Saprolite, however, may have magnetic susceptibility values low enough to differentiate it from the glacial drift in most cases.

8.2 Depth-to-Bedrock Seismic Tests

8.2.1 Summary

For several years we have been using reflection seismic profiles to help plan basal till sampling holes. The objective is to provide an accurate depth profile of interfaces, with the most important being the glacial deposits-bedrock interface.

In the 1988 program fourteen seismic profiles were completed and ten of these were drilled. The field work required 200 man hours using a four man crew. This was followed by another 200 hours of office work (Appendix 8-1). The sites were in Crow Wing, Itasca and Koochiching Counties. The geology at these sites was more complex than in previous surveys. A saprolite was logged in eight of the ten holes drilled where seismic profiles were done and a questionable saprolite found in the ninth hole. In spite of intensive efforts to improve accuracy it declined slightly from the 1986-1987 surveys, thirteen and one-half percent error between estimated and drilled bedrock depths (Table 13). This compared with twelve and six-tenths percent for 1987.

1988 seismic depth estimates were not as accurate as we would like. However, some important advances were made in our understanding of how to use cheap, single array, seismic profiles for depth estimates. In this report we review past difficulties with velocity model problems (Vrms) and describe the use of a normal-move-out correction to reduce or eliminate this problem. There were also problems with dipping glacial deposit-bedrock interfaces and the report describes the methods used to overcome these difficulties.

They are: (1) Be careful not to move the drill site in the interface up or down dip direction from the seismic profile site. (2) Align seismic profile arrays parallel to the trend of magnetic features. (3) Use a (T^2-X^2) graph in the field to determine updip minus downdip bedrock velocity changes and change array direction to correct.

We learned that orienting seismic profiles parallel to magnetic feature trends may create or exacerbate a problem with changing near surface velocities. This was the big problem for 1988. To solve this problem we need to spend more time in the field and in some places look at several alternate sites before selecting one where a good depth estimate can be made.

We also learned that trying to predict confidence of bedrock reflectors based on signal strength and normal-move-out is very difficult, at least where there is a saprolite. We still don't have a solution for determining reflectors from below bedrock ledge, but we do have a theory that worked at one site where there is good evidence of a bedrock reflector.

8.2.2 Recommendations

To date, seismic depth profiles have been done with no consideration of how site glacial deposits or the saprolite interface might affect the accuracy. With a limited number of annual site determinations we have been trying to reduce errors between estimated and drilled depths. The goal has been to make bedrock estimates with less than ten percent error.

We think by using the following recommendations this goal can be achieved: (1) Select sites with uniform surface conditions. (2) Align seismic profile arrays parallel to magnetic trends. (3) Use a (T^2-X^2) graph in the field to determine updip minus downdip bedrock velocity changes and change array direction to reduce these changes. (4) Use a normal-move-out correction to correct the velocity model for changes below the water table.

8.2.3 Introduction

The D.N.R. Division of Waters has used reflection and refraction seismic surveys to locate confined aquifers in glacial drift, (Stoner and Streitz, 1987). The Division of Waters contributed both personnel and equipment to conduct the seismic surveys of this report. The cooperation and help of Ron Nargang, Division of Waters Director and Andrew Streitz, Geophysicist, is appreciated.

They use a linear array of twelve geophones, spaced at a fixed three meter interval. First, short refraction surveys are completed to determine the velocity of the near surface unsaturated deposits, (Vu), and the saturated deposits below the water table, (Vs).

The velocities of saturated and unsaturated deposits are used as a velocity model in a second equation to calculate a root-mean-squared velocity, (Vrms), for N layers. The Vrms is then used to calculate the reflector depth.

With previous surveys a number of problems were observed which reduced the accuracy of the depth estimates. As solutions to some problems were tried other problems developed and sometimes the solutions created or exacerbated another problem. For bedrock interface depths the problems and solutions are:

(1) One of the first problems observed was locating the drill site some distance from the center of the seismic spread, where the actual depth estimate is made. Even with flat surface topography, dips on the bedrock interface can result in considerable error. The solu-

tion for this is simple. Locate the drill site at the center of the seismic site or along the strike of bedrock ledge rather than perpendicular to it.

(2) Another problem is an inaccurate velocity model because of changes in glacial deposits below the water table. The solution is to use a normal-move-out correction which varies the velocity by measuring and comparing changes in return times with geophone distances from the shot point. To work, the NMO correction must have a horizontal bedrock interface in the direction of the seismic array and uniform velocity lateral layers.

(3) The third problem is to orient the linear seismic array so that it parallels the strike of the bedrock interface. The solution is to orient the array parallel with the trend of airborne magnetic features. The reflector attitude is then tested by the use of (T^2-X^2) graphs to determine the reflector velocities from shots at both ends of the array. If the updip minus downdip velocities are small the interface is nearly horizontal.

(4) The fourth problem is uniform lateral layers, particularly changing near surface deposits from one end of the array to the other. This can create large errors if there are changes in the depth of low velocity unsaturated deposits. This causes errors in the NMO correction. At sites with a small area of changing surface conditions and insufficient room in all directions for the array, trying to orient it parallel to the trend of magnetic features can exacerbate this problem. The solutions are to study and select sites where the array can be properly oriented then study first return information from shots at both ends of the array to determine velocity differences.

(5) The fifth problem is selecting the right reflector to determine the bedrock interface depth. In Precambrian terrains we think the deepest reflector should be the bedrock interface. This is not always true, there can be faults, sills or other features acting as a reflector. We don't have a good solution for this problem but we do have a theory which works at one site.

The overall profile velocity (Vrms) should increase as bedrock is included in the profile. Given a horizontal bedrock interface as tested in problem three and uniform glacial deposits above it as tested in problem four, similar NMO corrected velocities for the bottom reflector and the reflector just above it should be a good indication that the lowest reflector is the bedrock reflector.

The near surface and velocity problems explained above also create errors for depth determinations of interfaces within the glacial deposits. In addition, there are some problems found only in glacial deposit interface depth estimates:

(1) We are unable to resolve interfaces which are separated by a small vertical interval, (less than a half wavelength of the seismic energy source). The solution is to use a higher frequency source (primacord) and a receiver system that responds to higher frequency energy.

(2) Inability to correctly identify designated reflectors, for example the top of the Rainy Lobe. There isn't a solution to this problem as the different observed reflectors, as defined geologically, do not have characteristic seismic features. With enough data and drill holes, empirical solutions to this problem will evolve.

8.2.4 Fieldwork and Survey Methods

Field work was completed in early May starting in Crow Wing County and finishing in northern Itasca and Koochiching Counties.

The work used a four man crew for a total of 200 man hours. Fourteen sites were surveyed and ten of these were drilled. We tried to orient the linear seismic arrays so that they paralleled the strike of airborne magnetic anomalies. This increased problems with changing surface conditions such as swamps or depths of low velocity glacial deposits from one end of the array to the other. The fourteen sites chosen could be accessed by a truck mounted drill rig.

The surveys were done with a Bison Geo-Pro, model 8012A, twelve channel, signal enhancement instrument. Note: the use of equipment brand names in this report is for identification purposes only and does not constitute endorsement by the Minnesota Department of Natural Resources. Forty hertz marsh case geophones were used with a ten foot geophone spacing in a linear array. On a few spreads 100 hertz phones were tried to see if sensitivity and resolution of subtle interfaces could be improved. There was little or no improvement although the 100 hertz geophones were not used enough to be conclusively tested. A twelve gauge pipe gun was used as the energy source for a few shots. Most of the work was done with four to six yards of fifty grain, reinforced primacord, fired with Rockmaster #0 electric blasting caps. The primacord was coiled around the cap to form a cylinder six inches in length and one inch in diameter. This was then secured with duct tape. The charge was buried with a shovel or small power auger and stemmed with fine sand or whatever was available. Care is taken not to work in the area of buried power or telephone cables.

