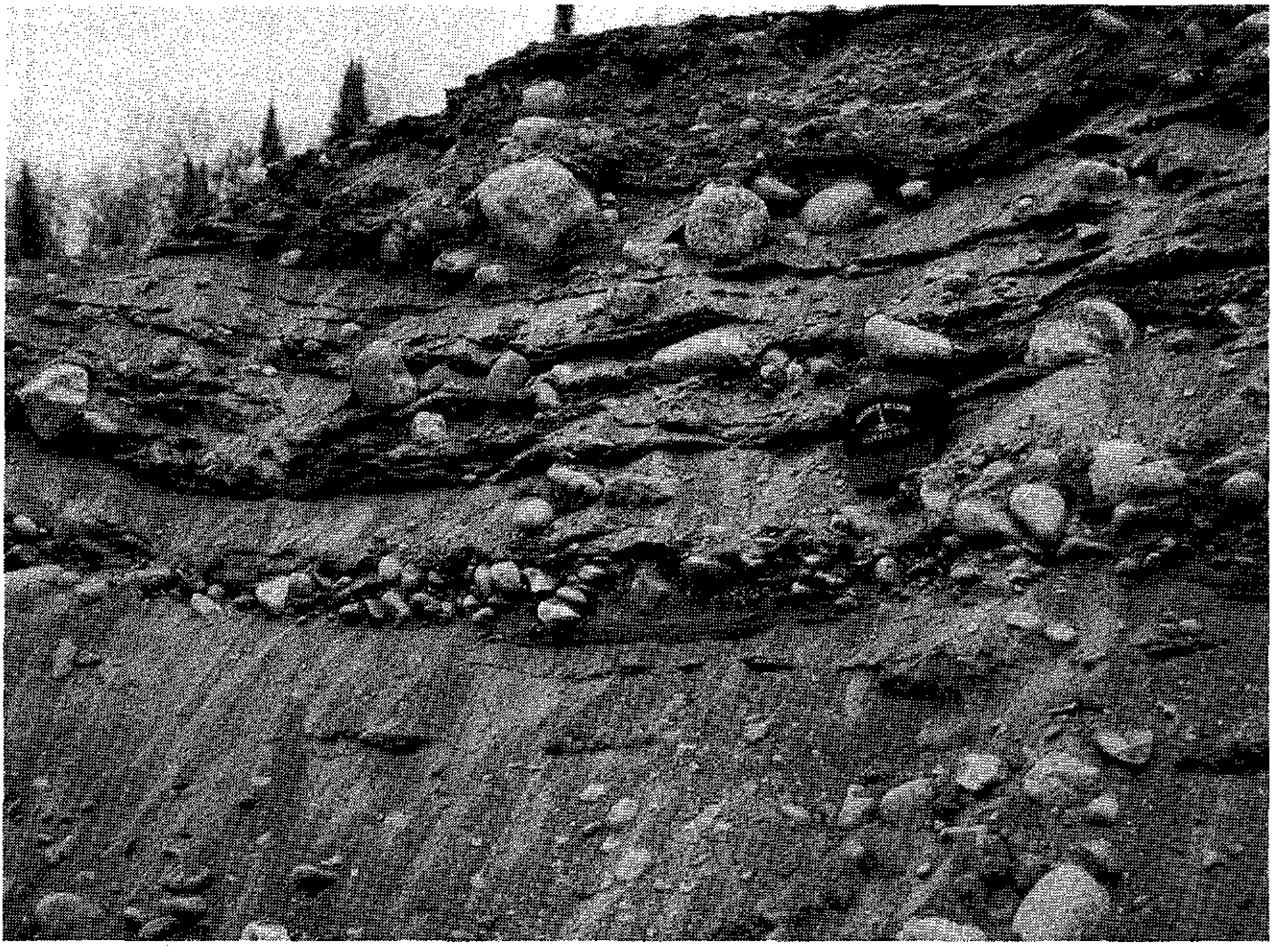
Esker Prospecting Over The Duluth Complex In Northeastern Minnesota



A cut in an esker near Gowan, Minnesota, reveals the diversity of clast sizes found in eskers.

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ESKER PROSPECTING OVER THE DULUTH COMPLEX IN NORTHEASTERN MINNESOTA

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PART I: PROJECT SUMMARY

INTRODUCTION AND OBJECTIVES

There are at least six general types of platinum (Pt) and/or palladium (Pd) mineralization models applicable to the Late Precambrian Duluth Complex (See Appendix A). Therefore, a project was initiated to evaluate the Pt and Pd potential of the Duluth Complex in Lake and St. Louis Counties. In addition, the potential for Au, Ag, Ti, Cr, Cu, and Ni would also be evaluated. Thus, a reconnaissance-scale glacial esker sampling program for one field season was chosen as the technique to be used. Two esker sample media were analyzed: (a) detrital heavy minerals, which have been the classical approach to prospecting for precious metals within stream sediments and (b) the -63 micron silt and clay fraction for labile base metals and other pertinent indicator elements. The sampling and processing procedures were designed to try to find occurrences of trace amounts (1 to 10 ppb range) of the precious metals in the esker sediments. Such occurences could be used to search by other methods for the bedrock sources. A graduate student at UMD worked on the project to fulfill the requirements for an M.S. thesis relating to the provenance of materials within these eskers.

Another objective was to determine whether this prospecting method would be an effective regional evaluation tool. It was felt that a significant number of samples would be required to properly evaluate the method.

Eskers were generally constructed by subglacial streams flowing in ice-walled tunnels along the glacier bed and formed during the terminal stages of glaciation when the ice was relatively thin and sluggish (Shreve, 1985). Preliminary maps of these esker systems were made by Morris Eng from air photo interpretation, based on extensive experience he gained while applying glacial geology to solving problems associated with groundwater and gravel resources. As a result, approximately 240 miles of esker ridges were mapped within a roughly 50 township area in parts of St. Louis, Lake, and Cook counties. These eskers are related to multiple glacial drainage systems of the Rainy and Superior ice lobes. (Plate 1).

The theory behind esker sampling can be summarized as follows:

1. Discrete dispersal trains with anomalous geochemical signatures can occur within lodgement till units. These dispersal trains can be correlated to the preferential paths taken by glacial lobes, and are strongly influenced by local bedrock topography. According to heavy mineral case histories, these often occur over very limited areas (1-10 square miles).

2. The sediment load flowing into an esker has good potential for containing material from <u>many</u> discrete lodgement till dispersal trains. The material contributed to the subglacial sediment load often includes a significant component of bedrock from within a 10-100 square mile area, or more, based on the case histories cited in Table 1. Thus, esker sampling provides an efficient means of finding regional-to-local <u>occurrences</u> of

certain elements in drift covered areas and with possible reduction in drilling costs by providing better data for determining the location for site-specific evaluations.

3. The hypothetical target model being considered here is a dispersal train of an ore mineral occurrence which could be 10 feet thick and a mile long within an esker.

SAMPLE LOCATIONS

The report area covers approximately 50 townships from T60N-R5W in Cook County southwest through Lake, St. Louis, Carlton, into Pine County, T44N-R20W. The foci of sampling were the intrusive rocks of the Duluth Complex, the boundaries of which are poorly delineated in some areas because of the glacial drift.

A site description worksheet was filled out in the field for each sample site and is available for inspection at the Hibbing office. A photograph was also taken at most sample sites. The information on the worksheets and the photographs were intended to serve two purposes: 1) to provide very specific site location descriptions for potential subsequent re-evaluation; 2) to provide descriptive data about the esker sediments and stratigraphy. Not all of the sample sites are on State land, and permission was obtained to visit some of the sites.

RESULTS AND DISCUSSION

The results, including assay data, are presented in Table 4. These have established a database for heavy minerals in eskers overlying the Duluth Complex. The results have also contributed to a greater understanding of the glacial geochemistry in the region.

The heavy mineral concentrate assays that appear to be above background are listed in Table 2. As expected, duplicate splits of the concentrates show variable precious metal values. Substantial sample concentrate has been saved and is available to the public for further analytical work.

Interesting platinum values occur in two samples which are located about one mile apart (Table 2). Detectable values of platinum were found in two out of three splits from sample TLR-2 (S34-T60N-R8W) and one out of two splits from sample DL-1 (S2-T59N-R8W). This area represents an overlap boundary zone where the NE-SW trending Highland Moraine of the Superior Lobe glacial deposits is partly overriden by the divergent E-W trending Vermillion Moraine of the Rainy Lobe, hence, the glacial geology is complex (Friedman, 1981, p. 53; Wright, 1972).

The interpretation of the TiO_2 assays must be viewed with caution, since the recovery ratio of the ilmenite or titaniferous magnetite (S.G. 4.7 to 5.2) by our jig-tabling system is unknown. The higher TiO_2 values may reflect, to some degree, areas of coarser-grained titaniferous magnetite, which could have higher recoveries than the finer-grained variety.

In most cases the sample intervals are too large to evaluate trends within an individual esker.

The assays from the seventeen silt/clay samples show some interesting results for Cu, Ni, Pb, and As. However, it is felt that not enough samples from various source lithologies were analyzed to develop good background values. This approach could have application to a smaller, more detailed prospecting survey.

The number of esker samples taken do not fully cover the area. Many more samples could be taken to satisfy the proposed prospecting model. An important consideration is that this model (and most other overburden geochemistry surveys) apply only to those mineralization areas that occur in outcrop or at the buried bedrock surface, where they could thus be incorporated into the subglacial sediment load.

Corraborative evidence for specific esker anomalies can be found by overlaying the lake sediment assay results, for example the 95%-tile of lead assays (Vadis and Meineke, 1982; MnDNR Report 171).

PART II: METHODOLOGY

SAMPLE TYPES, METHODS, AND ANALYSIS

A total of ninety-six samples were taken within a limited time frame from widely dispersed sample sites (Plate 1) through the able assistance of many student workers. Ninety-one samples were collected from esker ridges, four from drumlins, and one from outwash.

Maps compiled of the surficial deposits indicate these samples represent materials associated with events involving three different glacial lobes (Eng, 1979; Eng, 1985).

Heavy mineral concentrates were obtained from approximately 50 gallons of sample material collected at each site with a shovel and 5-gallon buckets from the face of selected gravel pits. A footage-weighted channel sample of between 5 and 10 vertical feet was taken from a cut in the pit. If more than 10 feet of pit face was available, a separate sample was taken for each additional 10 vertical feet.

A fine-grained silt + clay fraction sample was obtained by screening roughly 2 to 4 pounds through a 250 mesh Tyler screen (63 microns). Each fine-grained sample was selected from the best clay-rich 12-inch vertical section found within the 10-foot interval used for the 50 gallon granular sample. The two samples should complement each other. It was often difficult to find any significant clay laminae in the esker sediments because of the gravelly nature of these deposits.

There are few guidelines concerning basic factors pertaining to the sample site, sample interval, or sample size for a regional (or a local) esker survey. Many recently developed theories are contributing to new and innovative approaches to the problem. A list of factors that affect sampling is presented in Appendix C.

The analyses were performed at Bondar & Clegg, Vancouver, because of the special techniques required. A description of the details of the digestion and analytical techniques are available for inspection. Most of the procedures are total extraction methods.

HEAVY MINERAL CONCENTRATION METHODS and PROCESS TEST SAMPLES

The flowsheet for the sample processing of the heavy mineral concentrates is presented in Figure 1. To summarize, roughly 700 pounds was concentrated down to roughly 2 pounds, which is an average concentration factor of 350. The intent of the concentration process was to increase the precious metal content of the sample to a level well above the analytical detection limits and so that background values could be estimated. The guidelines used for the flowsheet were that the method should:

a) have good reproducibility;
b) recover +50 percent of gold particles of +70 micron diameter (or equivalent);
c) have the capacity to process hundreds of pounds within a reasonable time;
d) allow the equipment to be easily cleaned between samples.

The main process units chosen for the flowsheet were a hydromatic(1) jig (in the field) preconcentration device followed by a wet shaking table (in the lab) as the final concentration device. The jig and tabling procedures were standardized as much as possible, especially for processing time, to try to keep the recovery consistent. The perseverance of Jay Niebuhr, the jig operator, contributed much to developing uniform operating techniques and improving accuracy.

A number of samples were run to test the recovery of the complete jig-plus-shaker table process. A known weight of galena (S.G. = 7.5) was added to two separate samples and processed in the usual manner. The calculated recoveries were 76.6 percent and 79.2 percent (see Table 3). In contrast, the recovery of magnetite (S.G. = 5.2) was calculated from a probable "worst-case" example. Only 9.5 percent of the magnetite was recovered. A good discussion of methods for the recovery of fine placer gold, including reasons for losses, is presented by Wenquian and Poling (1983).

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(1) This is the trade name used by the manufacturer.

PART III: ESKER THEORIES

ESKER SEDIMENTATION

The six major characteristics of eskers are 1) location and path, 2) ridge morphology and size, 3) sediment composition, 4) sedimentary structures, 5) facies relationships, 6) paleocurrent direction variability, and 7) esker troughs and/or tunnel valleys. The origin of an esker is interpreted from these characteristics.

Theories on esker origins and deposition appear to be evolving rapidly at this time. The most coherent description of esker formation is presented by Shreve (1985) in terms of glacier physics.

There are three general sedimentation models or depositional environments proposed for eskers (Banerjee and McDonald, 1975; Baker, 1984): 1) ice-walled open channel, 2) tunnel, and 3) delta. The delta environment is further subdivided by Baker (1984) into either the Gilbert type, which is a "flat-topped feature developed where glaciofluvial material built up to the standing level of the glacial lake," or the sub-aqueous fan type, which "was debouched from the esker conduit and laid down on the lake bottom."

Furthermore, ridge morphology has been subdivided into four proposed examples by Banerjee and McDonald (1975): 1) single ridge with flanking outwash, 2) single ridge with no flanking outwash, 3) broad ridge with multiple crests, and 4) beaded eskers. A major question now is whether beaded (or segmented) eskers represent the sequential meltback of the receding ice front as Shilts (1973) proposes, with each bead being a younger delta than the one downstream from it, or are the beads simply deposited in a widening in the esker trough?