To locate confined aquifers in glacial drift, the Division of Waters has successfully used the following methods: They lay out a linear array of twelve geophones spaced at a three meter interval. First, short refraction surveys are completed to determine the velocity of the near surface unsaturated deposits, (Vu), and the saturated deposits below the water table, (Vs). This is done using a time-distance plot of the first breaks. The velocities are determined from the inverse of the slope that provides the best fit to adjacent data points. The depth of unsaturated deposits, (Du), is calculated using the formula:

$$1.\quad Du = \frac{Xc}{2}\left[\frac{Vs - Vu}{Vs + Vu}\right]^{1/2}$$

Xc is the distance between the source and the intersection of the two slopes taken from the time-distance plot.

The velocities of saturated and unsaturated deposits are used as a velocity model in a second equation to calculate a root-mean-squared velocity, (Vrms), for N layers:

$$2.\quad Vrms = \left[\frac{\sum_{i=1}^{N} Di\,Vi}{\sum_{i=1}^{N} Di / Vi}\right]^{1/2}$$

Where Di = thickness of layer i and Vi = velocity of layer i.

The depth of the reflector is then determined by a third formula:

$$3.\quad D(reflector) = \frac{\left[T^2 Vrms^2 - X^2\right]^{1/2}}{2}$$

Where T = arrival time of reflector signal and X = source to geophone distance.

The algorithm for calculating Vrms requires an unknown value for the depth which is the thickness of the saturated glacial sediments above the reflector. In an iterative approach an estimated depth is used in equation two which computes a Vrms. This is then used in equation three to compute the depth. The comparison of the estimated and computed depths determines accuracy. If there is a good agreement the depth is accurate, if they do not agree the algorithms are repeated until the difference between estimated and calculated reflector depths meet a suitable error criteria, (Stoner and Streitz, 1987). These calculations become cumbersome and subject to error if done by hand. Andrew Streitz wrote a program to make the calculations using a computer and we wrote a program to do them using a Hewlett-Packard 41CX calculator. This is included as Appendix 8-2.

A normal-move-out, (NMO), correction (Dix, 1952, pp 134-138) is calculated using formula number four:

$$4.\ N \approx \frac{X^2}{2\,T_o\,V^2}$$

using abbreviations of formulas 2 & 3 this equals:

$$NMO \approx \frac{X^2}{2\,T_o\,Vrms^2}$$

Where X = source or shot point to geophone distance, To = the reflection arrival time at the source, and V = the velocity

These calculations also become cumbersome if done by hand. We wrote a program which combines these calculations with those in algorithms 1, 2, and 3. Again these are for the Hewlett-Packard 41 CX calculator and are presented as Appendix 8-3 .

8.2.5 Interpretation

Reflection seismic surveys have been used for many years by the oil industry. In 1987 they spent $328.7 million dollars in the United States on seismic surveys for petroleum exploration (Senti, et. al., 1988, p. 43). Survey methods and data interpretation are well known and computer aided, sophisticated, algorithms are used in their interpretive processes. One of the big problems with seismic surveys for oil exploration has been accurate velocity data. They spend many millions of dollars measuring these velocities. The geologic units they work with often persist for many miles without lithologic or physical changes. This helps maintain accurate survey results.

The use of reflection surveys for estimating depths of glacial deposits is a recent development. Using expensive continuous profiles, the Geological Survey of Canada has shown they can provide useful stratigraphic profiles to the bedrock interface (Gagne, 1987). These profiles can be used in an empirical manner to estimate depth at any location along the profile. They also display some interfaces within the glacial deposits.

We have been trying to use cheap single array depth estimates in the complex glaciated terrains of northern Minnesota. Stratigraphic characteristics and velocity can change in a very short distance. Along with this, bedrock lithology, interface attitude and saprolite thickness can also change rapidly. Starting with the fairly simple interpretive methods used by the Waters division we have been working through the following process: (1) Making depth estimates. (2) Comparing these with drill results. (3) Determining what caused the errors. (4) Figuring out a way to correct the problem. (5) Trying the corrected interpretive method in the next round of drilling.

Each year drilling has been in areas of more complex geologic problems. These include: (1) Deeper glacial deposits of mixed glacial units below the water table. (2) The presence of saprolite having varying depths. (3) Drill sites with mixed near surface glacial deposits or changing soil/water interfaces.

We have also worked with a limited number of drill holes which make it difficult to get a significant sample for statistical analysis of what is causing problems. Drilling changes site conditions and if a site is reoccupied to try a modified interpretive method it is impossible to know whether seismic profile changes are due to changes made in survey methods or changes in site conditions. Modified survey methods may correct one problem and create or exacerbate some other problem.

Table 13 presents bedrock survey results for 1988 seismic surveys. Andrew Streitz used a computer program to calculate seismic depths without a normal-move-out correction (Appendix 8-2). I used the program (Appendix 8-3) with a Hewlett-Packard 41CX calculator to determine depths with a normal-move-out correction.

In the seismic records and drill logs there are numerous interfaces within the glacial drift. Any reflector depth estimated would be close enough to one of these interfaces to have a reasonable variation, but generally the interface would not be significant to a minerals potential evaluation. Therefore we did not interpret reflectors from interglacial interfaces.

In the first column of Table 13 the site number is shown. In the second column the site location is displayed. The third and fourth columns show the drilled depths to the top of the saprolite and the unweathered fresh bedrock. The fifth and sixth columns show the seismic depth estimates without a normal-move-out (NMO) correction. Usually these are the deepest reflector observed and the one above it, although a strong reflector with reasonable NMO times might be interpreted as a bedrock reflector.

The seventh column is labeled the percent difference, which means the variation or error between the seismic estimated depth and the closest one of the drilled depths. Saprolite was reported in this area from previous drilling but we did not know the depth or degree of bedrock weathering and we can't estimate the acoustic impedance of these two interfaces. These factors determine if one or both interfaces will act as a reflector. This forced us to make two seismic depth estimates. When we look at the drilled intersections of saprolite, it is too thin for seismic methods to resolve both interfaces and one of the estimates has to be an error. For seven of the ten holes, or eight with a NMO correction, the deeper estimate is closest to the drilled depth. This would be expected. For the other three, or two, sites there could be a bedrock reflector below the saprolite-fresh bedrock interface or an inaccurate velocity profile because of sand or silty sand below a saturated clay layer. Observe that where the estimated depth is above the drilled depth the error is negative, below it positive.

Columns eight and nine are seismic estimated depths using a NMO correction. Column ten is the percent difference again figured using the closest drilled depth. With a NMO correction eight of the ten nearest estimates are the deepest or expected estimates.

8.2.6 Conclusions

A list of problems and devised solutions is presented in the introduction. Here we will discuss the problems involved in the 1988 survey, how they were recognized and the solutions we believe will work. A more detailed description of each hole and the problems observed is presented (Appendix 8-1).

To reduce the error from dipping bedrock interfaces we oriented seismic arrays parallel to the trend of airborne magnetic features, ignoring visual observations of changing site conditions. This reduced the error from dipping bedrock interfaces as shown by lower updip minus downdip bedrock interface velocities. For seven 1988 sites these averaged 668 feet per second as compared with an average of 1,399 feet per second for nine 1987 sites.

While this corrected the dipping bedrock problem it exacerbated a problem with near surface velocity changes. This problem is recognized in seismic profiles for Hole OB-302, (Fig. 8-1). The first return velocities for one direction are faster than they are for the other direction. Fig. 8-2 shows a graph of percent error with a normal-move-out correction plotted against change in velocity. The squares show plots of raw data, and Xs a least squared trend line indicating a positive correlation. The correlation coefficient with a NMO correction is +0.92. Without an NMO correction (Fig. 8-3)there is a negative least squared trend line. This is skewed by the 83 percent error at a velocity change of thirty-one feet per second. Leaving out the 83 percent error the correlation coefficient is +0.13. The NMO correction uses reflection arrival times at the energy source (To), taken from the (T^2-x^2) graph, and compares them with geophone return times. If geophone return times are in error because of lateral velocity changes the NMO corrected velocity will be in error in direct proportion to the return time errors. These can be particularly onerous with near surface low velocity sediments. Depths calculated without a NMO will also be in error but it will be a random error.

At OB-401 a NMO correction eliminated an incorrect velocity profile problem and there is no near surface velocity change problem. The next to deepest reflector only has a one percent error compared with the drilled bedrock depth and it appears the deepest reflector is below bedrock ledge.

Theory suggest that if there is a reflector below the solid bedrock interface the NMO corrected Vrms for the deepest reflector should be faster than the NMO corrected Vrms for the next higher reflector. At OB-401 the corrected Vrms is 5,743 feet per second for the deepest reflector. For the reflector above it the Vrms is 2,851 feet per second. For this drill site the theory apparently works. For the 1988 survey this is the only site where it works but the other site where it might have worked has near surface velocity change problems which obscure the depth, below bedrock reflector problem.

We think that with careful site selection; orienting the array with the trend of airborne magnetic features; the use of a (T^2-X^2) graph; the use of normal-move-out corrections and velocity comparisons between reflectors, the errors can be reduced to less than ten percent. This will require increased field time per site and careful attention to these details.

9.0 Methodology for Geochemistry

9.1 Site Selection

The primary objective was to space one hole in each township in the Effie and Ironton areas. Sites were restricted to state-owned surface and mineral lands. Nine sites were selected by the MGS to support their bedrock mapping. Sites were generally located down-ice from known faults and other inferred major bedrock contacts. End moraines, eskers and major glaciofluvial and fluvial drainage systems were avoided. Summer access was required for the truck-mounted drill rig and support vehicles, and excessive site preparation costs were avoided.

Potential drill sites were then plotted on compilation maps that included all pertinent glacial and bedrock geologic data. Following legal review of surface and mineral ownership, all sites were field checked for off-road access, suitable ground conditions, and possible problems such as buried cables and overhead power lines. The sites were usually 100 feet or more off the road, and no sites were within any right-of-way. Drilling could not be done in seven townships because there was no summer access to state lands.

9.2 Rotasonic Drilling and Field Operations

The objective of the 1988 drilling program was to collect core samples of the glacial drift, saprolite and bedrock for analysis. A Rotasonic drill rig was used. Twenty-three holes were drilled in the Effie area, and three holes were drilled in the Ironton area. Drilling was conducted seven days a week, 12-hour shifts, over a six week period (May 18-June 30) with six days off and thirty-eight days actual drilling.

A complete summary of drilling statistics for the Effie and Ironton areas, such as total footage, recovery, time, supplies used, number of samples, water consumption and man-days is listed in Table 2. DNR field personnel traveled 10,000 miles during the field operations, using 1/2-ton pickups, 3/4-ton pickups, and a 6-ton Schwartzbed truck.

Rotasonic core drilling procedures were as follows:

1. resonate and rotate the core barrel, without any water, 10-30 feet into the formation to obtain sample;

2. resonate, rotate, and water-flush the casing down to the sample bit face;

3. pull core barrel and extension rods;

4. extrude core from core barrel into plastic sleeves;

5. repeat steps 1 through 4 until at least 5 ft. of bedrock core obtained.

DNR Minerals staff were always present to log drill resistance and other stratigraphic information and to insure sample quality through proper handling, labeling and boxing of the core. Core was stored in plastic sleeves in 4 ft. wooden boxes, put on pallets, and then covered with 4' x 4' x 1/2" plywood. Pallets were taken to a designated storage area near Effie and later transported to Hibbing. Boxes remained covered and plastic sleeves closed to keep the core moist, which greatly facilitates splitting and logging. Field drill logs and detailed site location maps are on file for reference at the DNR-Minerals office, Hibbing.

There were eight holes that did not reach bedrock due to excessive time, cost or depth. Holes OB-303, OB-320 and OB-327 were stopped in saprolite because the drilling rate was so slow it was no longer economical to continue. Holes OB-321 and OB-325 were stopped because of a high risk of losing costly drilling equipment in deep, thick deposits of sand and gravel. The casing broke in hole OB-403, the last hole of the program, and the hole was lost at that point. Hole OB-307 was not completed to bedrock because we simply ran out of time. In OB-312 a maximum contract depth of 296 feet was drilled without reaching bedrock or saprolite.

9.3 Sample Types, Sample Processing, and Analysis

Sample composites were taken from the Rotasonic core after the logging had been completed and were sent to appropriate labs for sample preparation and analysis. At least 1/4 of the Rotasonic core was preserved for long-term reference. Sampling was directed toward the lower 100 ft. of each drill hole with emphasis on tills. Five to ten foot intervals were sampled, trying not to cross drift type boundaries. Analyses were performed on four sample media (Table 2): nonmag HMC of glacial drift and saprolite; magnetic HMC fraction of glacial drift and saprolite; silt/clay fraction of glacial drift and saprolite; and bedrock samples. Mineral point counts, special assaying, and special mineralogy were performed on selected samples, primarily saprolite. All the saved portions of samples from the flowsheet are kept in the DNR Core Library, Hibbing, Minnesota, and are available for inspection or analysis.

For each glacial drift sample interval, an 8 kg minimum weight was sent to Overburden Drilling Management (ODM lab) for heavy mineral concentration, magnetic separation, and gold grain counts (see Flowsheet, Fig. 5). That sample was split to set aside 250 g for a reference sample. The remainder was wet sieved to -1700 um, with the + 1700 um fraction being saved. The -1700 um was run over the shaking table to obtain a heavy mineral concentrate. The HMC was cleaned with a heavy liquid (S.G. = 3.3) concentration step. The light fraction from this concentration (S.G. = -3.3) was saved. Next, the HMC of each sample was separated into the magnetic fraction and the nonmagnetic fraction. One-quarter split nonmagnetic fraction HMC was saved. The remaining 3/4 split nonmagnetic fraction HMC and the total magnetic fraction HMC were sent to Technical Service Laboratories, Mississauga, Ontario. A 31-element analysis package was performed there on the nonmagnetic fraction HMC and 26-element analysis package of the magnetic fraction HMC (Appendix 9-1). For the magnetic fraction, a screening step (150 mesh) is necessary during agate mill pulverizing of the assay pulp. That pulverizing + screening effectively removes most drill steel flakes found in this fraction.