Finally, it is pertinent to prospecting that Baker (1984, p. 53) noted the following in the Kirkland Lake Archean greenstone terrane: "The major esker systems were preferentially oriented along interesting fault lineaments while the course of small eskers was influenced by the local bedrock topography." Bedrock topographic control of eskers is discussed at length by Shreve (1985) and is cited by Hyyppa (1954), Harme (1961), Banerjee and McDonald (1975, p. 134), Shilts (1973, p. 4), and Lee (1965). A map (scale 1"=1 mile) of "Glacial Deposition in S.E. St. Louis County, Minnesota" (Eng, 1985) supports this concept. The course and direction of esker systems mapped here appear to be in delicate balance with the position of ice fronts and bedrock highs. Based on these observations in Minnesota, M. Eng theorizes that:

The location of the esker systems correlates closely with local and regional topographic bedrock barriers which caused deflection of the basal ice flow. Regional barriers are represented by high geologic formations forming divides or by contact with another lobe of a glacier.

This suggests the initial stage for esker formation is predetermined at an early phase in glaciation. It is postulated the barriers to the moving glacier stresses and weakens the basal ice at low points around or between the diverting obstruction.

Upon stagnation, glacial meltwater becomes focused into these stressed areas. Eventually tunnel valleys and esker ridges are formed within the ice following the trend prescribed by earlier glacial events. The size of the esker system seems to be proportional to the magnitude of the barrier impediment and the vigor of the glacier.

TRANSPORT OF MATERIALS IN ESKERS

There are two components of transport to final deposition within the esker. The first is the direction and distance of transport by ice within the glacier; and secondly, the direction and distance of transport by water within the esker system.

Drake (1983) describes this concept:

> Eskers tend to form late in glacial episodes as evidenced by their common position atop or slightly incised into till sheets. Their immediate source of sediment likely includes erosion of the upper portions of the basal till sheet plus whatever is still entrained in the ice at the final stages of flow. Since the basal till plumes in the area will already be developed at the time of the esker formation, I propose that the last distributions along eskers are initially inherited from the last plumes in the underlying tills and then sometimes modified by glacial- fluvial process.

The following comments by Lee (1965) pertaining to the extremely large Munro esker have guided recent workers:

> Short transport is expected in an esker because esker streams are thought to be short lived and overloaded with sediment.
>
> The author's investigations in the Munro esker have confirmed Hellakoski's observations (1931) that fragments from a particular bedrock source do not occur in maximum abundance over or immediately adjoining the source and, in fact, that the first appearance of the indicator fragments is some distance downstream along the esker from the source. The displacement distance between the bedrock source and the position of peak abundance for any component is here defined as the transport distance "K".

Lee, in his above definition of K, refers to a sample taken from a shallow pit on the top surface of the esker.

Drake (1983) defines K more clearly as "the map distance between the maximum surface concentration of an ore or distinctive lithology and its nearest upglacier outcrop or subcrop (after Lee, 1965)."

Specific studies of esker transport seem to indicate that K varies within one esker with clast size (boulders vs. cobbles vs. pebbles vs. sand) and with fragment density. Concentrations of boulders occur nearer the source (shortest K distance) compared to the smaller clasts.

Referring to studies in the Northwest Territories, Canada, Shilts (1973) concluded:

> Most eskers are probably built in short segments by streams extending a few tens of feet to a few miles back from the ice margin. As the ice margin retreats, the stream segment building the esker retreats, maintaining more or less constant length by extending itself headward.
>
> The implication of the segmented sedimentation hypothesis of esker formation is that, unlike normal drainage systems where sediment at any point is partially derived from points upstream to the limits of the drainage basin, sediment at any point in a segmented esker can only be derived from as far as the head of the short stream segment associated with its formation. Thus, although an esker may be traceable as a continuous ridge for 100 miles, if it is composed of sedimentation segments that average only five miles in length, five miles is the maximum distance of transport that may be expected.

Lateral input, which is transport perpendicular to the esker flow direction, appears to be variable and to be limited to a few kilometers or less (Riisto Aario, 1985, pers. communication, based on limited studies in Finland).

More recently, at a till geochemistry workshop, Shilts (1984) gave an overview of prospecting methods, including the following:

> In many regions eskers and other ice- contact deposits are an obvious and cheap alternative to sampling till. Although esker sediments are derived from the same basal load as till, a model for subsequent glaciofluvial transportation history has not been well defined.

In summary, these examples and a few unpublished ones (including one by the Ontario Geological Survey) indicate that eskers can contain locally-derived ore clasts. Specific transport models are beginning to be developed and tested, but no general transport model can be applied to all eskers.

ESKER GEOCHEMISTRY

The following topics are suggested as being very relevant to the interpretation of specific esker assay data.

Shilts (1984, p. 95) proposes that: "Mineral and chemical partitioning in till is marked because of the tendency of minerals to crush to certain specific sizes during glacial comminution."

In a workshop summary Shilts (1984, p. 121):

> ...showed results of recent research on mineral and chemical partitioning in till from Canada in which metal levels were found to be greatly increased in the fractions finer than 4 um. This enrichment was found for all metals studied (Cu, Zn, Pb, Co, Cr, Ni, U, Cd, As, Mo, Fe, Mn) and seems to occur within the lattices of the physically comminuted phyllosilicates that dominate this size fraction. The enrichment trend seems to exist in both weathered and unweathered samples. Similar research in Finland on tills found over known sulphide orebodies, such as Outokumpu, have shown almost identical trends for Cu and Zn. This implies that most of the metal from conventional "fine fraction" analyses (-180 um, -74 um) is derived from the -4 um fraction and that textural differences among samples may lead to false anomalies. The high concentrations of metal in these fractions can allow a much more precise identification of the distal parts of dispersal trains, resulting in a much larger target in reconnaissance geochemical mapping studies.

Note that precious metals unfortunately were not evaluated in the above reference.

There are different sample media in different locations within any one esker that could be sampled. The sample media types commonly analyzed and comments pertinent to interpretation include:

1. Individual clasts of any specific size range, especially boulders. Boulder counts in eskers are discussed by Drake (1983, p. 710). Lee (1984) notes that "macrochemistry of clasts in esker node gravels with boxwork and webwork structures were recognized and introduced as significant advances in base metal exploration."

2. All the clasts within a specific coarse size range.

3. The heavy minerals concentrated from various size ranges (and various densities). Folk (1968) cites the five general variables that apply to the evaluation of the heavy mineral content of a sediment as:

    a) Lithology of the source area.
    b) Differential stability of minerals to weathering in place in the source area.
    c) Durability of the mineral to abrasion.
    d) Hydraulic factor. [In glacial eskers, Shilts' "partitioning" concept is also pertinent here.]
    e) Post-depositional stability to weathering.

    A few references contain assay data for background values of heavy mineral concentrates (Wolfe et al, 1975; Shilts, 1973). A few indicate gold particle counts (Lee, 1963; Ferguson & Freeman, 1978; Lee, 1965 Lee, 1968).

In the case histories of overburden drilling reported by Gray, 1983, he discusses the occurrence of anomalous gold values in gravel units compared to basal till units:

> In places, the basal clastics are gravels composed of cobbles and pebbles from the till, with the finer grained till matrix washed away. These can be identified because the pebbles contain a range of rock types such as soapstone and rhyolite, carbonate and granite, with the range of hardness that could not accumulate in a true gravel because the soft particles would be abraded by the harder particles. In these washed tills, heavy minerals tend to remain in situ, so they are still useful for tracing up-ice towards a bedrock source. True gravels, deposited by storm action have a longer and more complicated transport history, and would be very difficult to trace to source...Hole T-44, located 327 meters further down-ice yielded 23,330 ppb Au, also from the basal clastics. There is a tendency for anomalous values to spread out over a greater till thickness as distance from the source increases. For this reason, it is valuable to have assay data through the whole coarse clastic section, rather than just analyzing basal samples.