The silt/clay fraction was obtained from a 2 kg sample split from exactly the same interval as the HMC sample of glacial drift. The samples were taken from the undisturbed middle portion of the core and were oven dried at 150° F. before shipment to TSL. At TSL, the samples underwent dry screening of the -63 um (silt) fraction followed by wet centrifugal separation of the clay fraction (Higgins, 1988, Geological Survey of Canada). At TSL, a 31-element analysis package was performed (see subsample wts., extraction and analytical methods in Appendix 9-1). Gold, silver, and CO_2 were assayed on the -63 micron fraction, while the remaining set of elements were assayed on the clay fraction. Two practical reasons for this include: (a) to compare our -63 micron gold database from DNR Report 252; and (b) it was not practical to obtain a sufficient sample weight of the clay fraction alone to reliably assay for gold.

Bedrock samples were sent to TSL where they were crushed and pulverized to -150 mesh using a ring mill, and then analyzed for a 47-element package (Appendix 9-1). Special bedrock samples from short intervals containing a high concentration of veins were also selected and assayed.

Mineral logging point counts were done by ODM lab on 109 selected glacial drift samples to make comparisons and help characterize stratigraphy. The mineral point counts were 100 grains per sample, using a 6x-40x binocular microscope. The ODM lab has experienced personnel and more than 100 mineral specimens in their private heavy mineral reference collection, including many color phases. Samples were chosen to get an even distribution between glacial units. The selected samples were primarily tills and included all samples with four or more gold grains.

Special assays and mineralogy were performed on one-foot intervals of the saprolite to get a more detailed account of the geochemistry, mineralogy, and internal stratigraphy. Bulk sample analyses were performed on eleven saprolite samples for a 47-element package. Special clay mineralogy was done by Hanna Research Center, Nashwauk, Minnesota, on these 11 samples plus an additional 9 saprolite samples (see Table 11). Many pH readings were taken on each horizon of the weathered bedrock (see Appendix 4-1). Approximately 50 grams were taken from the undisturbed middle portion of the core. Then a pH reading of the crushed solid/water slurry (1:3) was measured using a Radiometer PHM 53 specific ion meter.

9.4 Variability in Sampling and Analysis

The total variability can be described as the sum of the variability within the natural sample and that introduced during drilling, splitting, processing, and analysis. Within this project, the following tests were done to describe portions of the variability:

1. analytical precision;

2. analytical accuracy;

3. replicate pairs of core splits for silt/clay nonmagnetic HMC and gold grain counts;

4. replicates of HMC mineralogy point counts;

5. replicates of screen analyses for size distribution;

6. review of gold grain counts vs. subsequent gold assay; and

7. pure quartz sand samples to test screening "carry-over" and analysis.

The analytical precision is good, as demonstrated by the 13 analyses of a certified standard, SO-1, as every 20th sample within the silt/clay sample batches (see Table 7). An obvious error for Pb was identified in an entire batch, but the analytical lab re-analyzed that batch and only the final results are presented. The worst case for precision here is for W with 168%.

Similarly, the analytical accuracy was tested by inserting 2 more certified standards, GTS-1 and FER-2, for a total of 11 more analyses (see Table 7). Either the accuracy or the precision are not as good as we would like for As, W, Mo, Pb, Ni, and Mn.

The sum of natural, splitting, processing and analytical variability were tested with 11 pairs of replicate samples which were different splits of the same core interval (see Table 8). For the silt/clay fraction of these 11 pairs, the variability ranges from 29 to 187%. The worst case is for W with 187% precision. For the nonmag HMC fraction from these 11 pairs, there is generally less variability. On the whole, this variability is acceptable as long as HMC gold is considered separately. Since none of our pairs had 20 or more gold grains per sample, which is suggested by Clifton, et al. (1969) to be necessary to test precision, we must expect significant variability in the HMC gold assays.

Furthermore, only 6 samples had reported gold grain counts of zero, but later assayed gold [3 x median of the drift type], indicating that significant gold in some form was present. And 3 of those 6 samples were from Koochiching tills which are more clayey and also of less significance to exploration here. Hence, the ODM lab gold grain counting system appears to have worked well.

The 5 quartz sand samples were processed within the silt/clay sample batches (Table 7). The results indicate that carry-over from one sample to the next during screening is minimal and that calibration for the low trace element values in a quartz-rich matrix is good. A minor question arises as to the cause of the few relatively high Ni and Pb values.

10.0 Methods of Data Handling and Map Preparation

Interpretation of the Rotasonic drill core led to the identification of six stratigraphic packages within the glacial drift (see Fig. 7-3 and Table 3), plus saprolite. For practical purposes within the data handling and presentation, only five groups are contrasted here--Koochiching lobe drift, Rainy lobe drift, Old Rainy lobe drift, Winnipeg lobe drift, and saprolite. Thus, no distinctions were made between Old Rainy drift 1 vs. 2, between Winnipeg drift 1 vs. 2, or between different Koochiching lobe tills (see Fig. 7-3). Identification and correlation of these units between holes is very difficult at this time (e.g., Old Rainy 1 vs. Old Rainy 2).

Furthermore, each sample within the glacial drift is classified as till or other drift types (see Appendices 1-A and 1-B). Only samples of till are used in the statistical evaluations, except for a few cases that are clearly noted.

In adjacent regions, it became apparent that underlying bedrock type influenced the geochemistry of Rainy lobe tills (Martin, et al., 1988). Thus, the data here is classified with an underlying bedrock type (Table Appendix 3-1). Note that the base map (Map 1-7) was used for the underlying bedrock classification type and legend, especially for those few holes that did not reach sound bedrock.

Three geochemical sample media have proven useful to try to identify bedrock sources from the glacial drift samples: heavy mineral concentrates (HMC); -63 micron silt plus clay fraction; and clay fraction (see Section 12.5). Selected elements of those media have been presented on Maps 3-1 to 3-15.

To summarize, the subpopulations are grouped by stratigraphic unit, drift type, underlying bedrock type, sample media, and element assay (Table 3, Part III). Those subpopulations represent the natural groupings and obvious populations. For practical purposes, generalizations have been sought. In some subgroups, the number of samples is too small to be reliable. Yet, the long-term objectives require that we identify these subpopulations. In the short term, we have median values and suggested tentative threshold values for Rainy lobe till as starting points for further exploration in this region. Note that the number of samples, n, is listed with each threshold and the number of drill holes it is derived from. The small populations, n, for the pre-late Wisconsinan tills come from such limited numbers of drill holes that we felt meaningful threshold values could not be estimated from the data. The analytical data format was set up for software called INFO-PC from Henco. This PC software is a relational database manager system. Sixteen histograms and probability plots for selected elements of Rainy lobe tills are presented (Appendix 10-1) from software called PROBPLOT of the Association of Exploration Geochemists. A data summary is presented as spectrograms (Fig. 10-1), or multi-element graphs for all till samples in each of two sample media. These are part of a software package called Mineral Interpretation Programs (MIPS), purchased from Technical Service Laboratories. To use MIPS we also needed a data manipulation system called WATFILE/PLUS from WATCOM Systems, Inc. and University of Waterloo, Ontario. A complete, lengthy interpretation of each drill hole is not practical. Rather, our goal in data handling and presentation is twofold. One is to point out the drill holes we interpret as worthy of further investigation. The second is to present all the data so that the experienced reader could evaluate the information in detail.

11.0 Description of Geochemical Results

The data has been organized on computer media such that many different data items could be contrasted and compared (see Table 4). The project objectives, however, are directed at identifying regional patterns and the subpopulations that make up those regional patterns. Primary emphasis has been placed upon the distribution of gold. Since no "truth points", i.e. existing gold mines, are available for orientation work, all of the results and interpretation must be viewed objectively and with a critical eye at this point in time.

The raw geochemical data is summarized in Table 3 and is presented five ways [Appendices 1-1A through 1-26D]: (1) the summary information sheet by drill hole; (2) the HMC report of gold grain count, measurement and classification by drill hole; (3) the graphic lithology log by drill hole; (4) the complete sample information sheet, with all analyses, by drill hole; and (5) total listings of trace element distributions sorted by sample number, drift type, and underlying bedrock type [Appendices 2-0 through 2-9].

Listed on each summary sheet are elements that were observed to have elevated values within that drill hole. These are intended only to be a time-saving guide for this large database. Each value can then be compared to median values or suggested threshold values in Table 6 for interpretation.

There were 14 different combinations of the presence or absence of 5 units (Koochiching, Rainy, Old Rainy, Winnipeg, saprolite) found in the 23 drill holes in this Effie region. Based upon observations of the core and the analytical results, the authors suggest that any unit except the Koochiching lobe could be used locally for gold exploration. The dataset is presented so that the reader may test that hypothesis for himself. Thus, the basic presentation of information addresses: (1) identification of the glacial drift units present in the lowermost 100 feet of the drill core (see Table 9 and section on Quaternary Stratigraphy); (2) contrast within one glacial drift unit across the region; (3) comparison of trace element patterns between glacial drift units and also saprolite; and (4) comparison of trace element patterns across the region overlying different bedrock types, especially granite vs. greenstone at this scale.

Therefore, the raw data is presented with columnar sections by drill hole to show contrast within and between glacial drift units. Medians and suggested threshold values are presented (Table 6), which also permit comparison between glacial drift units (#3 above). A compromise is presented whereby averages are used to compare trace element distributions across the region (#4 above) on maps (see Maps 3-1 through 3-15). Averages admittedly do not perfectly represent the glacial drift samples since dilution generally creates lognormal distribution patterns; however, they do effectively summarize the large data set, do show marked variability across the region, and show the regional distribution of the stratigraphic units.

To conclude, the trace element distribution maps are not meant to demonstrate patterns--the variability is too great for the sparse data points at this stage. Rather, the arithmetic averages are a crude way to summarize (a) the presence and absence of stratigraphic units, (b) the variability, and (c) the composition of units underlying the Rainy lobe that could be incorporated into it.

11.1 Gold Grain Counts in Nonmagnetic Heavy Mineral Concentrates

There were 330 total gold grains counted in 154 samples in the Effie area. The gold grain count data are presented on Map 3-1 and Table 5. Based upon total grains per drill hole and average number of grains per 10 kg of sample (Map 3-1), the three drill holes showing highest total grain counts and also average grains per sample are: OB-318, OB-321 and OB-315. Restricting the population to include only till samples (i.e. excluding gravel, sand, etc.), the same three drill holes remain the highest. Moreover, there is are high grain counts in OB-307, a "one-sample" high in OB-322, and unusual grain counts in the Winnipeg till (usually barren) in OB-301.

The sample with the highest gold grain count, 30, is #22589 in OB-321. It also contains an unusually high weight of magnetic fraction. The sample with the best gold classification (i.e., number of delicate and irregular grains; see Fig. 4) is in Rainy till in OB-307. It has one delicate gold grain, one irregular grain, and 7 abraded grains, but this occurrence is more than 120 feet above bedrock.

For comparison, the Rainy lobe till samples in this region contained an arithmetic average of 2.7 vs. 0.6 gold grains per 10 kg (n = 51 samples here vs. 89 there) in the similar geologic terrane adjacent to the east (Martin, et al., 1988). Thus, there are at least four times more gold grains in the Rainy lobe till of this region, even though the areal extent of granitic rocks is also greater here. The Old Rainy lobe till has similar values, yet in contrast the saprolite (n = 15) had very low gold grain counts, 0.3 per 10 kg.

It should be noted that the Old Rainy lobe unit in hole OB-321 contains about half of all gold grains in Old Rainy samples (55 out of 116, see Map 3-1), thus, significantly increasing the Old Rainy average. Similarly, hole OB-301 has 15 gold grains in Winnipeg lobe samples, or 15 out of 20 total, to significantly increase the Winnipeg average.

11.2 Gold Grain Size Data

The gold grain size distribution for each glacial lobe, for all Effie drill holes, and for selected individual drill holes are presented (Fig. 6). The graphs partly reflect the loss of the finest gold particles (-25 microns) during the concentration process.

The sizes 63 and 250 microns are also indicated. Note that the majority of gold grains are in the fgr-sand size range, +63 microns, and so would be excluded from the silt/clay fraction. Also note that the Old Rainy lobe data is skewed by one drill hole, OB-321, with 55 gold grains.

Contrasting the lobes, the Rainy lobe contains more gold grains in the smaller mass classes than the older drift of the Old Rainy and Winnipeg lobes (Fig. 6A vs. B & C).

Comparing the total from this area to that of the combined Orr and Littlefork areas (Martin et al., 1988), the percentage distribution of -63 micron gold grains is much lower here (23% vs. 33% there).

Comparing the individual drill holes, OB-321 contains more of the larger gold particles (76% greater than 1 ug) than the other holes. Hole OB-315 contains more of the smaller gold particles.

These results of the gold grain sizes are good estimates but are imperfect in many ways. They are based upon the Overburden Drilling Management lab reports (see each drill hole HMC report). For example, neither free gold particles less than 25 microns nor occluded gold are counted, even though they may be present in the HMC. The assays show that six of the samples reported with zero gold grains have assays greater than 3X median gold assay for the drift unit and, therefore, do contain gold in some form. In general, trying to replicate gold grain count numbers is a controversial topic.

11.3 Sample Media Results

11.31 Nonmagnetic HMC Assays and Mineralogy

The nonmag HMC sample fraction assay data is best summarized by the median values and other statistics sorted by drift type in Table 6. The multi-element patterns are summarized on the Summary Map 3-16. The distribution of six elements are presented on Maps 3-1 through 3-15. The median values by drift type and underlying bedrock type are suggested to be the best available estimate of background values. There are enough samples to estimate threshold values only for the Rainy lobe tills, and then only by lumping underlying bedrock types together. We suggest 3 x median to be a good general threshold value approximation. Time did not permit a rigorous statistical evaluation of this massive dataset (Appendix 10-1); however it is available on computer media for review.

To summarize, the background values for Au, As, Sb, Se, W, Cu, Pb, Ni and Zn for the Labradorean source tills are sufficiently low as to provide a good contrast in an expected anomaly. It is not as clear for the Keewatin source tills. The Koochiching clayey till in the Littlefork area (Martin, et al., 1988), for example, contains such high exotic values of As, Se, Pb, Ba, Zn, Mo, Sb, Hf and Th that it is not useful (see also OB-331). So the Pb and Ba occurrence in Winnipeg till in OB-306 should be viewed cautiously. The meager subpopulation in that drift type, consisting of six samples in only two drill holes, probably does not provide a valid background (median) value.

The point count data for nonmagnetic HMC mineralogy is presented by drill hole (Appendix 2-8, 2-9, or 1-1C). Time did not permit manipulation of this data. The calculation of the normalized nonmag HMC weight per original sample weight (grams HMC/kg sample) combined with the point count percent should offer a powerful tool to differentiate drift types and to confirm bedrock sources of drift anomalies. An example of the contrast in that sample media occurs in OB-327. Also, the mineralogy of gold-bearing sample #22426 in OB-321 is relatively simple, suggestive of a placer source. The mineralogy of the gold-bearing Winnipeg till in OB-301 may provide clues to its local provenance.