Although the gravels referred to above by Gray are probably not eskers, nevertheless the occurrence of gold is cited in "local" gravels.

The trace element composition of "heavy rock fragments" (S.G. greater than 2.85; diameter +60 mesh, minus 18 mesh) of eskers are discussed by Shilts (1973).

4. The silt/clay (-63 um) fraction.

Shilts (1973) noted a very important concept for esker sampling and prospecting, based on a study of base metals in eskers in permanently frozen terrain: "The -250 mesh fraction of eskers has a much higher ratio of minerals with high exchange capacity to minerals with low exchange capacity than does the equivalent fraction of till." And he claims that "the background concentrations of trace elements in -250 mesh material in eskers are roughly 6 to 10 times those of adjacent tills, although heavy mineral trace-element values for eskers and adjacent tills are broadly comparable." No such evaluations have been found in the literature concerning the distribution of precious metals by screen fraction in eskers or other glaciofluvial deposits. Not enough assays are available on the -250 mesh samples from the Duluth Complex esker project to draw conclusions on this topic.

5. The clay (-2 um) fraction.

"The more labile ore minerals, such as sulphides, are destroyed by weathering to depths several meters below the postglacial solum. This destruction is often accompanied by a concomitant increase in metal concentration in the clay-sized (less than 2 um fraction)" (Shilts, 1984).

Assay data for -2 um clay from eskers is presented by Shilts (1973).

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Table 1. Examples cited of distance of transport in eskers.

Reference Cited	Esker Name or Location	Transport Distance Cited	Fragment type
Lee, 1965, p.8	Munro Twp., Ontario	"K" = 8 (±2) miles	Dunite fragments 3.35 mm to 8 mm (note 3 examples)
Lee, 1965, p. 12	Munro Twp., Ontario	"K" = 3 (±2) miles	trachyte fragments 8 mm to 16 mm
Lee, 1965, p. 12	Munro	"K" = 2 (±2) miles	gold grains -10 microns
Lee, 1968, p. 2	Munro	"K" = 2 miles	pyrope garnet grains 0.5 mm - 1.23 mm
Szabo et al, 1975, p.1539	McDougall Lake	1 km = first appearance 15 km = "K" ?? -1 km, " a short distance"	granite pebbles 1.9 - 3.8 cm granite boulders "as much as 80%"
Shilts, 1973, p. 13, 18, 19	Kaminak Esker, Northwest Terr.	specular hematite and red volcanics at least 60 miles transport	sand and cobble;
	Kaminak Esker, Northwest Terr.	about 1 mile from known Cpy-Sph mineralization	Zn, Ni, and Cu anomalies in -250 mesh
	Copperneedle esker, Northwest Terr.	about 200 to 300 feet from known Cu-Ni mineralization	Cu and Ni in -250 mesh
Drake, 1983, p.710	Pine River	"K" = 1 km from special boulder plume	"average density boulders"
Trefethen and Trefethen, 1944	Kennebec Valley, Maine	within 5 miles; within 6 miles; "nearby" and "not far beyond source" "In general, the majority of minerals have been transported for distances of 3 to 8 miles, hence is principally of local origin." (p. 524)	shale pebbles; granite pebbles; pyrite in heavy minerals
Davis, 1892, pp. 477-499, as cited in Trefethen and Trefethen	Newton-Auburndale esker, Mass.	2 to 4 miles	(unknown)
Stone, 1899, p. 432, as cited in Trefethen and Trefethen, 1944	Unknown	one example...less than a mile from outcrop source	(unknown)
Alden, 1918, p. 287, as cited in Trefethen and Trefethen, 1944	Wisconsin Eskers	91.5% derived from local rock	(unknown)
Hellaakoski, 1930, pp. 1-41, as cited in Trefethen and Trefethen, 1944	Laitila Esker SW Finland	majority of esker material transported 3 to 5 miles	Rapakivi granite
Cohen and Stanley, 1982	Ireland	transport less than 2 km	(not defined)
Wolfe, Lee, Hicks, Hicks, 1975	James Bay Lowlands Ontario	in general "K" = 1 mile	pebbles

Note "K" is defined in Transport of Materials in Eskers section of this report.

Table 2. Selected assay results that appear to be above background values.

A. Heavy Mineral Concentrates

Sample	Location S-T-R(W)	Elements Ag (OPT)	Au (OPT)	Pt (PPB)	Cr (PPM)	Ni (PPM)	TiO_2 (%)	Pb (PPM)
SIR-1	30-61-7	0.07						
SL-1	18-59-10	0.05						
SIR-3	36-61-8		.095					
RIL-3	12-59-8		.039					
SBR-1	5-55-13		.038					
TLR-2	34-60-8			55;80				
DL-1	2-59-8			55				
EMCO-1	33-59-11				11,200		21.5	
ARC-1	5-60-8					3,250		
GL-1	15-60-9						21.2	
ROL-1	16-55-12						22.2	
IVER-1	32-49-17							150

B. Minus-63-micron Silt/Clay Sample (screened, not concentrated)

Sample	Location S-T-R(W)	Cu (PPM)	Ni (PPM)	Pb (PPM)	As (PPM)
ISR-1	29-61-9	500	200		
ARC-1	5-60-8	400			
SHAM-1	4-60-10		550	20	
RIL-4	12-59-8	250		10	10

Table 3. Calculations for process recoveries.

Galena Tests with -65 mesh +150 mesh galena

Test 103, Sample CLQ-1

	Weight	Pb (Wt.%)	Pb units	% Recovery
Concentrate (Calculated)	454 g	86.6	393.16	100
Concentrate (Assay)	1180 g	26.4 average	311.52	79.2
Sample Number 14404 A1		24.80		
Sample Number 14404 A2		28.00		
		26.40 average		

Test 104, Sample CLQ-4

	Weight	Pb (Wt.%)	Pb units	% Recovery
Concentrate (Calculated)	454 g	86.6	393.16	100
Concentrate (Assay)	646 g	46.6	301.04	76.6
Sample Number 14407 A1		45.23		
Sample Number 14407 A2		47.97		
		46.60 average		

Magnetite Test on a real sample

Test 101, Sample CLQ-3

	Weight	Weight % Magnetics	Magnetite in Magnetics	Magnetite Units	Distribution %
Head (Calculated)	508 lbs.	(0.45)		(1034.79)	100
1st Jig Concentrate	900 g	16.48	66.13 average	98.08	9.5
2nd Jig Concentrate	570 g	10.11	61.39 average	35.38	3.4
Tails *	21 lbs.	16.01	58.92 average	901.33	87.1

The jig tails were saved, then run over the shaker table to determine what the jig lost.

Table 4. Summary data and assay results from esker samples in St. Louis, Lake, Carlton, and Pine Counties. All assays performed at Bondar-Clegg, Vancouver.