Note the siderite present within the laterite samples (see OB-327 or Table 11). That explains the common occurrence of siderite in the nonmag HMC samples. It also points to the incorporation of laterite in the glacial drift (see OB-327).

11.32 Magnetic HMC Assays

The intent of this data is to provide additional pathfinders to mineralization and, more importantly, seek a fingerprint to help back-track a dispersal train within a till. The dataset contains both major elements of the spinel family and trace elements (Appendix 2-10 or Complete Sample Assays by Drill Hole).

An example of a fingerprint could be the high chromium content, 4.5%, in one sample each of OB-301 and OB-302, near the ultramafic rocks of the Deer Lake Complex.

The laterization process seems to complicate the use of this fraction. Note in OB-329, the high values of Mg, Cu, Ni, Co, and As in this fraction within the saprolite samples (see Section 12.4).

11.33 Silt/Clay Assays

The silt/clay assay data is presented in Table 6 and on Maps 3-1 through 3-16, where it is easily contrasted with the complementary nonmag HMC maps. A plot of the -63 um assays vs. the HMC gold grain count from the same sample interval is presented (Fig. 11-1). There seems to be no correlation to the gold grain count. This probably results from most of the mass of gold in the background population (i.e., # of gold grains, see Fig. 6) being greater than 63 microns in size, so excluded from the silt/clay fraction. The opposite conditions are probably true within the "head" of a gold dispersal train (Averill, 1988). The screening process, wet vs. dry, needs to be evaluated to ensure that a bias is not being introduced.

In regards to the glacial drift samples (saprolite is discussed in next section), there are no anomalous gold patterns that are interpreted from the data. There are patterns interpreted as background that emerge from other elements when the data is grouped by drift type and underlying bedrock type (see As in clay, Koochiching tills, in the spectrogram Fig. 10-1).

In summary, the median values are sufficiently low for all drift types and most elements that good contrast would be expected if anomalous patterns were encountered.

11.34 Saprolite Assays

The saprolite data is listed in Appendix 2-6. This geologic unit shows the greatest variability, both in general mineralogy and trace element distributions, in all sample fractions (i.e., nonmag HMC, mag HMC, silt/clay). For example, in the nonmag HMC fractions in holes OB-327 and OB-329, the arsenic values range from 6 to 6,000 ppm. Due to this variability in internal stratigraphy, mineralogy and geochemistry, background values were not established.

In the silt/clay fraction, samples in holes OB-329 (388 ppb) and OB-319 (34 ppb) contained significant gold. The other elements in this fraction seem to be as low or lower than comparable median values in the glacial drift.

In the nonmag HMC, in contrast, the elements Ag, As, Sb, Cu, Ni, W, Mo, Zn and Fe are greatly enriched compared to glacial drift (see OB-329 and OB-320). The weight of the nonmag HMC is significantly lower, perhaps five times lower, than in glacial drift. Still such high trace metal content as in OB-329, with 6000 ppm As, 3.6% Cu, and 11 ppm Sb in 3.6 grams of nonmag HMC, could create an anomaly even when incorporated into glacial drift.

The elements W, Mo, and Zn are elevated in OB-320, but not OB-329, and probably reflect contrasting bedrock types, granite vs. volcanics. There are two high gold assays in the saprolite nonmag HMC, OB-303 with 257 ppb and OB-319 with 1650 ppb, yet zero gold grains were counted in both.

Finally, numerous yellow flakes of Cu + Zn ± Sn ± Pb ± trace Au ± trace Ag and also native copper (in addition to the above 388 ppb Au silt/clay) were found in HMC from a replicate split of saprolite core sample #22496. The original nonmag HMC #22496, or adjacent intervals, contained anomalous Cu, As, Ag & Sb. Scanning electron microscope photographs and EDS x-ray element analysis sheets (see open-file data) of the flakes are available for inspection in the open-file. One author (D.P.M.) believes these to be supergene minerals, but the possibility of artificial contamination cannot be ruled out. If further tests were conducted to verify these as real supergene minerals, then the rating for this occurrence should be significantly upgraded.

The high values of Sb, Se, As and Zn in OB-320 seem to imply incorporation of saprolite into the drift to cause a false anomaly. Mineralogy work should be able to discriminate such false anomalies.

Consistently high pH readings that range from 6.1 to 9.5 were recorded for the weathered bedrock samples. From these results, however, zones in the weathering profile cannot be easily differentiated with pH readings alone.

11.35 Bedrock Assays and Mineralogy

The assay results show no obvious gold occurrences (see Drill Hole Complete Sample Information Sheets or Appendix 2-7). Time did not permit an indepth review of the bedrock samples; however, three cores--OB-314, OB-315, OB-326--do show alteration (see Bedrock Description by Boerboom and Jirsa on Drill Hole Summary Sheets).

For example, the bedrock in OB-314 is a tonalite which has been altered to calcite, aegirine, adularia, and apatite. It has pervasive veining with two vein systems. The composite sample assay has +7% Na_2O.

The bedrock in OB-315 is a felsic volcanic that has pervasive veining with 4 vein systems and complex alteration. The veins have calcite, talc, adularia, pyrite and blue riebeckite. The minerals and the +7% Na_2O assay imply late-stage Na-metasomatism. The fluorine assay is 7,200 ppm over a 9 foot interval.

Lastly, the bedrock in OB-326 is a highly sheared quartz-sericite-chlorite schist. The chlorite is probably Mg-rich, based on x-ray diffraction, and the wholerock MgO = 15 wt. percent. The MGS drilled a hole near this site in 1989, and that information will be published soon (Jirsa, 1989A).

12.0 Discussion of Geochemical Results

We suggest a three-fold working theory for the data at this time. First, the older tills should contain more weathered bedrock and associated laterite gold. Consequently, the late Wisconsinan Rainy lobe should contain more sound bedrock and associated primary gold. However, in some townships the Rainy lobe is underlain by such thick deposits of older tills, it cannot reflect local bedrock there.

Secondly, the landscape on the regional scale in front of the advancing Rainy lobe ice--thus available for incorporation into it--was a "patchwork" of areas of sound bedrock outcrops, laterite, Winnipeg lobe drift, Old Rainy lobe drift, and interglacial deposits. The determination of whether such diversity will be encountered at the local--and property--scale remains to be determined.

Thirdly, it seems likely that as the Labradorean ice lobes advanced southwestardly over the tier of townships near T152N (see Saprolite Map 1-6), they encountered a significant or dominant volume of weathered granitic rocks. The geochemistry should reflect this on the regional scale, but we had no time to evaluate our dataset for it. A significant question remains as to how the Cretaceous weathering event influenced the relief of the landscape, which would have significant influence on subsequent till deposition and composition.

There were a number of means by which geochemical anomalies could be generated within the samples. This is compounded when a subsequent glacial event, such as the Rainy lobe ice advance, overrides, erodes, transports and "recycles" an anomaly. The objective of locating original bedrock sources is complicated by the complex geologic history in this region (see example in Maurice, 1987). But recycling may broaden the size of a mining camp-scale anomaly and increase the effectiveness of a regional survey.

Ice transport was the primary dispersion mechanism evident in tills. However, as the ice masses receded, there were large quantities of meltwater available to create placer deposits from the gold grains in the till (estimated 250 gold grains per cubic meter of till). These should be accompanied by magnetite, so the ratio of mag:nonmag heavy mineral concentrate weight can be a guide (see Map 3-4). During the interglacial times, additional placer deposits could have formed. More commonly, the upper surface of the till deposits were weathered. During this weathering, labile elements were released from sulfides and available for adsorption on clay minerals, hydrous iron oxides or manganese oxides.

12.1 Summary of Significant Drill Holes: Discussion

An interpretation of the significant drill holes is presented (Map 3-16), based upon multielement or multisample anomalies. Four holes contain higher gold grain counts: OB-321, OB-318, OB-301 and OB-315 (see Executive Summary & Table 4).

In OB-321, the highest gold grain count, 30, occurs in sample 22589. The adjacent sample has anomalous gold (19 ppb) in the -63 um fraction and anomalous Pb (122 ppm) in the clay fraction. But both the nonmag and magnetic heavy mineral concentrate weights are very high (Map 3-4) and the mineralogy is simple, so recycling of a placer source must be considered (see Sections 11.1 and 11.2). The occurrence is greater than 86 feet above the bedrock, so glacial transport of a mile or more is possible.

In OB-318, the high gold grain counts, W assay, relatively simple stratigraphy and shallow depth, and location near Vermilion fault zone support further evaluation of the area.

In OB-301, the high gold grain counts in the usually barren Winnipeg till are supported by high HMC weights, elevated values of Zn, Mo, Sb, As, shallow depth, and nearness to Coon Lake syenite pluton.

In OB-315, the high gold grain counts in Rainy and Old Rainy tills, three gold grains classified irregular, bedrock alteration (Section 11.35), and elevated Ni, W, and Bi are worthy of more review.

In OB-310, there are many anomalous elements--Cu, As, Sb, Pb, Bi, Ni--in a sulfide-bearing HMC (see Open-file Mineralogy) of Rainy lobe till resting on bedrock. Of all the occurrences, this may be relatively close to the bedrock source.

In OB-313, the anomalous Cu, W, and Se occur in all three Rainy till samples, which rest on saprolite. This occurrence is also likely to be relatively close to the bedrock source. It lies along a granite margin (Map 1-7).

The occurrences in OB-306 and OB-320 should be viewed cautiously. The anomalous Pb and Ba in a Winnipeg till in OB-306 looks like the exotic (very long distance transport) common to the Koochiching lobe (Martin, et al., 1988). And the anomalous Sb, Se, Zn and As in OB-320 looks like incorporation of underlying saprolite, which does contain high contents of those same elements.

Finally, OB-329 and OB-307 are not indicated on the summary map. But if the metal flakes found in the saprolite in OB-329 are determined to be natural (not contamination), then its rating should be significantly upgraded (see Section 11.34). The numerous gold grains found in the unusually thick Rainy till in OB-307 (Map 3-1) may be indicative of a local-scale (vs. property scale) bedrock source between OB-307 and OB-303.

12.2 Gold Grain Counts and Gold Grain Size Data: Discussion

The size distribution of secondary laterite gold elsewhere in the world ranges from very small (Bird, 1988) to large nuggets (Berrange, 1987). A significant contribution or skewing of the size distribution by laterite gold is not readily apparent in our total dataset (Fig. 6). The smaller number of -63 um gold grains (23% Effie vs. 33% Orr/Littlefork) is the only apparent change. One author's (D. P. Martin) interpretation of Figure 6 is that the -63 micron fraction alone does not represent the total sample nor background values very well and does not generally provide a good sample media for gold.

The dataset for the older tills is enigmatic. If one drill hole is subtracted from the Old Rainy data (OB-321) and one from the Winnipeg data (OB-301), then the average number of gold grains in the remaining samples is much lower:

Old Rainy 61 gold grains/30 samples = 2.0/sa.

Winnipeg 5 gold grains/10 samples = 0.5/sa.

The conclusion being that the upper horizons of laterite incorporated into the older tills contributed low gold content. It is probable that most laterite gold was of local origin anyway (Smith, 1987).

A final observation is that some till samples were higher up in the stratigraphy and thus farther from local bedrock. The implication is that such tills, for example, Rainy lobe tills in the southern part of the area, may only reflect the regional geochemistry and gold content. Since bedrock (or laterite) relief is poorly known and the continuity of distribution of older tills is likewise unknown, this interpretation is equivocal.

12.3 Background and Thresholds for Sample Fractions: Discussion

Following the ideas of Hawkes and Webb (1962), the median values are presented as the best estimate of background for these small populations. We have used [3 x median values] as general estimates for threshold values. All median values for the various subpopulations are listed in Table 6 and Appendix 10-1. Once you have selected an anomalous value, check all the available information concerning that sample or drill hole (Tables 1 and 4). The results are best presented visually on the spectrograms (Fig. 10-1). The question of whether the median values represent local versus regional background is unanswered yet. That is, within the accuracy and precision of our analyses (see Section 9.4), there seems to be no significant difference within one drift type (Table 6) over the granite versus greenstone rock types. The exception is for gold, for which the data is enigmatic. Differences in geochemistry were expected, based on similar Rainy lobe till samples to the east and north (Martin, et al., 1988). Therefore, factors are proposed that may have "homogenized" the results: (a) the presence of laterite, (b) lack of classification within dataset for subglacial vs. supraglacial till samples, (c) lack of a ranking system for distance (feet) above bedrock (ex. 0-50', 50-100', +100') for the till samples, or (d) small subpopulations.

Nevertheless, a practical generalization for exploration emerges, since the Labradorean provenance tills (Rainy and Old Rainy) have very similar trace element contents in the nonmag HMC fraction. That should permit some flexibility and economy for exploration at the local scale (probably not applicable to property scale) whereby separate sets of threshold values are unnecessary. If the general guidelines of Averill (1988; see Table 4) are followed, that generalization should also apply to gold.

12.4 Laterite and Glacial Dispersal: Discussion

The oldest event was the intense tropical weathering that occurred during the Cretaceous. Based upon examples from similar Archean terrane in Australia (Mann, 1984; Smith, R.E., 1987), the geochemistry of the resulting zones within the weathered bedrock is quite variable. There are enriched upper horizons for such elements as Au, As, Cu, Sb and depleted lower zones (see Fig. 7B). There are a number of geochemical models for specific landscapes in this weathering environment (Smith, 1987). It appears that very few laterite geochemical anomalies, except placers (Berrange, 1987), occur beyond 1000 meters from the bedrock source.

It is important to recognize that the geochemical processes active during "mild" weathering, such as during our current climate or earlier interglacials, are very different from those during tropical weathering, such as during the Cretaceous. It has been proposed that the morphology of secondary gold grains created during these contrasting climate regimes differs. That is, gold grains in a lateritic supergene occurrence have botryoidal, spherical, dentritic or other forms. No examples of these forms have been found in mildly weathered, oxidized till (Averill, 1988) prior to our drilling. Rather, in mildly weathered till, the gold is thought to be associated with hydrous iron oxides, sometimes in the silt/clay fraction and other times (Owl Creek Mine) with secondary iron oxides that are present in all grain size ranges (DiLabio, 1988; DiLabio, et al., 1988).