									Heavy Mineral Concentrates															Unprocessed "Silt/Clay" Samples***									
Sample Number	Location (S-T-R)	Total Sample Weight (pounds)	Sample Feed Weight to Jig (minus ½ inch size; pounds)	Final Concentrate Weight (From Shaker Table; grams)	Concentration Factor (Total Sample Weight÷ Final Conc. Weight)	Photo of Sample Site	Assay Sample Number	Element Units	Pt PPB (1)	Pd PPB (1)	Cu PPM	Ni PPM	Cr PPM	Co PPM	V PPM	As PPM	Sb PPM	W PPM	Sn PPM	Ag PPM (3)	TiO_2 PCT (4)	Au OPT (1&2)	Ag OPT (1&2)	Ag PPM	Co PPM	Cu PPM	Mn PPM	Zn PPM	Ni PPM	As PPM	Sb PPM	Pb PPM	Se PPM
SIR-1	30-61-7	766	661	1280	271		CF14372		L15	4	130	200	750	65	500	15	L5	70	L10	2.5	4.45	0.002,L0.002	0.07,0.02	L0.5	25	160	1000	100	80	L5	L5	L5	L5
SIR-2	30-61-7	687	634	1570	198		CF14373		L15	4	120	250	1100	90	850	10	L5	130	L10	L0.5	10.35	L0.002,L0.002	L0.02,0.03										
JPC-1	31-61-8	673	598	1480	206		CF14374		L15	2	130	250	950	70	550	15	L5	70	L10	L0.5	5.25	L0.002,L0.002	0.02,0.02										
JPC-2	31-61-8	798	678	1500	242		CF14375		L15	4	140	300	1050	100	1000	5	L5	140	10	L0.5	13.00	L0.002,L0.002	0.02,0.03										
JPC-3	31-61-8	817	622	1590	233		CF14376		L15	4	160	250	900	85	800	15	L5	110	L10	L0.5	8.10	L0.002,L0.002	L0.02,0.03										
SIR-3	36-61-8	812	647	1060	348		CF14377		L15	4	140	200	750	75	750	L5	L5	110	L10	L0.5	7.50	L0.002,0.095	L0.02,0.04										
IC-1	27-61-9	736	593	820	409		CF14378		L15	2	160	300	950	110	1500	10	L5	200	L10	L0.5	18.80	L0.002,L0.002	L0.02,0.02										
SPGL-1	27-61-9	881	701	1340	299	x	CF14379		L15	4	150	250	650	90	1400	15	L5	140	L10	L0.5	14.10	L0.002,L0.002	L0.02,0.02										
ISR-1	29-61-9	759	-	630	550	x	CF14380		L15	2	140	350	1200	100	900	10	L5	150	L10	L0.5	11.40	L0.002,0.002	L0.02,0.02	L0.5	50	500	750	100	200	L5	L5	L5	L5
IC-2	35-61-9	783	-	750	475	x	CF14381		L15	4	150	300	700	75	450	10	L5	70	L10	L0.5	5.30	L0.002,L0.002	L0.02,0.02										
4ML-1	8-60-5	599	449	1750	156	x	CF14382		L15	2	130	200	450	85	1450	L5	L5	160	L10	L0.5	12.70	L0.002,L0.002	L0.02,0.02										
HC? HCR-1	5-60-6	748	628	1420	238		CF14383		L15	2	140	150	300	55	550	L5	L5	90	L10	L0.5	5.80	L0.002,L0.002	L0.02,0.02										
MICr-1	24-60-6	788	-	1290	277	x	CF14384		L15	4	120	140	300	50	700	15	L5	60	L10	L0.5	4.30	L0.002,L0.002,L0.002	L0.02,0.02										
HL-1	29-60-6	695	545	1150	275		CF14385	(L15)	L15	L2,2	130	150	450	70	1050	15	L5	130	L10	L0.5	8.10	L0.002,L0.002	L0.02,0.02										
WR-1	33-60-7	895	730	490	895	x	CF14386	(L15)	L15	L2,6	130	200	650	95	1650	L5	5	200	L10	L0.5	19.30	L0.002,L0.002	L0.02,0.03										
TLR-1	34-60-8	769	731	1580	221		CF14387	(L15)	L15	L2,4	130	200	450	85	1300	L5	L5	160	L10	L0.5	13.00	L0.002,L0.002	0.02,0.02	L0.5	25	85	950	80	55	L5	L5	L5	L5
TLR-2	34-60-8	670	617	680	447		CF14388	(55,L15)	80	L2,L2,2	120	180	650	80	1500	L5	L5	200	L10	L0.5	15.10	L0.002,0.004	L0.02,0.03	L0.5	50	110	1600	160	95	L5	L5	L5	L5
SIR-4	10-60-8	810	600	1370	268		CF14389		L15	L2	150	250	900	100	1800	15	L5	250	10	L0.5	19.60	L0.002,0.002	0.02,0.02										
JPC-4	7-60-8	745	625	1400	242		CF14390		L15	2	140	200	900	85	1550	5	L5	180	L10	L0.5	14.30	L0.002,0.006	L0.02,L0.02										
WCC-1	7-60-8	809	689	1330	276		CF14391		L15	4	120	180	600	75	1300	10	L5	160	L10	L0.5	11.50	L0.002,L0.002	L0.02,0.03										
ARC-1	5-60-8	685	610	1630	191		CF14392		L15	2	130	3250	1200	110	1150	L5	L5	150	10	L0.5	12.00	L0.002,L0.002	L0.02,0.04	L0.5	50	400	110	120	140	L5	L5	L5	L5
GL-1	15-60-9	744	564	1700	199		CF14393	(L15)	L15	2,2	130	200	850	95	2100	L5	L5	250	L10	L0.5	21.20	L0.002,L0.002	L0.02,0.04										
GL-2	15-60-9	650	-	1500	197	x	CF14394		L15	2	110	180	650	80	1500	10	L5	200	L10	L0.5	13.50	0.004,L0.002	L0.02,0.03										
SHAM-1	4-60-10	683	578	1200	259	x	CF14395		L15	L2	90	500	1950	140	1100	15	L5	250	10	L0.5	14.80	L0.002,L0.002	0.02,0.03	L0.5	85	120	1050	100	550	L5	L5	20	L5
DL-1	2-59-8	599	591	1035	263		CF14396	(55)	L15	0,L2	120	190	600	90	1800	5	L5	250	10	L0.5	19.70	L0.002,L0.002	L0.02,L0.02	L0.5	15	90	600	70	40	L5	L5	5	L5
DL-2	1-59-8	764	584	1390	250	x	CF14397	(L15)	L15	4,L2	120	200	550	85	1500	10	L5	250	10	L0.5	16.90	L0.002,0.002	L0.02,L0.02										
RIL-1	12-59-8	653	458	960	309	x	CF14398	(L15)	L15	L2,2	110	170	450	75	1350	L5	L5	160	10	L0.5	12.00	L0.002,L0.002	L0.02,0.04										
RIL-2	12-59-8	690	540	345	908	x	CF14399	(L15)	L15	2,L2	120	180	550	85	1750	L5	L5	250	L10	L0.5	19.20	L0.002,0.002	L0.02,0.03	L0.5	20	85	750	70	50	L5	L5	L5	L5
RIL-3	12-59-8	741	-	1210	279	x	CF14400	(L15,L15)	L15	4,2,2	140	160	550	75	1200	10	L5	120	L10	L0.5	10.10	0.039*,0.003	L0.02,0.04	L0.5	25	150	750	100	70	5	L5	5	L5
RIL-4	12-59-8	706	-	1610	199	x	CF14401	(L15)	L15	L2,4	140	200	600	90	1850	5	L5	190	L10	L0.5	16.00	0.002,0.003	L0.02,L0.02	L0.5	40	250	1300	130	85	10	L5	10	L5
McD-1	11-59-10	643	-	1230	237	x	CF14402		L15	4	150	250	900	90	1350	L5	L5	170	L10	L0.5	11.90	L0.002,0.002	L0.02,L0.02										
GRR-1	29-59-10	850	752	940	411		CF14403		L15	4	140	190	750	70	1000	10	L5	120	L10	L0.5	7.10	L0.002,0.002	L0.02,L0.02										
SL-1	18-59-10	601	511	700	390	x	CF14404 (2)		L15	4	160	450	1900	130	1550	L5	L5	200	10	1.5	15.40	0.002,L0.002	0.05,L0.02	L0.5	25	60	650	55	160	L5	L5	L5	L5
EMCO-1	33-59-11	797	572	600	604		CF14405	(L15)	L15	L2,4	150	800	11200	170	2300	L5	L5	300	L10	L0.5	21.50	L0.002,L0.002	0.02,0.02										
GWC-1	26-58-11	816	651	1440	257		CF14406		L15	2	150	250	1100	95	1500	5	L5	170	L10	L0.5	11.60	L0.002,L0.002	L0.02,0.02										
MC-1	33-57-11	-	-	1300	-	x4	CF14407		L15	L2	140	250	800	90	1650	L5	L5	190	L10	L0.5	13.70	L0.002,L0.002	L0.02,0.02										
TDF-1	32-57-12	706	668	1700	189		CF14408		L15	4	120	250	850	80	1100	L5	L5	130	L10	L0.5	9.80	L0.002,L0.002	L0.02,0.02										
LSC-1	36-57-14	803	533	1650	222	x	CF14409		L15	4	100	250	1200	75	950	L5	L5	100	L10	L0.5	8.60	L0.002,L0.002	L0.02,0.02	L0.5	25	150	750	80	120	5	L5	L5	L5
ML-1	18-56-11	805	-	1600	229		CF14410		L15	4	100	160	350	45	300	L5	L5	30	L10	L0.5	2.15	L0.002,L0.002	L0.02,L0.02										
DMIR-1	13-55-12	844	544	513	747	x	CF14411		L15	4	200	250	700	120	2300	10	L5	300	L10	L0.5	18.30	0.002,L0.002	L0.02,L0.02										