Our Effie area samples are unlike typical Canadian till samples reported in the literature, in that laterite gold grains have been incorporated into glacial drift. The problem is that Averill's (ODM lab) delicate vs. abraded classification may have errors whereby laterite gold is mistaken for abraded background gold (see Sopuck in Averill, 1988). We had photomicrographs taken of one gold grain--three others were lost--from a saprolite sample that was "in place," i.e., not transported. We submitted the sample to the ODM lab for HMC processing and classification. It was not abraded, since it was not transported, and the photo shows its pitted surface--yet ODM lab classified it as abraded. The intent here is not to criticize ODM lab for they have done good work for us and one example is not conclusive. Rather, the intent is to notify future explorationists to the problem and to seek a solution to it.

An analogy would be "core stones" of sound, unweathered bedrock that exist within a laterite weathered zone. In such a case, over granitic rocks for example, the glacier may pick up a relatively rounded granite core stone that came from within the laterite but was essentially in-place. That "core stone" would begin its transport already fairly rounded. It is possible that many granite boulders in northern Minnesota have such an origin.

Gary Meyer has suggested that a major valley, possibly preglacial, crosses this region (Map 1-4). The possibility of placer gold occurring and being available for later glacial transport cannot be ignored, especially in the case of hole OB-321 (see example in McArdle and Warren, 1987; or Eyles and Kocsis, 1988). The simple mineralogy in the nonmag HMC and the ratio nonmag HMC weight:magnetic HMC weight of sample #22426 (see Complete Sample Information Sheet) suggests this.

The presence of marcasite, siderite, and native copper in till samples indicates a component of laterite within it. Other supergene minerals could be expected, based on the potential primary mineralogy. Similarly, the trace element signature of the magnetic fraction may be useful as an indicator of weathered material, based on the 13 samples we extracted from saprolite cores. It appears that as the magnetite grain oxidizes, coprecipitation of trace elements and limonite occurs (Overstreet and Gordon, 1985).

12.5 Individual Sample Fractions: Discussion

A summary report (Lehmuspelto, 1987) clearly states that in Finland dispersal trains in the -63 micron fraction typically are only a few hundred meters long. This probably results from mechanical comminution of common sulfide ore minerals down to the silt size range. It is not helpful in our regional survey approach, but it provides still another means to discriminate anomalies that are very close to bedrock source. Combined with the HMC results, an anomaly in both media is a good indication for a nearby bedrock source. Following that line of reasoning, none of the drill holes in the Effie area appear to be within the "head" of a dispersal train, although our clay fraction is not strictly comparable to the Finn's -63 um fraction.

We have chosen not to assay base metals in the -63 micron fraction. Rather we are seeking hydromorphic dispersion of base metals into the clay fraction in this regional approach. Such dispersion could have occurred prior to, between, or after the multiple glacial events. The assay results are clearly labelled as to which fraction was used. Moreover, a practical methodology is to process HMC, count gold grains, and assay the HMC, then follow up the anomalous samples with mineralogy work and -63 um screening and analysis (Table 4).

Laterite gold can be very fine-grained (Mann, 1984; Bird, 1988; Saarnisto & Tamminen, 1987). Two of our saprolites contained significant gold, 34 ppb and 388 ppb (OB-319 & OB-327), in the -63 micron fraction. It is cautioned that the silt/clay fraction be checked in areas within this region where laterite or pre-late Wisconsinan tills are the dominant sample types over bedrock until the gold distribution within such samples is better defined on a local scale.

In review, the -63 micron fraction would be useful where gold occurs as primary -25 micron size grains, in secondary form from temperate weathering of tills, in secondary form from laterite, or in supergene caps of ore zones, or to try to confirm that an HMC anomaly is close to the source. The clay fraction alone, undiluted by the volumes of silt created during mechanical glaciation, should be useful to identify hydromorphic anomalies.

In contrast, the nonmag HMC is interpreted to provide a good sample media overall for property scale, local, and regional mineral evaluation for gold in this region. It has proven very effective in property-scale surveys in Canada (Averill, 1988) where mechanical glacial transport of primary ore mineralization has been found. In areas where laterite is present, this fraction should provide anomalous values of gold and pathfinders, especially those associated with hydrous iron (or Mn) oxides, once thresholds are established.

The resistant nature of gold and some other heavy minerals, combined with supraglacial transport mechanisms (Hickok, 1986) across mining-camp scale anomalies, should provide regional HMC geochemical patterns. That may be showing up in some data from Canada as presented by Averill (1988). There is not enough data to recognize patterns across the three greenstone belts of this region.

Regarding the magnetic HMC, examples of its usefulness have been reported (Martin, et al., 1988). It can, in some cases, provide an easy means to fingerprint a specific dispersal train within a till. Since mineralization often contains unusual magnetite compositions, this media has proven popular in geochemical surveys around the world, and there is considerable information available (Overstreet and Gordon, 1985).

Regarding the laterite present in this region, Smith (1987) and Farrell (1984) provide examples based upon Australian Archean greenstone terrane that suggest methods to use the laterite itself as a sample media. Regionally, the landscape is too complex for that, but it may be possible on the local- or property-scale.

13.0 Conclusions

The survey is based upon concepts of Fortescue (1980) (see Appendix 3-2) on landscape geochemistry, that is, geochemistry is a means to define the landscape. Those concepts suggest that specific elements, sample fractions, and drift stratigraphy units that would work well in T154N-R25W are not useful 25 miles to the south in T149N-R25W, where older tills and laterite seem common. That is, in the north where Rainy lobe rests on top of sound bedrock, a Rainy lobe till is a useful sample media in contrast to a location such as T150N-R26W where Rainy lobe till lies high above bedrock on older tills and saprolite.

The combination of 3-D overburden mapping and geochemistry has proven to be a powerful mineral evaluation tool. Yet, without more complete 3-D mapping information (the distribution of material up-ice is unknown), the interpretation of true vs. false vs. recycled anomalies is admittedly difficult. The description of geologic materials (e.g., topography, relief, glacial drift type, saprolite, and bedrock lithology) in the up-ice direction is the most important factor to geochemistry of Labradorean source tills (Rainy, Old Rainy 1, Old Rainy 2). There is considerable complexity in these geologic materials within some parts of this region, but the scale of that complexity is poorly defined by our data. It has been the overall objective of this report to describe those complex geologic strata and their inferred history, in order that exploration may proceed in a more orderly and efficient manner within these natural constraints. The long-term objective of this information database is to permit the development of working models (Bradshaw, 1975) that ultimately permit exploration economics, i.e. depth-to-bedrock and drilling cost estimates, etc., to be the primary factor in exploration decisions here rather than a fear of the complex geochemistry.

During this phase of the project, the framework has been established for further exploration. The glacial drift stratigraphy has been described, bedrock mapping has been improved, depth-to-bedrock estimates have been improved, saprolite has been described, and methods for geochemical exploration have been described. These can be combined with the new MGS bedrock map (Jirsa, 1989A) and the new USGS aeromagnetics (Bracken & Godson, 1988) to perform more systematic mineral evaluation surveys in the future.

The survey has identified four holes with unusually high gold grain counts and four holes with unusual trace metal contents, of which the latter may be caused by incorporation of laterite. Within one greenstone belt or a township, the survey has not been able, at this stage, to define specific geochemical parameters, nor to narrow down the area into zones of higher gold potential, nor to define the glacial drift variability and thus geochemical variability. All of these hinge upon acquiring more data points, which means more drill holes, the importance of which cannot be minimized.

To summarize, the glacial drift stratigraphy in much of this area is complex and somewhat deep. That is offset by the excellent potential for gold and the higher overall gold grain counts observed.

14.0 References

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