Table 4. (Continued)

									Heavy Mineral Concentrates															Unprocessed "Silt/Clay" Samples***									
Sample Number	Location (S-T-R)	Total Sample Weight (pounds)	Sample Feed Weight to Jig (minus ½ inch size; pounds)	Final Concentrate Weight (From Shaker Table; grams)	Concentration Factor (Total Sample Weight÷ Final Conc. Weight)	Photo of Sample Site	Assay Sample Number	Element Units	Pt PPB (1)	Pd PPB (1)	Cu PPM	Ni PPM	Cr PPM	Co PPM	V PPM	As PPM	Sb PPM	W PPM	Sn PPM	Ag PPM (3)	TiO$_2$ PCT (4)	Au OPT (2)	Ag OPT (2)	Ag PPM	Co PPM	Cu PPM	Mn PPM	Zn PPM	Ni PPM	As PPM	Sb PPM	Pb PPM	Se PPM
ROL-1	16-55-12	698	697	547	582	x2	CF14412		L15	4	200	250	850	110	2600	L5	L5	350	10	L0.5	22.20	L0.002,L0.002	L0.02,L0.02										
SBR-1	5-55-13	751	511	510	670	x	CF14413	(L15)	L15	4,4	200	200	1100	90	1200	L5	L5	250	L10	L0.5	12.10	L0.002,0.038	L0.02,L0.02										
WOL-2	15-55-13	817	607	1560	237		CF14414		L15	4	130	300	1250	100	1700	L5	L5	200	L10	L0.5	14.90	L0.002,L0.002	L0.02,L0.02										
WOL-1	16-55-13	562	554	1785	143	x	CF14415		L15	4	160	250	1100	90	1400	L5	L5	160	L10	L0.5	10.40	L0.002,L0.002	L0.02,L0.02										
BLRNE-1	32-55-13	-	-	1170	-	x	CF14416		L15	4	140	180	650	70	650	L5	L5	80	L10	L0.5	6.45	L0.002,L0.002	L0.02,L0.02	L0.5	35	200	950	110	120	L5	L5	L5	L5
BL-1	36-55-13	706	-	486	660	x2	CF14417 (2)		L15	4	170	170	550	85	1100	5	L5	120	L10	L0.5	7.75	L0.002,L0.002	L0.02,0.02										
BL-2	36-55-13	839	599	1820	209	x2	CF14418		L15	4	140	250	650	120	2000	5	L5	250	L10	L0.5	18.20	L0.002,L0.002	L0.02,0.03										
MarTr-1	35-55-14	572	497	1020	254	x	CF14419		L15	L2	170	250	850	120	1950	L5	L5	250	L10	L0.5	17.40	L0.002,L0.002	L0.02,0.02										
JR-2	36-55-15	862	-	1080	362		CF14420		L15	L2	130	160	550	70	800	L5	L5	90	L10	L0.5	4.90	L0.002,L0.002	L0.02										
STEW-1	6-54-11	822	522	517	721	x	CF14421		L15	4	200	200	400	100	1750	L5	L5	250	L10	L0.5	12.25	L0.002,L0.002	L0.02										
MTE-2	6-54-13	712	517	688	468	x4	CF14422		L15	4	130	250	1100	90	950	5	L5	100	L10	L0.5	6.00	L0.002,L0.002	0.02										
BLRNE-3	2-54-14	711	614	1270	254		CF14423 (2)	(L15)	L15	4,4	130	190	706	80	1200	10	L5	100	L10	L0.5	6.90	L0.002,L0.002	0.02	L0.5	25	120	800	75	95	L5	L5	L5	L5
BLRNE-6	16-54-14	634	490	970	296	x	CF14424		L15	4	150	200	650	80	1100	L5	L5	100	L10	L0.5	7.40	L0.002,L0.002	L0.02										
BLRNE-7	16-54-14	788	750	896	400	x3	CF14425		15	4	150	200	750	80	1450	5	L5	120	L10	L0.5	9.70	L0.002,L0.002	L0.02										
JR-1	1-54-15	716	566	1370	237		CF14426		L15	4	180	250	850	110	2100	L5	L5	200	L10	L0.5	16.30	L0.002,L0.002	0.02										
PL-1	14-54-16	793	635	960	376	x	CF14427		L15	L2	60	100	300	25	400	L5	L5	30	L10	L0.5	1.85	0.002,L0.002	L0.02										
PL-2	14-54-16	698	-	790	401	x	CF14428 (2)		L15	2	70	110	400	30	500	L5	L5	40	L10	L0.5	2.40	L0.002,L0.002	0.03										
ATE-1	12-53-12	-	-	1860	-	x2	CF14429 (2)		L15	4	160	140	350	40	650	L5	L5	30	L10	L0.5	4.35	L0.002,L0.002	0.03										
TL-1	11-53-14	721	638	675	484	x	CF14430		15	4	190	200	500	55	1150	5	L5	90	L10	L0.5	8.60	L0.002,L0.002	0.02										
IL-2	25-53-15	-	-	1380	-	x2	CF14431		L15	4	150	200	600	50	650	L5	L5	50	L10	L0.5	4.50	L0.002,L0.002	0.03										
BLR-1	25-53-15	755	672	1330	258	x2	CF14432		L15	4	150	180	400	45	800	L5	L5	60	L10	L0.5	8.10	0.002,L0.002	0.02										
ISLE-3	4-52-14	776	648	1610	219	x	CF14433		L15	6	200	170	350	45	1050	5	L5	90	L10	L0.5	12.90	L0.002,L0.002	0.02	L0.5	10	65	500	65	50	L5	L5	L5	L5
VR-1	5-52-14	690	660	960	327	x	CF14434		L15	6	190	190	300	45	900	L5	L5	70	L10	L0.5	10.60	L0.002,L0.002	0.03	L0.5	15	85	700	65	50	L5	L5	L5	L5
IL-1	5-52-14	-	-	1285	-	x2	CF14435	(L15)	L15	6,6	160	150	250	35	450	L5	L5	40	L10	L0.5	5.85	L0.002,L0.002	0.03										
FL-1	29-52-15	737	727	1500	223	x	CF14436		L15	6	200	180	300	40	850	5	L5	70	L10	L0.5	10.55	L0.002,L0.002	L0.02										
BR-1	30-52-15	810	622	417	880	x	CF14437		L15	6	180	170	300	30	500	10	L5	40	L10	L0.5	9.00	L0.002,L0.002	0.02										
BR-2	30-52-15	854	741	1440	269	x2	CF14438		L15	4	120	120	255	40	340	10	L5	20	L10	L0.5	1.90	L0.002,L0.002	0.03										
BERG-1	14-52-16**	844	619	1133	339		CF14439		L15	6	125	135	470	50	555	15	L5	30	L10	L0.5	3.45	L0.002,L0.002	0.02										
MPL-1	25-52-16	753	655	1262	271	x	CF14440		L15	6	125	170	735	55	550	L5	L5	35	L10	L0.5	4.50	L0.002,L0.002	0.02										
DWP-1	35-52-16	714	549	1125	264	x	CF14441		L15	6	145	190	655	70	1045	5	L5	85	L10	L0.5	7.85	L0.002,L0.002	0.02										
ET-1	36-52-16	750	540	1500	227	x	CF14442		L15	6	135	135	310	50	660	5	L5	40	L10	L0.5	3.80	0.002,L0.002	0.02										
ARTL-1	7+8-52-17	725	605	1080	305	x	CF14443		L15	2	220	220	1160	85	1450	5	L5	125	L10	L0.5	12.60	L0.002,L0.002	0.02										
NERC-1	11-51-16	748	688	650	519	x2	CF14444 (2)		L15	4	210	210	805	80	1380	10	L5	110	L10	L0.5	10.50	L0.002,L0.002	L0.02										
NERC-2	11-51-16	689	-	925	338		CF14445		L15	4	140	140	470	50	675	5	L5	45	L10	L0.5	4.50	L0.002,L0.002	0.02										
CS-1	23-51-16	573	505	1495	174	x	CF14446		L15	6	140	180	650	70	1150	5	L5	130	L10	L0.5	9.45	L0.002,L0.002	0.02										

→ Alden Twsp. Ester ?

Table 4. (Continued)

Sample Number	Location	Total Sample Weight (pounds)	Sample Feed Weight to Jig (minus ¼ inch size; pounds)	Final Concentrate Weight (From Shaker Table; grams)	Concentration Factor (Total Sample Weight+ Final Conc. Weight)	Photo of Sample Site	Assay Sample Number	Element Units	Heavy Mineral Concentrates Cu PPM	Pb PPM	Zn PPM	Ni PPM	Mn PPM	Mo PPM	Cr PPM	W PPM	V PPM	As PPM	(3) Ag PPM	(2) Au OPT	(2) Ag OPT	Unprocessed "Silt/Clay" Samples*** Ag PPM	Co PPM	Cu PPM	Mn PPM	Zn PPM	Ni PPM	As PPM	Sb PPM	Pb PPM	Se PPM
SUNL-1	9-51-17	748	-	1000	340	x	CF14447		170	5	250	170	2100	30	605	70	L10	10	L0.5	L0.002,L0.002	L0.02										
PRL-2	27-51-20	552	-	1130	222	x3	CF14448 (2)		180	10	250	200	2500	35	770	130	L10	L5	L0.5	L0.002,L0.002	L0.02										
PRL-3	27-51-20	554	-	1820	138	x	CF14449		150	10	250	190	2100	35	705	200	L10	5	L0.5	L0.002,L0.002	L0.02										
LGL-1	1-50-17	709	701	1750	184	x	CF14450		170	10	250	160	2300	30	375	70	L10	5	L0.5	L0.002,L0.002	L0.02										
MUDL-1	21-50-20	651	646	1720	172	x	CF14451		140	5	200	150	1900	30	550	60	L10	5	L0.5	L0.002,L0.002	0.03										
PRL-1	21-50-20	709	-	1000	322	x2	CF14452		90	L5	130	90	1100	17	400	30	L10	L5	L0.5	L0.002,L0.002	0.02										
AUD-1	12-49-17	731	481	1590	209	x	CF14453		150	15	200	170	2300	25	375	40	L10	L5	L0.5	L0.002,L0.002	0.02										
CLQ-1	26-49-17	553	508	-	-		CF14454 (2)																								
CLQ-2	26-49-17	682	607	-	-		CF14455																								
CLQ-3	26-49-17	777	672	-	-		CF14456 (2)																								
CLQ-4	26-49-17	712	592	646	501		CF14457																								
CE-1	26-49-17	621	620	903	314		CF14458		100	20	110	85	1600	17	285	40	L10	L5	L0.5	L0.002,L0.002	0.02										
CE-2	26-49-17	674	670	1490	205		CF14459		120	15	120	85	1600	18	290	30	L10	10	L0.5	L0.002,L0.002	0.02										
CE-3	26-49-17	657	-	1080	276		CF14460		100	10	130	80	1300	14	265	80	L10	10	L0.5	L0.002,L0.002	0.02										
CE-4	26-49-17	874	784	570	694	x	CF14461 (2)		120	10	130	95	1300	17	255	30	L10	L5	L0.5	L0.002,L0.002	0.02										
IVER-1	32-49-17	577	-	700	375	x	CF14462		140	150	170	95	2000	30	400	60	L10	15	L0.5	L0.002,L0.002	0.03	L0.5	5	40	350	40	20	L5	L5	5	L5
OBLAKE-2	23-48-18	886	751	1760	228		CF14463		85	10	75	65	900	7	260	L10	L10	10	L0.5	L0.002,L0.002,L0.002	0.03										
Sec.14-1	14-48-18	685	-	1870	166		CF14464		180	30	250	120	2400	30	520	50	L10	5	L0.5	L0.002,L0.002	0.02										
OBLAKE-1	16-48-18	858	745	1170	333		CF14465 66 = WBMR-1 67 = KETR-1		70	10	80	60	860	9	265	L10	L10	5	L0.5	L0.002,L0.002	0.02										
BPG BGP-1	11-46-19	846	741	648	592	x2	CF14468		140	10	140	90	1500	19	290	30	L10	20	L0.5	L0.002,L0.002	L0.02										
WLWR-1	20-44-20	634	619	783	369	x2	CF14469		150	35	190	90	1900	35	435	60	L10	5	L0.5	L0.002,0.004	L0.02										

?

Note: Ten samples were analyzed by semi-quantitative XRF methods for 35 elements. Results are available in open-file for inspection.

Footnotes

1. Fire assay sample of 30 grams
2. Fire assay sample of 14.58 grams
3. Acid digestion sample of 0.5 grams
4. X-ray fluorescence analysis

* "Au was found in the +150 mesh fraction after screening and calculated into the total", note from Bondar-Clegg, for sample RIF-3.

** Pb bullet found and removed from jig concentrate of sample BERG-1.

*** A few pounds of the finest-grained sediments in the exposure (usually from a one foot vertical interval) were collected. All or part of it was screened through 230 mesh (63 microns). The split from the minus 230 mesh (-63 um) was assayed.

L = less than
(L15) = Parentheses denotes a separate 30g split re-submitted for assay.

Table 5. Assay data for standards and paint (contamination) chips.

Sample Number	Location	Assay Sample Number	Element Units	Pt PPB	Pd PPB	Cu PPM	Ni PPM	Cr PPM	Co PPM	V PPM	As PPM	Sb PPM	W PPM	Sn PPM	Ag PPM	Au OPT	TiO_2 PCT
BLRNE-1 + Yellow Paint	32-55-13	CF14477		L15	6	110	150	220	60	800	5	L5	80	L10	L0.5	L0.002	5.10
BLRNE-1 + White Paint	32-55-13	CF14478		L5	4	115	170	750	65	800	L5	L5	80	L10	L0.5	L0.002	6.40
Standard Pt & Pd (PTA-1= 3050 ppb Pt)		CF14479		3650	25	240	15	15	10	80	15	L5	10	20	4.0		
Standard Gold (GTS-1= .010 OPT Au)		CF14480														0.009	

Appendix A. PGE mineralization models that may apply to the Duluth Complex. (See also Appendix B)

1. Minor concentrations of PGE in Cu-Ni ores (Ryan and Weiblan, 1984; Meineke and Listerud, 1977, Report 93)

2. PGE in "complexly-differentiated gabbro-dolerite intrusions,-...which are deposits of the Noril'sk type." (Razin, 1977, p. 100)

3. "Palladium deposits, associated with late-magmatic copper-sulphide and titanomagnetite mineralization of meso- and melanocratic gabbros of pseudo-stratified clinopyroxenite-gabbro massifs in the Middle Urals, which are deposits of the Volkovo type." (Razin, 1977, p. 100)

4. PGE "in layered gabbro-norite-ultramafic intrusions, (the Merensky Reef) which are deposits of the Monchegorsk type." (Razin, 1977, p. 100; see also C. A. Cousins, 1969, or Vermaak and Hendriks, 1976, for Merensky Reef; see S. G. Todd et al., 1982, or C. Bow et al., 1982, for the Stillwater).

5. Pegmatitic pyroxenite with sulfide and chromitite segregations in basic and ultra-basic rocks. (Boyle, 1974, p. 39)

6. Skarn type, where basic rocks intrude carbonates. (Boyle, 1974, p. 39) [Note that the Thomson Formation locally contains carbonates as does the Biwabik Iron Formation.]

7. Hortonolite - dunite pipe deposits. (Boyle, 1974, p. 39; or Stumpfl and Rucklidge, 1982, or Schiffries, 1982, for Bushfeld dunite pipes)

Appendix B. References to Tentative PGE (Platinum Group Element) Mineralization in the Duluth Complex

1. In Canada, the Crystal Lake Gabbro has small reserves of Cu-Ni, "plus low values in platinum, palladium, and gold..." (The Northern Miner, 3/26/1968 in Mudrey, 1972, p. 411 of MGS Minnesota Centennial Volume).

2. Platinum minerals (sperrylite, $PtAs_2$) were identified in massive sulfide samples from the Minnamax shaft (Ryan and Weiblan, 1984).

3. PGE minerals were identified by T. Sabelin at the MRRC in two different locations in drill core selected by L. W. Gladen, DNR Minerals.

   > The PGE minerals occur in an oxide (65%)-plagioclase (25-30%)-olivine (5%) host and an olivine (40%)-oxide (30%) -plagioclase (25%) host. Titaniferous magnetite is the dominant oxide and is associated with minor hercynite and ilmenite. Sulfide mineralization in these rocks is minor and is primarily of the finely disseminated type. Chalcopyrite, bornite and pentlandite are the main sulfide phases. ...The five monomineralic grains occur in the olivine-oxide-plagioclase rock. Four of the five grains consist of a Pt-Fe alloy...The four grains have similar compositions and consist mostly of Pt with minor Fe and lesser amounts of Pd, Cu and Ni. The fifth grain is a Ru sulfide with minor Os and traces of Ir and Fe. (T. Sabelin, 1985, LSI abstract)

4. E.H. Dahlberg has recently analyzed a number of drill cores as part of a mineral potential evaluation project (DNR Report 242, 1985). The following summarizes the best precious metals assays:

   S-T-R: 31-61-11 (Lake County)
   DDH DU-12 2734.6'-2758', cgr to pegmatoidal troctolite and oxide-spinel-plagioclase rock. Pt 80-300 ppb, Pd 210-430 ppb. Associated elements with elevated values: Cu, Ni, As, Sb, Te.

   S-T-R: 35-57-13 (St. Louis County)
   DDH SE-1 629'-830'; troctolite and anorthosite. Pt up to 120ppb, Pd 10-50 ppb. Associated elements with elevated values: Cu, Ni, Co, Cr, Sb, C, Au, S, Rb, Zr, Th, U.

   S-T-R: 25-59-9 (Lake County)
   DDH NR-1 901.8'-903.8'; oxide gabbro. Pt 150 ppb, Pd 300 ppb.

   S-T-R: 36-55-13 (St. Louis County)
   DDH BL-1 had selected samples with: - 380 ppb Au
   - 4.0 ppm Ag
   - 1.75% Cu

Appendix B (continued)

S-T-R: 2-59-9 (Lake County)
DDH IS-1 had selected samples with: - 1.1 ppm Au
- 2420 ppm Cu

S-T-R: 10-52-15 (St. Louis County)
DDH FHL-1 had selected samples with:

160.2'-164.8'	105 ppb Pt and	40 ppb Pd
224.7'-225.4'	255 ppb Pt and	140 ppb Pd
256.3'-258'		110 ppb Pd
304.4'-305'		115 ppb Pd
305.0'-315'		145 ppb Pd
386.1'-387'		125 ppb Pd
399.0'-405'		190 ppb Pd

Associated elements with elevated values: Sb, Te, Co, Ni, Cu, S, Os, Ir, Ru, Au, Ag, C

5. Based on a bulk sample from Inco's Spruce Pit (T62N-R11W, Lake County): "Data available from INCO's bulk sample tests on the Spruce deposit indicate recoverable grades of 0.0262 OPT Ag, 0.00075 OPT Au, 0.00107 OPT Pd." (Listerud and Meineke, 1977, Report 93, p. 30)

Appendix C. Sampling Factors to be Considered when Comparing Results of Different Esker Surveys.

1. The parent glacier.

2. The number of miles of esker to be sampled.

3. The target elements or minerals and their specific mobilities and characteristics.

4. The esker height, and the availability of gravel pits or road cuts determines how many potential vertical intervals are sampled.

5. The esker length and type - segmented vs. non-segmented and how many segments.

6. The sampling method - channel sample, footage interval, sample weight, or composites.

7. The concentration method and concentration ratio.

8. The analytical detection limits and sub-sample weight.

9. The details of a specific sample site, such as calcite cement between pebbles, or a high water table, or clast size (such as 90% cobbles at a given site).

Fig. 1. Summary flow-sheet of the heavy mineral sample processing.